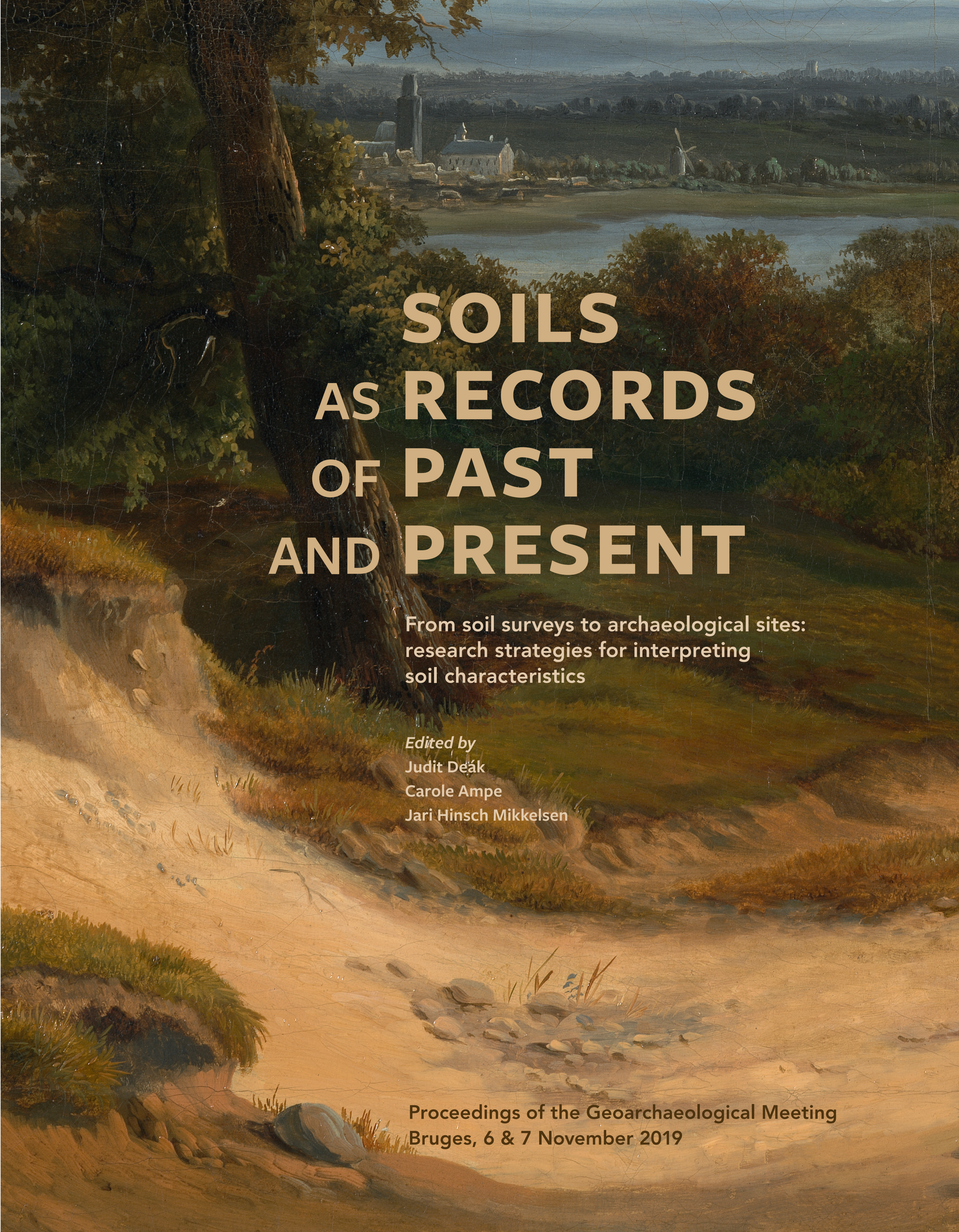

SOILS AS RECORDS OF PAST AND PRESENT

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
Bruges, 6 & 7 November 2019

This book is published on the occasion of the Geoarchaeological Meeting:

Soils as records of Past and Present.
From soil surveys to archaeological sites: research strategies for interpreting soil characteristics

on 6 & 7 November 2019 in Bruges, Belgium.

Editors
Judit Deák, Carole Ampe and Jari Hinsch Mikkelsen

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4. Past climates and environments

5. Present and future use of soil data

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FOREWORD

As proud citizens of the city of Bruges, a UNESCO World Heritage Site, we often ask ourselves the question: what is under our feet? The answer to this question is always interesting and often complex. Bruges is situated on a unique landscape position, on the verge of the Belgian coastal plain and the sandy region, which strongly influenced and shaped its history. For this reason, the answer to our question can only be found through interdisciplinary investigations involving archaeologists and earth scientists specialised in understanding past environments and anthropic activity.

The scientific symposium 'Soils as Records of Past and Present', organised in the heart of Bruges on the 6th and 7th of November 2019, provided the opportunity to exchange knowledge and present new assessments on interactions between the environment and human activity. A series of outstanding speakers from all over Europe presented their work and views on how archaeology and earth sciences, more precisely soils science, can and should complement one another. These inspiring presentations and a poster session provided the basis for a unique collection of papers that offers new insights into interdisciplinary research approaches focussed on archaeological and palaeoenvironmental issues that are successful in various parts of Europe.

Today, when the environment is a hot topic, it is crucial to look back and gain insight into the errors and learn from the solutions of the past. Most importantly, this knowledge should not only be kept within the academic community, but shared with wider audiences, such as those who work in the field, as the organisers of this conference and editors of this book have endeavoured. While looking towards the future, the administrators of the city of Bruges, strongly encourage initiatives such as this one, that permit an exchange of awareness and more judicious management of resources.

If the soil is a book, as suggested by Prof. Em. Dr. R. Langohr, one should read every chapter. We encourage you to do the same with this collection of papers.

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Mayor of the city of Bruges

Nico Blontrock
Alderman for Culture of the city of Bruges

Pascal Ennaert
Chairman of Raakvlak

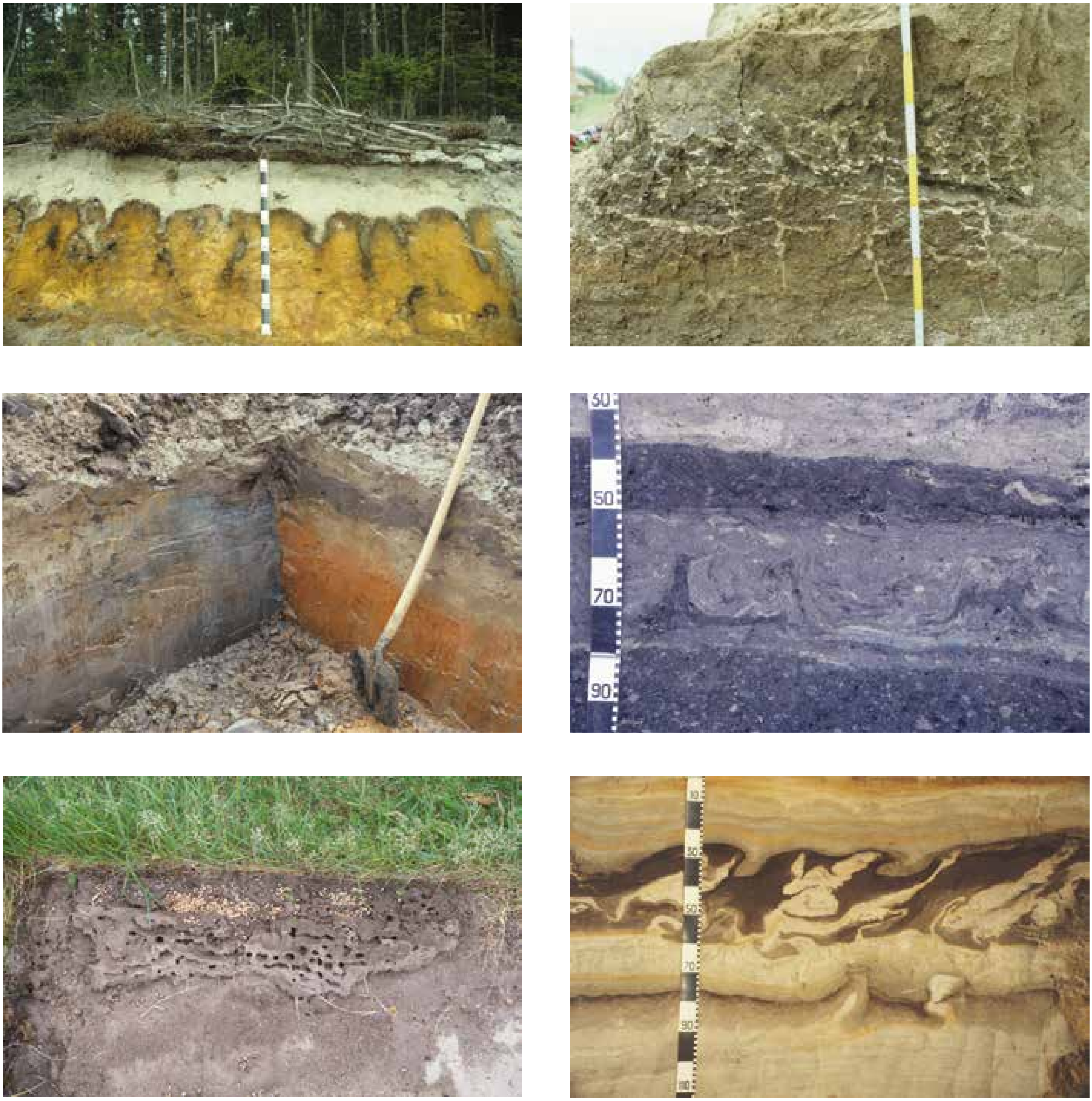

Figure 1. A few examples of soil characteristics that can be observed in the field. (Photos Roger Langohr)

FROM SOIL SURVEYS TO ARCHAEOLOGICAL SITES AND BEYOND

Research strategies and original approaches for interpreting soils, anthropic activity, and environmental changes

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'The soil is a book'

The importance of soil science in various research fields has increased tremendously over the past decades. Soils are among the most fundamental elements that support life on Earth. They provide numerous ecosystem services and document past environments and cultural heritage. Many renowned scholars contributed to this understanding; amongst them Roger Langohr. For more than 50 years he has been an international authority within various fields of soil science research and as such he contributed substantially to the improvement of interdisciplinary research strategies. His holistic approach on understanding the book of nature through field observations of soils has inspired researchers from far beyond the borders of Belgium. Those who had the privilege to follow his lectures or collaborate with him have learned that to understand soils, one has to start in the field by observing the soil characteristics, by drawing them, and by recording their vertical and horizontal variability (Figure 1). Additionally, profiles should (always) be made very deep and wide (deeper and wider than they are often dug) to overcome local variability (Figure 2). Indeed, countless times we could observe that by enlarging soil profiles the first hand interpretation would change considerably. One also needs to face the complexity and be aware of the fact that the absence of features is as important as their presence. We were also taught that soils have to be studied on various scales, from a macro, to meso and to a micro scale (Figure 3). Each soil profile can be considered as a page in the book of the history of the larger soilscape. Thus, in order to understand the whole story, one needs to read all the pages and chapters.

With this book, we would like to pay honour to all the scientific contribution of Roger Langohr, who manages to fascinate, motivate and promote scientists that are active in various research fields and come from all parts of the world.

Questions raised in this book

In the past few decades, soil science has contributed greatly to discussions on climatic and environmental changes, as well as to the understanding of various topics of human impact on landscapes and the environment. This

Figure 2. Profiles should (always) be deep and wide. (Photos Roger Langohr)

book aims to address these complex issues and demonstrate how they are approached and unravelled through past and current interdisciplinary research. In the following chapter, the reader will find views and diverse research strategies of answering the following questions:

- What is the current state of research on soils as a record of past and present?
- How is soil research able to contribute to the unravelling of important archaeological issues?
- How do formerly collected soil data help us today?
- Can we still learn from nature through field observation?
- Is there still time to do fieldwork?
- Is fieldwork sufficiently relevant, or should it be entirely replaced by graphs and modelling?
- How do we deal with limited budgets when an infinite number of soils characteristics exist, and many analyses are possible?
- How to continue when sometimes authorities are reluctant, and collaborations are hampered?
- What are some of the future challenges?

In answering these questions, the twenty-one papers that follow address a broad range of subjects and cover a wide geographical scope: soils and related questions from Belgium, France, Hungary, Luxembourg, Spain, and Switzerland are presented. These contributions testify that an interdisciplinary approach, since long advocated by Roger Langohr, works well and proves it to be a successful tactic.

In Belgium, systematic soil surveys were carried out right after World War II until the beginning of the 1980s. Even today, small-scale surveys are still executed according to the survey principles, methods, and field legends worked out almost 70 years ago. The huge amount of data collected during these decades of intensive prospections are still relevant today and applied for various purposes. The data are included in the Flanders Subsoil Database (*Databank Ondergrond Vlaanderen* or DOV), which is freely available to all users as presented in the paper of K. Oorts et al. DOV connects, develops, and disseminates information about the soil and subsoil of Flanders and is an outstanding example of how to apply soil science data that were gathered in the past to handle issues of the present and future.

Among the numerous questions targeting soils nowadays, a frequent question is the one of how to preserve heritage. The contribution of C. Ampe and K. Gheysen emphasises that pedologists and archaeologists are strongly needed to increase the awareness of the heritage value of soils and various remains of anthropic activity incorporated in soils. They present an interesting case from Flanders (Belgium), demonstrating how soil science and archaeology can be involved in land development projects.

Understanding past soilscapes and among them the original soil(s) (i.e. the soil(s) that existed before deforestations and agricultural practices) is one of the research topics thoroughly investigated and often taught by Roger Langohr. Thanks to him, nowadays, it is widely known that the Sonian Forest (Belgium) is a unique heritage site for earth sciences and archaeology. The paper presented here by Roger Langohr is supported by data collected throughout many years of comprehensive field observations, carried out during all seasons, among others in the Sonian Forest. These data permit us to understand the settlement dynamics of Neolithic farmers in this part of the world, where both the chemical and physical fertility were strong limiting factors for food production. These soils were still widely present in Central Belgium during Roman times, as revealed by the paper by S. Dondeyne and S. Deckers, who combined the soil classification and soil evolution issues in an original questioning of the Abc soil types. Their data illustrate how understanding soil formation processes helps us to comprehend the past evolution of landscapes and land-uses.

The landscape evolution and past groundwater fluctuation in the the Mol-Dessel Area, north-east Belgium could be reconstructed through field soil survey techniques as presented in the contribution of K. Beerten. This approach drew attention to the fact that the distribution and thickness of drift sands covary with the morphology of the buried Podzols and that these data can be used to reconstruct water-table variations.

It is well known that in the past soils were among the resources that influenced the functioning and wealth of communities. As such, when soils presented marginal suitability for agropastoral activity, farmers had to find solutions to improve their soils. This is well illustrated in the interdisciplinary paper of J. Hinsch Mikkelsen et al. that presents the functioning of Roman-dated stable houses through morphological and analytical data, providing chemical amendments in the quartz-rich, nutrient-poor region of the northern Campine (Belgium) area. Plaggen-like soilsare the result of centuries of such management and they are the witnesses of the sustainable subsistence strategy adopted by the inhabitants. The question concerning the soil's fertility is also addressed in the article of J. Deák et al. about the nutrient rich, but often poorly drained and/or clay rich soils that existed in the surroundings of Late Bronze Age lake-dwelling sites, located near Neuchâtel (Switzerland). Here, comparative analyses of archaeological and pedological data of two settlements situated in two distinct bays, surrounded by lands with markedly distinct agro-forestry potentials, suggest that the two communities kept in close interaction throughout their development and in handling the lake-level variation challenges.

Figure 2. Soil is a book and it has to be studied at all the scales. (Photo Giovanni Boschian)

Understanding soil forming processes is crucial for understanding artefact distribution and might have important implications for archaeological surveys as demonstrated by the multidisciplinary approach in the contribution of Ph. Crombé et al. This original study suggests that in the region of the Belgian-Dutch sand belt, in the augering survey projects focussing on Mesolithic and Neolithic sites, the sampling depth should be adapted to the different soil types. The paper of J. Vanmoerkerke et al. provides an example on how ignoring soil science and ecological data might bring about erroneous archaeological interpretations. This is the case with vertical and slightly inclined wood fragments in soils, that are most often interpreted as posts witnessing former buildings, fences, etc. This paper recalls that, as demonstrated by Roger Langohr more than 20 years ago, these features might simple be large tree branches pressed into the soils by the weight of a falling tree. Their correct interpretation allows for valuable dendrochronological records for periods little documented so far, as is the case in the north-east of France.

The question of origin of charcoal in soils is another often discussed subject in archaeological contexts. The paper of C. Menbrivès et al. brings novel reflections and data on the origin of combustion residues. This multiscale interdisciplinary case study, triggered by combustion traces documented in the Ardennes (Belgium,) encouraged the authors to review the various ways of how charcoal arrives in soils. Through this, they emphasise the often neglected technique of 'écobuage', that consists of the preparation of soils for crop production with a preliminary extraction, burning, and reintegration of the surface sods. M. Rué and A. Hauzeur, in turn, explored the delicate and still little studied subject of differentiating natural and anthropogenic soil characteristics through micromorphology. Their combined field and micromorphological study, focussing on a presumed habitat site situated near Paris (France), showed that earth fragments, initially interpreted as earth building material fragments, are likely to be the result of natural pedogenetic processes. Micromorphology is a crucial tool in studying Dark Earths, too. The case study describing a site of Aalst (Belgium) by Devos et al. illustrates how succession and superposition of anthropic activity and natural depositional events can be unravelled by facing complexity and using interdisciplinary research techniques.

The paper of F. Cruz et al. is an interdisciplinary study presenting the challenges of documenting the alluvial settings of Kerkhove Stuw (Belgium) in a rescue archaeological context, where time is short and the amount of data to document and investigate is huge. The paleoenvironmental reconstruction presented in this paper is complemented by an evaluation of potentials and limitations of various field recording techniques and, as such, it highlights the crucial role of field work, as often emphasised by Roger Langohr. Several case studies inspired by rescue archaeological prospections and excavations from Lorraine (France), presented by A. Gebhardt, testify to the potential of combining field and micromorphological techniques. She emphasises the benefits of a systematic follow up of archaeological interventions performed in a large region. Moreover, she points out that a strong personal determination is also needed when the administrative load replaces the time foreseen for research and interdisciplinary collaboration. The paper of Fechner et al. synthesises twenty years of studying soil characteristics and their significance related to anthropic activity. This contribution concerns Neolithic and Bronze age sites located between the Rhine and the Sein (Belgium, Luxembourg, and the north of France).

On a more local scale, the contribution of F. Beke et al. narrates the long and complex history of a barrow excavated in north-western Belgium. Starting out as another routine archaeological excavation, the interdisciplinary approach chosen here proved to be a crucial decision. The soilscape and micromorphological analyses completed the archaeological documentation and revealed that this burial mound, that was constructed during the Bronze Age, witnessed multiple renaissance phases through new functions and morphological modifications that occurred during the Late Iron Age, Roman Age, and High Middle Ages. D. Verwerft et al. discuss the successful collaboration of archaeologists and earth scientists in discovering and characterising a Roman terp, another type of man-made raised platform, situated north of Bruges (Belgium) in the tidal estuarium of the Zwin. Overall data permitted them not only to unravel a good knowledge of the landscape and its opportunities, but also to point towards the engineering skills employed at that time and the considerable organisational tasks effectuated.

Looking at soil characteristics is also proven valuable when scientists are interested in paleoenvironments. A. Mindszenty, while looking at paleosols outcroppings in Hungary that formed on Late Triassic carbonate platforms, highlights the importance of a process-oriented approach, rather than targeting the classification. The paper of E. Horváth is an interdisciplinary revisiting of several famous Quaternary loess sections situated in Hungary. The palaeosoils preserved in these sediments are known as important stratigraphic markers and this contribution underlines the importance of the documentation of the variability of soils characteristics for a novel understanding of landscape evolution and climatic changes. Past environments are also recorded in the present-day soils. This is thoroughly explored in the paper of R. Poch et al. through field, micromorphological, and analytical data collected for soils from the Tremp basin (NE Iberian Peninsula).

The last paper of the book reviews the history of teaching soils science to archaeologists in Flanders (Belgium). M. Pieters explains that, although soil science is crucial for understanding archaeological issues, such training in Flanders was only possible for a short time. It was done in the frame of the International training Centre for Post graduate Soil Scientists, a worldwide known institution, where the highly skilled teaching staff taught soil forming processes, micromorphology, soil mineralogy etc. Among them, Roger Langohr kept the doors wide open to archaeologists and at the same time guided fellows with various academic backgrounds to discover the wonderful pages of the book of soils on archaeological sites. Today, these doors are closed and this a serious issue when archaeological interventions face an increasing demand in earth science expertise.

To conclude, every one of these papers are examples on how looking at soils, soil characteristics, and processes with an open-minded approach, allows for a better understanding of the complex and fragile interactions between human societies and their environments. Today, when environmental questions are more than actual, the original research strategies presented here, often appealing to the collective intelligence, are also meant as an intergenerational transmission of knowledge.

A participative project

The organization of a meeting entitled ***'Soils as records of Past and Present: the geoarchaeological approach. Focus on: is there time for fieldwork today?'*** was first formulated in September 2018; the first, preliminary, call for participation was distributed in December 2018. The main organisers Judit Deák, Jari Hinsch Mikkelsen, and Carole Ampe are all alumni of the International Training Center for Post-Graduate Soil Scientists at the University of Ghent. In the 1990s they were students and collaborators, working on MSc. and Ph.D. thesis and working on various scientific projects under the supervision of Roger Langohr. The time they spent in 'the corridor' C, building S8 of the Sterre Campus was characterized by intensive field and laboratory training, scientific challenges and all that in an inspiring environment. The solid and broad scientific background that they acquired during these years was complemented by fantastique opportunities to meet other fellow students and scientists, and to build up a network of friendships and scientific collaborations that has lasted ever since.

After a first call for contributions, the response and interest from the scientific community for the conference was overwhelming, which showed the relevance of organising this meeting. Initially we thought of a one-day meeting with self-printed papers. But, like in the 'old days of team Corridor C', and in the spirit of one of Roger Langohr's favourite sentences "small is beautiful", the original project evolved and diversified and ended up becoming a two-day meeting with a scientific excursion, followed by a scientific symposium, and accompanied by a book with twenty-one reviewed papers, printed by a professional printer. This evolution meant, for all involved, a lot of self-engagement, the capacity for rapid adaptation, cooperation, and mutual understanding, as several organisational aspects changed with time and the final deadline was very short.

The first call for contributions to this book was launched in January 2019 with a deadline of 15^{th} of June 2019 for the first manuscripts, to be reviewed during the summer and the final versions to be submitted by the 5^{th} of September 2019. This schedule is almost synonymous with 'mission impossible', yet the book is here. This was only possible thanks to the strong motivation and dedication of not only the organisers, but also of all the contributors and reviewers. Despite the considerable extra working load, the authors and co-authors of the papers in this book managed to write and submit their contributions in record time. They were also asked to assume not only the scientific and copyrights responsibility of their work, but also the verification of content and formatting of bibliographic data included. The scientific reviewers (see list here below) played a crucial role in the accomplishment of this publication. Their constructive remarks and suggestions contributed generously to the scientific quality of the papers, while their rapid feedback and interactions were decisive in meeting the deadline and having all the papers in the book.

This book is not only a printed document. It is also a collection of a freely available (open access) documents. All of them have an individual digital object identifier (doi, indicated on each paper) and are hosted by the non-commercial depository archive (Zenodo). Moreover, the authors keep the copyright of their contribution. The online contributions are distributed under the Creative Commons Attribution Share Alike, 4.0 License (CC-BY-SA). Under these terms, the readers are free to: **share** — copy and redistribute the material in any medium or format, **adapt** — remix, transform, and build upon the material under the following term: **attribute** — must give appropriate credit, provide a link to the license and indicate if changes were made; **ShareAlike** — if the reader remixes, transforms, or builds upon the material, he/she must distribute his/her contributions under the same licence as the original.

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Many people kindly and generously supported and contributed to the successful outcome of the meeting of the 6^{th} & 7^{th} of November 2019 and the publication associated with it.

Raakvlak, Archaeology, Monuments and Landscapes of Bruges and Hinterland, assumed the logistics and financial side of the organisation of the meeting and book editing. The enthusiastic commitment of the entire team of Raakvlak permitted an appropriate set up of the many aspects involved with the organisation. We would like to express our sincere gratitude and appreciation in particular towards archaeologist Mariebelle Deceuninck, who handled the administrative parts of the organisation, the general communication, and did the enormous work of technically editing this book. Also, archaeologist Caroline Landsheere did the essential job of improving the English language of most of the papers, for which we are strongly indebted. The tremendous work of finalising all papers for printing was carried out by Frederick Moyaert from the publishing company Van de Wiele, for which we are sincerely grateful.

The study bureau '4terres', through the work of Judit Deák, supported this meeting in its launching, follow up, and editing of the book. We would like to express our full appreciation to Sonia Wüthrich, the head of the Office du Patrimoine et d'Archéologie de Neuchâtel, section Archéologie (Switzerland), who kindly supported and encouraged this project for the crucial part of its structural setup and scientific values. The scientific assistance of Dr. Sylvie Vullioud significantly contributed to the realisation of the online open access publication of the contributions included in this book and we would like to express to her our sincere acknowledgements. The CH-QUAT (Swiss Society for Quaternary Research) financially contributed to the realisation of the open access part of the publication and we would like to thank them as well. The webpage of the meeting (https://www.4terres.ch/gamb19/) could only be set up thanks to the substantial help of M. Anibal Jaimes, who constructed the framework of the website, transmitted the basic tools, and assumed the hotline of it. We express our deep gratitude for all these actions.

As mentioned above, 14 scientific reviewers, through their prompt and generous involvement, permitted editors and contributors to improve and finalise the papers. We would like to express our highest appreciation for all their work.

The idea of organising a meeting in the honour of Roger Langohr was first time launched by Jan Vanmoerkerke and we would like to thank him for raising the question that led us into this adventure.

For planning, organising, and executing the excursion, we would like to express our sincere gratitude to W. De Clercq, J. Trachet and R. Dreesen for their enthusiastic input.

The organisation of the venue would not have been possible if it was not for the facilities offered by the City of Bruges and the Museum of Bruges. City of Bruges will in 2020 celebrate their 20th year of UNESCO World Heritage status. By supporting meetings like this, they commit to this status.

To conclude, this participative approach of all people involved testifies to the genuine interest to follow, share, and transmit Roger Langohr's field and holistic scientific approach. Last but not least it is clear that there is a continuous interest in understanding the book of nature and that cooperation and interdisciplinarity are powerful tools to move forward.

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1

Present and past soilscapes and land use

SOILS AS RECORDS OF PAST AND PRESENT
FROM SOIL SURVEYS TO ARCHAEOLOGICAL SITES:
RESEARCH STRATEGIES FOR INTERPRETING SOIL CHARACTERISTICS

Proceedings of the Geoarchaeological Meeting, Bruges, 6 & 7 November 2019
Edited by J. Deák, C. Ampe and J. Mikkelsen.

SETTLEMENT OF THE FIRST FARMERS IN THE BELGIAN LOESS BELT

The edaphic factor

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ABSTRACT

The first farmers to settle in the Belgian loess belt belong to the Linearbandkeramik Culture (LBK), formerly Danubian Culture, and the Blicquy/Villeneuve-Saint-Germain group. As elsewhere in Europe, these populations preferred settling on loess soils. We can distinguish three patterns when they reached Belgium. Firstly, they settled only at the southern and eastern fringe of the loess belt. Secondly, the village occupations lasted only about one generation (some 25 years). Thirdly, after 2 to 3 centuries the occupation ends, leaving a hiatus before the next period of settlements. Several hypotheses are proposed to explain this particular behaviour, such as a research hiatus, contact with the hunter-gatherers that lived in the area, and heredity rules. In this paper attention is paid to the impact of the edaphic factor, an essential element besides climate when it comes to crop production. From archaeopedological research on LBK sites, it appears that the soilscape in this European Atlantic biogeographical area was similar to the soils that occur today in the 50 km² tall Sonian Forest. Exceptionally, this area situated in the middle of the Belgian loess belt, has never been cleared for agricultural purposes and the soils have very low chemical and physical fertility. This status provides a plausible explanation for the particular behaviour of the first farmers reaching the Belgian loess belt. Simple shifting cultivation, as practised in the equatorial forest, was not sustainable in this temperate climate and therefore whole villages would have to move. Obviously, the workload for these Neolithic farmers was too severe and they abandoned the further colonisation of the Atlantic loess belt.

KEYWORDS

LBK farmers, loess, Belgium, soil fertility, crop production, Sonian Forest, shifting village

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1. Introduction

Some 7300 years ago (= cal BP) the first farmers arrived in Atlantic (Western) Europe through a vast migration that started around 8100 in Anatolia (Mazurié de Keroualin, 2003, 91, 153). The settlement occurred in the Atlantic period, the climatic optimum of the Holocene, i.e. the warmest and most humid period of this interglacial, with dominance of oak, lime, elm, ash, hazel and alder (Damblon, 2013).

This movement occurred in two main directions (Toussaint, 2013; Hauzeur and Jadin, 2013, 17):

- One through the Balkans and further West through Central Europe, which resulted in the development of the 'Linearbandkeramik' Culture (LBK), formerly called the 'Danubian' Culture.
- One along the Mediterranean and further north from southern France, resulting in the 'Cardium' Culture. It is still under discussion as to whether a few sites in the loess belt of Belgium, attributed to the Blicquy/Villeneuve-Saint-Germain group, belong to this movement.

In Central and Western Europe, many of these LBK settlements are located on soils with silty texture, mostly associated to loess deposits of the Last Ice Age (Weichsel) (Hauzeur and Jadin, 2013, 19). This sedimentation ended latest around the transition period from the Pleniglacial to the Late Glacial, some 15,000 years ago (Haesaerts et al., 1981; Haesaerts et al., 2016; Rousseau et al., 2018). In Belgium, all Early Neolithic sites are located on such loess soils.

Originally these sediments contained variable amounts of calcium carbonate. In Belgium and northern France about 10 %; in other regions such as along the Rhine and Danubian rivers, these amounts can go up to 25 % (Rousseau et al., 2018).

When studying the behaviour of these populations along their migration route, we can distinguish three patterns when they reach Belgium.

- Surprisingly, this vast population movement didn't colonise the whole loess belt, but settled in relatively small territories in the southern, south-eastern and eastern fringes (Fig. 1) (Meylemans et al., 2018, 9; Hauzeur and Jadin, 2013).
- The duration of the village occupation was much shorter in this region, mostly what can be considered as one generation period, or 20-25 years (Hauzeur and Jadin, 2013, 22), while in the Central European loess area, several phases of house reconstruction can be observed (Lüning, 1982, 18).
- After some two to three centuries, the local occupation stops. The villages are abandoned and no new settlements are detected between the end of the Early Neolithic and the first traces of the middle Neolithic Michelsberg Culture (Damblon, 2013, 16; Jadin, 1999; Hauzeur and Jadin, 2013, 33).

The interaction of various causes is mentioned to explain this particular conduct, for example, a hiatus in the present-day research (Meylemans et al., 2018, 8), contact with local population of hunters/gatherers (Vanmontfort, 2008), the impoverishment of an acid soil (Damblon, 2013, 12, 16), a climatic impact (even if, according to Damblon (2013, 12), the climatic conditions appear to be stable), heredity rules and disintegration of the social fabric (van de Velde and Amkreutz, 2017).

In this paper we focus on the edaphic factor, an item not so important when discussing cattle raising and meat production, but crucial when it comes to crop production.

2. The edaphic conditions in the Early Neolithic

The soil types these farmers met in the Belgian loess belt, are the result of four main soil-forming factors: soil parent material, age, erosion and climate, since pedogenesis started.

2.1. SOIL PARENT MATERIAL

In Middle Belgium, the loess sediment came mainly from the North Sea region which was largely dry, because of the 100 – 120 m lowering of the sea level (Sima et al, 2009; Rousseau et al., 2018, 5). Soils are developed here in sediments of the last period of accumulation, between about 25,000 and 15,000 uncal BP (Haesaerts et al., 2016), labelled as 'Brabantian loess formation'. According to the Belgian Quaternary lithostratigraphic units (Gullentops et al., 2001) this is a Late Weichselian (Mis 2) 'member' (GxB) of the Gembloux 'formation' (Gx) that contains all loess units of Middle Belgium deposited during the periglacial stadials of Middle and Upper Pleistocene. The particle size of this dust is dominated by silt (0.002 - 0.050 mm), some 10-15 % clay (size less than 0.002 mm) and a few per cent of very fine, and fine sand (0.050 – 0.250 mm). The 'silty region' ('région limoneuse' -fr., 'leemstreek' -nl) of Belgium (Fig. 1) is characterized by a nearly continuous cover of this sediment. The deposit was homogeneous, very finely stratified but without contrasting strata. The lime content was relatively stable, between 8 to 11 %. Besides the lime, the sediment is dominantly composed of quartz with minor amounts of feldspars, chlorite, amphiboles and glauconite. Latter mineral originates from the erosion in the landscape of the Tertiary marine sediments that occur as substratum in Middle Belgium. The clay fraction is dominantly smectite and some mica and kaolin, quartz, feldspars and interstratified minerals (Van Ranst, 1981; Van Ranst et al., 1982).

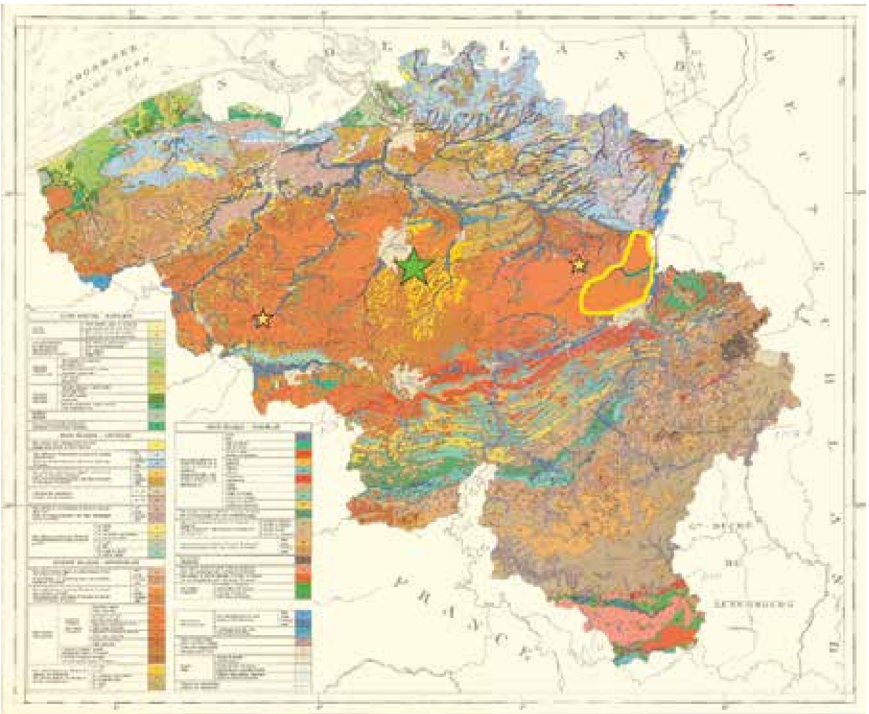

Figure 1. Soil Association Map of Belgium (Marechal and Tavernier, 1971). The brown colours correspond to silty (= loess) soils. The yellow stars and the yellow delineation indicate the Early Neolithic LBK site areas. The green star is the site of the Sonian Forest.

2.2. AGE

At the transition from the Pleniglacial to the Late Glacial, some 15,000 years ago, the climate shifted from severe periglacial to Boreal, coinciding with the end of the loess input and the development of permanent forest vegetation stabilizing definitively the soil surface in the loess belt. This can be considered as the start of the loess soil evolution (the 'age' of the soilscape). Accordingly, the first farmers cultivated soils that evolved already since some 7000 to 8000 years. This hypothesis is in opposition to the ancient view that pedogenesis started only in the beginning of the Holocene. (e.g. Louis, 1955; Tavernier and Louis, 1971; Modderman, 1988, 81; Gullentops and Corrijn, 2009, 29).

2.3. EROSION

Except for all human interventions, just one 'natural' erosion (Soil Survey Staff, 1951, 251-253) period is recorded since the start of the soil evolution in the Belgian loess belt. This process, very limited in extent, affected only some steep valley slopes and valley bottoms (Sanders, 1981; De Corte, 1982; Cruzado, 1982; Baes, 1985; Langohr and Sanders, 1985a; Sanders et al. 1986). The resulting remodelling of the relief is specific for processes active in a periglacial environment with in some areas a water flow over frozen ground during snowmelt. Such events occur today in cold Atlantic climate areas such as Atlantic Canada (Bernsdorf et al., 1995) and southern Norway (Øygarden et al., 2006, 10). In other areas of the loess belt, the erosion occurs as local landslides on segregation ice along valley slopes (Gullentops and Corrijn, 2009, 22, 29; Langohr, 2008, 74). According to the soilscape characteristics in both the eroded and non-eroded areas, this particular climatic event occurred most probably at some moment in the Younger Dryas when the soils were already well developed with the presence of a clay accumulation horizon.

2.4. CLIMATE

Throughout the 15,000 years of pedogenesis, climate changed considerably during several periods. For the soil evolution in the Belgian loess belt, three phases are important.

There is first the strong leaching boreal climate dominating in the Late Glacial Bølling and Allerød periods (12,500-11,000 uncal BP) (e.g. Langohr and Marcelino, 2012; Bos et al., 2017, 2018). During this period, lime was leached in the loess soils down to at least 1.2 m, a clay-accumulation horizon (Bt) developed between 25/45-100/120 cm depth and the surface horizons became very acid and N-poor.

In the last phase of the Late Glacial, or Younger Dryas (ca. 11,000-10,000 uncal BP), soils underwent a severe periglacial climate, with permafrost. The strong desiccation and the growth of ice blades within the permanently frozen soil created a fragipan horizon between 25/40-100/120 cm (Mackay, 1974; Van Vliet and Langohr, 1981; Langohr, 1983; Langohr and Sanders, 1985a; Payton, 1992). This development was responsible for strong physical soil deterioration, as roots can only penetrate the deeper horizons through a set of vertical streaks displaying a polygonal pattern and representing less than 10 % of the soil volume.

The last important climatic period is the Holocene with, in Atlantic Europe, a relative stability and dominance of a moist temperate Atlantic climate. For soils, the main climatic impact is the frequent excess of precipitation over evapotranspiration, inducing further acidification and the dissolution of calcium carbonate, if present.

2.5. CONCLUSION ABOUT THE SOIL DEVELOPMENT

At present, the loess belt is known for its 'fertile' soils of the Luvisol (World Reference Base for Soil resources, 2014) type (Fig. 2 and 3). However, this fertility is the result of centuries of soil amelioration through manuring, liming and fertiliser applications (Langohr, 2001). The previous paragraphs clarify the status of the Belgian loess soilscape when the LBK farmers reached the area. Instead of fertile soils, they were facing very acid and nutrient-poor soils down to at least 1 m depth. In addition, these soils had a very low physical fertility due to a compact fragipan horizon, with an upper limit at only a few decimetres from the soil surface.

3. Rationale in the search for a present-day representative of the Neolithic soilscape

Detecting a site today with a soilscape that would be identical, or at least close to the edaphic conditions Early Neolithic farmers were facing in Atlantic Europe, sounds utopic. Particularly in Europe, where human impact on nature is widespread for thousands of years, except for some areas in western Scandinavia. Evidently, priority will go to sites that are under forest. However, the majority of forests today are located on less favourable soils for crop growth, such as steep slopes, sandy soils and soils with a rock substratum close to the surface. Loess soils, and silty soils in general, are considered by farmers as being potentially advantageous, often because a good chemical fertility and certainly because the silt texture, versus sand and clay, is optimal for water supply to plants. Despite this priority to silty soils for crop production, some forests of Western Europe grow on such soils. Yet two factors may reduce the potential to find out the fertility of these soils in the Neolithic: many of these forest sites have been once under agriculture and others have previously been intensively grazed. Both management types have an impact on soils, mainly by increasing the chemical and physical fertility. The input of fertiliser, mainly manure and lime, may vanish when the site is reforested in an area with an excess of precipitation over evapotranspiration. However, some elements such as phosphorous can remain as they are not soluble in well-drained soils. Such modification, increasing the chemical soil fertility, is traceable for several thousands of years (e.g. Georges-Leroy et al., 2014). But the most important impact of former crop production or grazing is at the level of increased physical fertility. Diminishing the soil acidity and the carbon/nitrogen ratio

Figure 2. The present-day slightly undulating landscape on the LBK site of Darion, in the Eastern fringe of the Belgian loess belt. This area has been under continuous agriculture since at least the Roman period (see also Fig. 3).

Figure 3. The characteristic homogeneous soil on the old agricultural land at the site of Darion. As a consequence of centuries of manuring, and fertilising associated with intense tunnelling activity of earthworms and moles, this soil has today a high chemical and physical fertility.

by liming, manuring and by the input of excrements and urine by grazing cattle, will raise the soil faunal activity, mainly of deep burrowing earthworms like Lumbricus terrestris, and dung beetles. This soil fauna is important nutriment for moles that drill through the soil in search of food. All this soil bioturbation increases the soil porosity down to several decimetres, thus favouring the plant rooting depth. Here the Sonian Forest, south of Brussels and situated in the middle of the Belgian loess belt, has to be mentioned (Fig.1 and 4). This 50 km² tall forest has never been cleared for cultivation since loess soils started to develop some 15,000 years ago. In addition, as this Royal Forest represented an important financial input through timber and charcoal production (Tack et al., 1993, 93-94), it is not a surprise that the owners tried to regulate the right of free grazing. Several other forests in the Belgian loess belt present limitations in this research.

- The Meerdaal Forest, 1700 ha large, west of Leuven, was probably under agriculture in the Iron Age and Roman Period (Vawalleghem et al., 2004; Langohr 2008).
- The Halle Forest, 552 ha large, west of the Sonian Forest, but not a Royal Forest, has been under many different ownerships throughout the last 1000 years. The soils show characteristics for intensive grazing during some periods (https://www.hallerbos.be/en/history, Baeté, 2003).
- Part of the 210 ha Bertem Forest, west of Leuven, has a comparable soilscape to the Sonian Forest, but the limited surface does not include all geomorphic positions.

Figure 4. A characteristic view of a beech stands in the Sonian Forest. Since the initial stability of the soil surface, at the end of the loess dust deposition some 15,000 years ago, no erosion has occurred except in the small valley bottoms.

- The Terrijst Forest, 25 ha large, west of Brussels, was probably cultivated during at least the Roman Period (Langohr, 2007).
- In NW France, the large Mormal Forest (9163 ha), on loess soils, has probably never been cultivated, but was intensively grazed (Dubois, 1973; Duceppe-Lamarre, 2011). It has, in addition, a groundwater table relatively close to the soil surface.

A source of information in this search for crop productivity on the original Neolithic soilscape, are the experimental sites. However, a review study of nine of such sites in Europe (Louwagie and Langohr, 2005) has shown that none of them has a database sufficiently elaborated to check if the experimental sites are situated on a soilscape that has not already been influenced by past human activities.

From the above review, we can conclude that the Sonian Forest seems to be the most appropriate site for the research about Neolithic farming in the Belgian loess belt.

5. Potentials and limitations for crop growth on the Belgian loess soils by the LBK farmers

The LBK farmers, migrating from the Balkan through Central Europe towards the Atlantic area, settled preferentially on the loess soils (e.g. Clark, 1952, fig. 45; Lüning, 1982, Barker, 1985, 141-143; Lefranc, 2007, fig. 1, Saile and Posselt, 2007, 55, Mordant, 2008, 120-121). Whether the cultivation was of the shifting type, or more permanent, is discussed for example by Barker (1985, 141-143) and Bogaard (2002). Evidently, this choice must have been done according to the soilscape characteristics. Large areas along the Danube and Rhine valleys have a climate with little or no excess of precipitation over evapotranspiration, corresponding to an annual precipitation of about 550 to 650 mm/year or less. On the soil map of Europe (European Soil Bureau Network, 2005) Chernozems, Phaeozems and Luvisols (World Reference Base for Soil resources, 2014) are today very common soils in these regions. Yet, although some changes occurred since the start of cultivation, these soil types were also present in the Neolithic period (Lüning, 1982; von Suchodoletz et al., 2019). Within rooting depth, these soils are either calcareous or have at least a high base saturation. Also, the fragipan horizon, a physical barrier for root penetration, was not present in these soils. Hence people could grow crops year-in, year-out, with not much need of extra mineral fertilisation except the input of manure. This is evidenced by, for example, long-lasting settlements with successive reconstruction of several generations of houses (e.g Lüning, 1982, 18). From the biogeographical point of

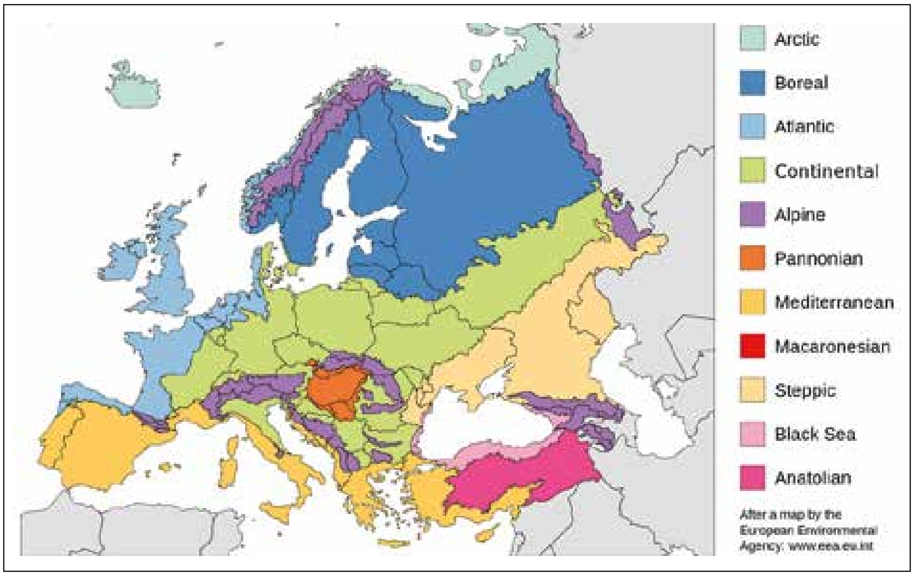

Figure 5. Biogeographical Regions of Europe (European Environmental Agency, 2017). The Atlantic region coincides with strongly acidified loess soils, an area that the LBK farmers colonised only partly (see Figure 1) and abandoned after a few centuries.

view, these areas fit in the European 'Continental region' (EEA Report 1/2017, 24-26, Fig. 5) encompassing central and eastern Europe. When progressing more westwards, the LBK farmers reached around 7250 years ago (eg. Lanting and Van der Plicht, 1999-2000) the 'Atlantic region' (EEA Report 1/2017, 24-26, Fig. 5), where soils had undergone a leaching climate since several millennia. Here the silty soils, still convenient for the construction of the characteristic large LBK houses (Fig. 6) were very acid and presented a physical barrier for root penetration (the fragipan) from a few decimetres' depth, all restraining severely the crop production (Langohr, 1990).

This hypothesis is sustained by archaeopedological investigations of Early Neolithic LBK sites in the Belgian loess belt (Pieters, 1986, 97-127; Langohr and Sanders, 1985b) showing that 7200 years ago, the soils were very similar to the present day soilscape of the Sonian Forest (Fig. 7 to 11). Moreover, this status is supported by the growth, on the harvested parcels, of acid-tolerant plants such as heather (Calluna vulgaris) (Heim, 1985, 36, Fig. 12). Under such edaphic conditions, it is impossible to grow crops permanently. After clearing and burning the forest, one crop growth is possible thanks to the supply of the wood ash and its soluble mineral plant nutrients. Unfortunately, under the climatic conditions of Central Belgium, with an important excess of precipitation over evapotranspiration, this input of soluble nutrients is rapidly lost through the leaching process. This process is even more intensive in an open field, with much less interception and transpiration of the crop versus a tree stand. Consequently, one can expect that most of the soluble ash elements that were not taken up by the crop and associated weeds, leached out within one to two years. Subsequently, in order to supply the village with sufficient food, it will be necessary to clear a new forest parcel within at least two to three years. This slash-and-burn type of shifting cultivation, as practised in tropical areas with nutrient-poor soils, represents a very important labour effort for the LBK farmers. In addition, under the hypothesis that within 10 to 20 successive forest clearings, the whole area in the neighbourhood of the village would have gone through this process, the new clearing and burning of the forest growing on the first parcel will not be enough to guarantee a correct crop production. Indeed, versus the tropical areas, plants grow in this country only during 6 months, temperatures are lower and the total precipitation is less. Consequently, one can expect a forest stand of only 15 to 20 m tallness, not enough for a sufficient supply of ash. This is in contrast with the tropics where after 20 years of fallow, one can expect a 30-40 m tall forest, allowing a sustainable shifting cultivation around the village (Fig. 13).

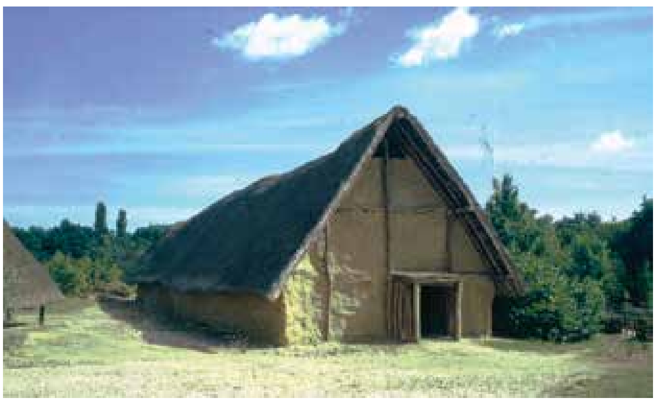

Figure 6. A reconstructed typical LBK house. The walls are made of adobe. Silty (loess) soils associated with straw provide excellent material for such construction.

Figure 7. A characteristic loess soil of the Sonian Forest. The very thin humiferous surface horizon (a few cm) is characteristic for soils with very limited bioturbation by burrowing animals. Down to 35 cm is a biologically active horizon with many roots. This part of the soil is very acid and nitrogen-poor. From 35 to 110 cm depth, is a clay accumulation horizon with vertical light-coloured streaks that form a polygonal pattern in horizontal section. All roots are situated in these streaks that represent less than 10 per cent of the soil volume at this level. This pattern is typical for a fragipan horizon, a soil characteristic that develops under permafrost conditions. This part of the soil is acid.

Figure 8. Darion LBK site. Buried soil profile under 30/40 cm colluvium just below the archaeological site. This buried soil is morphologically very similar to the soil profile of the Sonian Forest (Fig. 7).

Figure 9. Darion site. The LBK settlement was surrounded by a ditch, at least 2.5 m deep. The palynological study of the sediments at the bottom of this ditch indicate the presence of heather (Calluna vulgaris) on the surrounding cropland in the early phase of fallow.

Figure 10. Darion site a and b. In the lower part of the ditch fill occur fragments from the upper horizons of the original soil. These fragments are identical to the horizons at 60 to 90 cm deep of the buried soil at Darion shown in Figure 8, and 35 to 60 cm of the soil profile from the Sonian Forest (Fig. 7). Similar observations were made by Bosquet et al. (2004) at the site of Remicourt-en Bia Flo II.

Figure 11. Example of heather (Calluna vulgaris) growing today on the very acid soils of the Sonian Forest.

Figure 12. Shifting cultivation in the tropical forest of the Amazon (Yurimaguas area, Peru). After some 20 years of fallow, the forest regrowth is reaching a height of about 40 m as seen on the background parcel. The slash and burning of such parcel allows a sustainable crop growth. Similar conditions didn't exist in Atlantic loess belt 7000 years ago, as forest regrowth after 20 years would reach a height of only 15 to 20 m. This is not sufficient for a new slash and burn cycle. In the Neolithic, the shifting of the village to a new neighbouring virgin forest area would allow it to survive, but at the expense of a very intense effort.

6. Conclusions

The problem of crop production on chemically and physically poor loess soils in the European Atlantic belt, is a plausible explanation for a set of particular behaviours of the LBK farmers:

- Why these Early Neolithic farmers frequently moved their villages, which probably lasted less than 20-25 years.
- Why this initial colonisation, after migrating through Europe from East and South, did not move further into the loess belt and remained limited to its southern and eastern fringes.
- Why these farmers abandoned to settle in the Dutch and Belgian loess belt area after about two to three centuries, leaving a hiatus before the next period of settlements - the Michelsberg Culture period in the second half of the fifth millennium (Meylemans et al., 2018).

From this data we conclude that in this area, farmers were most likely not applying just a 'shifting cultivation', but rather a 'shifting village' rotation, better adapted to a harsher edaphic stress as compared to growing crops in the so said 'poor' tropics. It is not excluded that the clusters of settlements (e.g. Bakels, 1982) correspond to the shifting of one village in a limited area.

Thanks to the minimum human impact on its soilscape and the very limited faunal perturbation, the Sonian Forest represents a unique site (Langohr, 2009a, b) to discover the land and soilscape the first farmers, after crossing Europe from East and South, were facing some 7300 years ago in the Atlantic belt of Europe. The loess soils of this permanently forested site are very similar, morphologically, chemically and physically, to the at present detectable, remnants of the soils on which the LBK farmers established.

In the future, the Sonian Forest offers a unique opportunity to set up experimental sites in order to test the constraints of growing crops on soils identical to those the LBK farmers were facing 7300 years ago.

Both soilscape and geomorphological configuration of the 50 km² large Sonian Forest display exceptionally well-preserved characteristics that predate the Holocene. Hence this site represents a unique heritage for earth sciences and deserves to be considered as a UNESCO Global Geopark Site (www.unesco.org/geoparks/) or, on a larger scale, a UNESCO World Heritage Site (https://whc.unesco.org/).

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LAND USE AND SETTLEMENT DYNAMICS IN THE BAYS OF BEVAIX AND CORTAILLOD (NEUCHÂTEL LAKE, SWITZERLAND) DURING THE LATE BRONZE AGE

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ABSTRACT
Several bays located on the north-western shores of Neuchâtel Lake (Neuchâtel canton, Switzerland) were intensively occupied during the Late Bronze Age (HaB, corresponding to 1060-850 BC). The dendroarchaeological data of the two bays, Bevaix and Cortaillod, were confronted with evidence stemming from the terrestrial sites and archaeopedological study, in order to get insight into the interaction between settlement dynamics, land use, and handling environmental challenges. Although these bays were occupied almost continuously between 1060-1050 and 850 BC, archaeological data reveal that in the hinterland, behind the bays, only few structures attributed to the HaB period are documented. This absence seems to be related to occupational dynamics. The exhaustive study of the piles of the palafittic villages indicates that shoreward colonisation of the lake was carefully planned. The synchronous expansion of satellite villages in two bays has been interpreted as an indication of recurrent interaction between their populations. Moreover, the oak piles, mostly used for the construction of houses, suggest that forest resources exploited by inhabitants of the two bays were considerably different. These data correspond well with the agronomic and forestry potentials of the hinterland as it is reconstructed by applying the principles of land evaluation. This investigation showed that a large part of the soilscape was too humid or too clayey both for cereal production and optimal oak growth. Significant differences of agricultural and forestry suitability of soils in the vicinity of the two bays was revealed as well. To conclude, the superposition of data permitted us to unravel new understandings of the occupation dynamics and management strategies of the environmental challenges faced by the Late Bronze Age population in the studied region.

KEYWORDS
Neuchâtel Lake, bays of Bevaix and Cortaillod, Bevaix Plateau, Areuse delta, Late Bronze Age HaB, lake-dwellings, hinterland, village organisation, terrestrial settlements, dendrochronology, archaeopedology, land evaluation, forest resources, agronomic potentials of soils

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1. Purpose and research context

1.1. ARCHAEOENVIRONMENTAL STUDY FRAMEWORK

This paper aims to present selected research results of a large-scale interdisciplinary research project that was carried out in recent decades in the vicinity of the north-western shores of Neuchâtel Lake. This region is characterised by the presence of numerous lake-dwelling sites, of which several are classified as Unesco heritage sites (Arnold, 2009). Between 3870 BC and 850 BC, during low lake level periods, the shores were periodically occupied by lake-dwellers. Large scale hydro-engineering works carried out by the end of the 19th century lowered the lake level with 2.7 meters (Nast, 2006), which permitted the discovery and documentation of several dwelling sites that had remained hidden under water for centuries. The lowering of the lake level triggered an enhanced erosion risk; therefore numerous rescue excavations were performed (Arnold, 2009). Thanks to these rescue excavations, a significant amount of scientific data witnessing the various aspects of the lake-dwellers' every-day life and their environment has been assembled. In addition, the construction of the A5 highway, which started in the sixties, permitted the documentation of not only the archaeological, but also the environmental aspects of numerous terrestrial sites; these results are referred to in numerous publications (Bednarz et al., 2006; Weber-Tièche and Sordoillet, 2008; Leducq et al., 2008; Anastasiu and Langenegger, 2010; Grau Bitterli and Fierz-Dayer, 2011; Akeret and Geith-Chauvière, 2011; Elmer et al., 2016; Jobin and Wüthrich, 2017). Among these investigations, as an assumed choice to better understand the relationship between soils and human activity (B. Arnold, com. pers.), systematic archaeopedological investigations were also performed between 1995 and 2000. A synthesis of these results is underway and this paper focusses on land use questions, which emerged during the comprehensive study of piles of Late Bronze Age settlements. The details of this interdisciplinary investigation were communicated during the meeting *Entre terres et eaux, les sites littoraux de l'âge du Bronze, spécificités et relations avec l'arrière-pays,* which took place in 2017 in Agde (Hérault, France) and were published afterwards (Deák et al., 2019). Herewith we intend to highlight the main elements concerning settlement dynamics during the Late Bronze Age with a special focus on the characterisation of the soilscape, potential land use, and the interaction between the lake dwellers' communities having different land resources.

1.2. ENVIRONMENTAL SETTING

The studied region is situated on the north-western shore of the Neuchâtel Lake (Figure 1). The geomorphology is comparable to an amphitheatre (Fig 2a,b). This is related to a long geological history that started during the Mesozoic and was shaped by erosion sedimentation processes related to glacial passages during the Late Pleistocene. On the north-western part of this territory, the Boudry Mountain (Jura Massive), culminating at 1390 m a.s.l., is composed of Jurassic and Cretaceous limestones (Meia and Becker, 1976), locally covered by glacial deposits containing alpine, non-calcareous material, too. Here, the important slopes (16-40 %) are covered by forest and meadows. Starting from about 470 m a.s.l., the Bevaix Plateau is a triangular landscape unit of about 8 km² and is built up of tertiary molasses (sandstones, marls, and limestones), covered by Pleistocene glacial (moraines, glacio-fluvial, and glacio-lacustrine) deposits and post-glacial fluviatile, palustral, and slope sediments (Weber-Tièche and Sordoillet, 2008). It is characterised by an irregular topography due to the presence of several, more or less, large depressions, some of them being traversed by active or buried rivers and brooklets. Today, several more or less large settlements are located on this plateau which is crossed by the A5 highway; the main land use is intensive agriculture. Towards the lake, the Bevaix Plateau is delimited by steep slopes (15-20 %) and is composed of tertiary and quaternary mostly fine sediments (Weber-Tièche, 1998; Letessier, 2004). Most of these slopes are south-oriented and today are covered by vineyards. The land between these slopes and the lake is rather narrow (100-150 m) and is the place of accumulation of lake sediments and slope deposits. This area is the littoral platform, which was affected by lake level variations throughout the Holocene and was the place of installation of palafittic settlements.

The north-eastern part of the studied region, the plain of the Areuse, is a triangular territory of about 4 km² between the Jura Mountains and the Neuchâtel Lake. It is situated some tens of meters under the Bevaix Plateau, at altitudes between 440-429.3 m a.s.l. In the past it has been crossed by numerous channels of the Areuse river (31 km long, with a hydrological basin of 405 km²), while today the river flows along a rectilinear canal and the plain is intensively used for crop production. The actual mean lake level is 429.3 m a.s.l.

The present-day climate in the study region is characterised by mean annual temperatures of 9.4 °C (Neuchâtel, 485 m a.s.l.), while higher up in the mountains it is 6.3-6.4 °C (La Chaux-de-Fonds, 1018 m a.s.l.). For the same stations, the mean annual precipitations are 987 mm and 1468 mm respectively (Météosuisse, 2016). The mean annual evaporation for the Neuchâtel station is 573 mm (Météosuise, 2005), thus on an annual basis leaching conditions prevail. During the Holocene, these climatic parameter values varied significantly (Magny, 1998). The Final

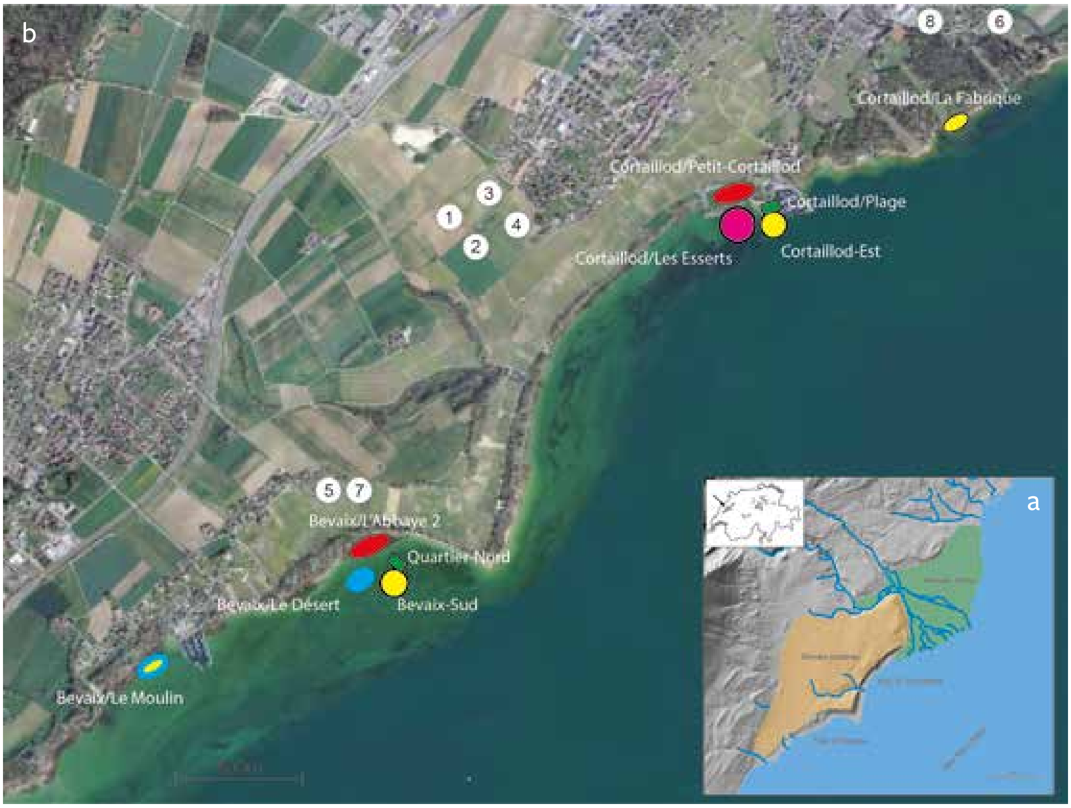

Figure 1. Location of the studied region, geomorphological setting and position of the sites discussed in this paper:

a. Geographical location and geomorphological setting.

b. Position of lake-dwelling sites (red, yellow, blue, green spots; their chronology see Fig. 3) and terrestrial sites (1. Boudry/Les Buchilles; 2. Cortaillod/Petit Ruz ; 3. Cortaillod/Petit Ruz; 4. Boudry/Les Buchilles; 5. Bevaix/Les Pâquiers; 6. Boudry/Chézard; 7. Bevaix/La Prairie-ouest; 8. Boudry/Champ-le-Sage-Centre).

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Bronze Age is considered a period with optimal climatic conditions, characterised by prolonged dry and relatively warm growing seasons and low lake levels throughout the northern Circum-Alpine region. During this period, the mean lake-level of Neuchâtel Lake was at about 426-427 m a.s.l. (Arnold and Langenegger, 2012). Before this, during the climatic deterioration of the Middle Bronze Age, the mean lake-level rose up to 433 m (Deák et al., 2018) and the lakeshores were abandoned (Arnold, 2009). The end of the Late Bronze Age corresponds to a major climatic deterioration, characterised by an important rise of lake-levels all through the northern Circum-Alpine region (Magny, 2015). This is also the end of the lake-dwelling civilisations all over this region (Menotti, 2015).

In the absence of anthropic activity and with the exception of the steep slopes and river channels, the potential vegetation all through the studied area is deciduous forest (Béguin and Theurillat, 1985-86). This was also the case when the first farmers colonised the region (Hadorn, 1994).

2. The bays of Bevaix and Cortaillod during the Late Bronze Age (HaB)

2.1. LAKE-SHORES AND LAKE-DWELLINGS AT NEUCHÂTEL: BRIEF INTRODUCTION

In the studied region, the first lake dwellings emerge around 3870-3850 BC during the Middle Neolithic. The lake shores were definitively abandoned around 850 BC towards the end of the Late Bronze Age, when, because of an important climatic deterioration (Bourget phase, Magny 1998), the lake-level rose markedly and buried these settlements. This time span of 3000 years does not mean a continuous and permanent occupation of bays and shores. In fact, this long period is marked by more or less long phases of climatic deteriorations triggering the lake level to rise and on several occasions forcing the population to abandon the shorelines and seek refuge in less exposed and better protected areas of the hinterland. During the Neolithic, for a period of 1450 years, recurrent and shifting lake settlements occupied most of the shores of the studied region evenly. The Early Bronze Age (dated around 1600) palafitic phase is little documented so far. Following this, after 600 years of abandonment, starting from 1054 BC, a Late Bronze Age population reconquers the lakeshores at a moment when the mean lake-level is low. Starting from this moment on, the settlements are concentrated solely in the principal bays. Four of them have been thoroughly documented, while a fifth one is presumed, but not explored, as it is deeply buried under backfills, permitting the lakeward expansion of Neuchâtel town (Arnold, 2009). The bays of Bevaix and Cortaillod are two of the locations among the four thoroughly studied Late Bronze Age (HaB) piles-dwellings in the studied region.

2.2. LATE BRONZE AGE SETTLEMENT DYNAMICS AS REVEALED BY A DENDROARCHAEOLOGICAL STUDY

The dendroarchaeological study of posts of four exhaustively studied Late Bronze Age lake-dwellings (Bevaix-Sud, Cortaillod-Est, Hauterive-Champréveyres, and Auvernier-Nord) permitted the development of a theoretical model of occupations of the bays during this period (Langenegger, 2012). Although the discussion below is focussed on the data concerning the bays of Bevaix and Cortaillod (Figure 1 and 3), most of the enumerated facts are valid for the other bays, too.

The available dates indicate that in the studied region the recolonisation of the shorelines was almost synchronous all over and took place around 1057-1054 BC.

Figure 2. Aerial photos of the studied region:

a. Boudry Mountain and Bevaix Plateau with the slopes towards the lake.

b. Areuse Delta. Copyright Laténium.

The first houses were built close to the actual shoreline, while later on the expansion of the houses occurred towards the lake, indicating the gradual lowering of the lake-level. Based on their size, their duration (180 years), and their continuity, these first settlements are considered 'founding villages' and they most probably played a central role in the development of an important community in each bay. The 'founding village' of Bevaix bay, the site Bevaix/L'Abbaye 2 (Figure 3) occupied up to 2 ha at its maximum development. The 'founding village' at the Cortaillod bay was not yet discovered, but its existence is deduced from the extensive regeneration of forest witnessed by dendrochronological data of wooden piles of the satellite villages (Deák et al., 2019). These settlements developed by expansion phases towards the lake through the construction of 'satellite villages' (Figure 3 and 1). In each of the bays, the 'founding villages' were completed by one or several 'satellite villages'. Their location in the neighbourhood of the 'founding villages' indicates that they belonged to the same community. Each of them possibly had a specific role in the social and economic functioning of the local society and most probably, they all relied on the same agricultural and forestry territory. The 'satellite villages' functioned for a shorter period and most probably were constructed to face the demographic growth and/or to permit the reconstruction of some of the first-generation houses of the 'founding villages'. The maximum lifetime of a palafittic house is about 40 years.

The best-studied 'satellite villages' are the ones called Bevaix-Sud (Arnold and Langenegger, 2012) and Cortaillod-Est (Arnold, 1986) (Figure 1). Along a straight line, they are about 2 km apart and the dendrochronological data of about 4600 piles indicates that they developed for about 60 years and in a completely synchronous manner. The cutting of oak trees started at the same time, during the winter of 1011/1010 BC. Between 1009 and 1004, the innermost houses of the two villages are finished and surrounded by fences in beech wood at Bevaix and in oak wood at Cortaillod. The last construction phase at Cortaillod-Est started in 964 BC and corresponds to a new cluster of houses (called Cortaillod-Plage) located outside the fence, towards the lake. A similar construction dynamic and chronology has been revealed at the site of Bevaix-Sud with the construction of Quartier-Nord. The exhaustive study of piles from the Bevaix-Sud site showed that its construction was extremely carefully planned. Indeed, even a geometric division of the village space before its construction could also be unravelled (Arnold and Langenegger, 2012). Earthworks and development works were also associated with this. As an example, 33 tons of pebbles were brought into the village to consolidate the surfaces.

These 'satellite villages' were abandoned shortly before 950 BC and in 920 BC a new series of these villages started to be constructed (such as Bevaix/Le Désert) or re-occupied (Bevaix/Le Moulin, Figure 3). From 920 to 880 BC the 'founding villages' continued to be occupied, while the new 'satellite villages' continued to develop.

Between 878 and 871 BC a major change must have occurred in the living conditions of the communities living on the shores of Neuchâtel Lake. Indeed, the former 'founding' and 'satellite' villages were permanently abandoned for a new generation of large villages. Three of such new villages have been documented so far throughout the lake shores located in the Neuchâtel canton. These new, regrouped villages, are characterised by a very short occupation period, lasting for about 20 years. In the case of the formerly intensively populated bays of Bevaix and Cortaillod, this second bay was chosen as the location of a newly constructed village. Known as Cortaillod/Les

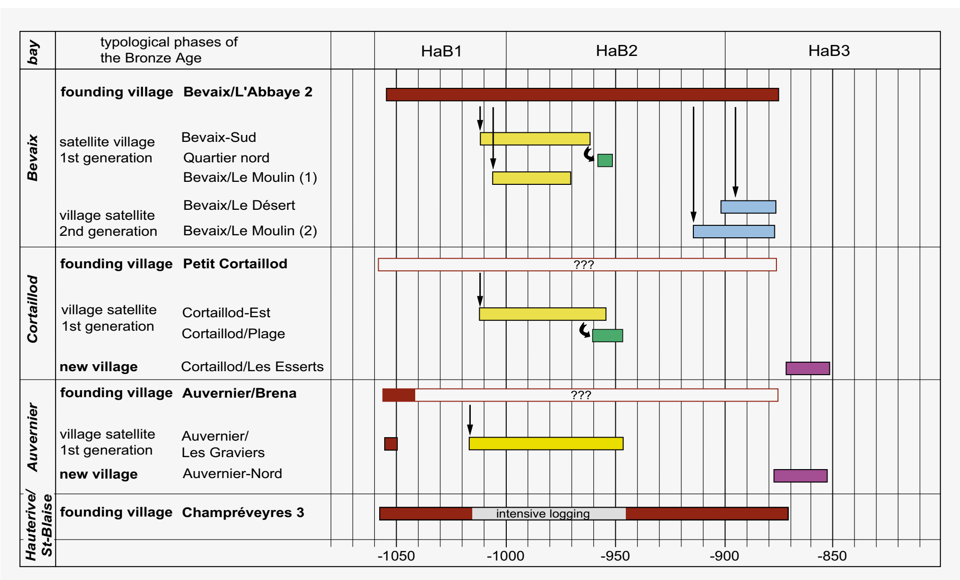

Figure 3. Chronology of 'founding' and 'satellite' villages. Location of the settlements of bay of Bevaix and Cortaillod are represented on Fig. 1. The bays of Auvernier and Hauterive are situated north-east from the studied bays. Modified from Arnold and Langenegger, 2012.

Essert site (Figure 1 and Figure 3), it included about 60 houses, was inhabited between 871 and 862 BC and was surrounded by a triple fence rim (Arnold and Langenegger, 2012). These major population displacements are also reflected by modifications in the artefact assemblage. This is known as the HaB3 assemblage (Rychner, 1987). Around 850 BC, thus about 30 years after their creation and despite the buildings still being in a good state, these new villages were also abandoned, similarly to all the lake-dwelling settlements of the northern Circum-Alpine region (Menotti, 2015). This is most probably related to the major climatic degradation (cooling and increased precipitation) that starts around 850/800 BC which resulted in a major rise in lake-levels (Magny, 2015) as well as possibly triggering a decrease in crop yield (Tinner et al., 2003). The beginning of this climatic change corresponds to the onset of the Iron Age.

2.3. FOREST RESOURCES AND 200 YEARS OF STRUCTURED INTERACTION

Overall data indicate that the internal organisation of the two bays is strongly alike: the annual tree fellings, unravelled through the study of the piles used for the construction of houses, indicate a perfect chronological superposition of periods of construction, reparation or expansion in each of them (Figure 4a, 4b). This suggests a strong link in the functioning of the communities populating these two bays. The development of the settlements was thus synchronous and presented the same dynamics, but local adaptations could also be discovered: the orientation of the houses took in consideration the dominant or the most violent winds, while the cutting techniques to obtain the right dimensions of the posts were adapted to the wood used. Indeed, the dendroarchaeological study revealed that the size and age of oak trees used for the posts varied, suggesting two distinct forest resources. The forests exploited for the houses constructed in the bay of Bevaix were composed mainly of 200-300 years old trees, while the ones employed for the dwellings of the Cortaillod bay were clearly younger (Figure 4b).

3. The hinterland: archaeological data

In the hinterland behind the lake dwelling sites, the archaeological vestiges dating from the Late Bronze Age are rare, despite the intensive investigations performed before the A5 highway construction. The fact that in these areas archaeological finds belonging to several other archaeological occupation phases systematically exist, suggests that this absence is not related to erosion processes, but rather reflects a reality triggered by occupation dynamics.

3.1. SEASONAL OR SPECIFIC HABITATS AND/OR OUTBUILDINGS

The lake shores settlements were constructed starting from 1057-1054 BC and this marks the beginning of the second part of the Final Bronze Age (HaB). The colonisation of the lakeside was not a massive and hasty act, but rather a transitional process planned through 2-3 generations in the conditions of climatic improvements associated with the lake-level retreat and the outcropping of silty marl lake sediments on the littoral platform. This implies a progressive 'abandonment' of the terrestrial settlements occupied during the previous periods. As such, the population continues to use the hinterland as a habitat during the construction phase of lake dwellings.

In the studied region, only two architectural remains dating from before and during the construction of the first lake-dwelling settlements could be found, despite

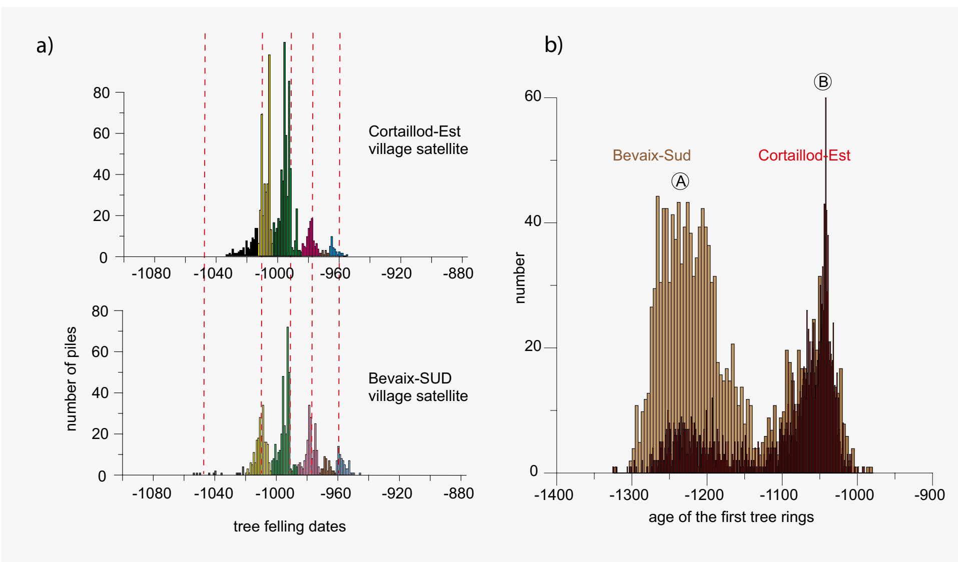

Figure 4. Lake dwelling settlement as unravelled by dendroarchaeological studies:

a. Chronological evolution of two synchronous 'satellite' villages and their settlement dynamics as indicated by the number of piles used for construction.

b. Age histogram of wood population used for their construction.

the large-scale investigations. They are part of Boudry/Les Buchilles and Cortaillod/Petit Ruz sites (Anastasiu and Langenegger, 2010), located about 1 km away from the lakeshore in the hinterland (Figure 1). The two isolated houses are situated at about 300 m from each other in a humid depression, on the banks of two small brooklets and they are characterised by modest dimensions comparable with the houses documented for the preceding Middle Bronze Age. The first house, identified by four piles, contains a fire place, but no artefacts. Only few pottery fragments have been found in the soil surrounding it. The second building is identified by piles, a bottom plate, and a floor made up of a gravel layer. It contained both pottery fragments and lithic artefacts. A fire place situated in the neighbourhood has also been linked to this structure. A waste disposal area containing, among others, a large concentration of pottery fragments has also been documented along the riverbanks and in the watercourse of the brooklets passing next to this building (Anastasiu and Langenegger, 2010). Taken as a whole, the archaeological finds, together with the available C^{14} dates suggest an anthropic activity here at about 1060 BC, corresponding to the planning and beginning of the construction phase of the first lake-dwelling houses. This is interpreted as an indication that at least parts of the population still lived and were active in the hinterland, while waiting for the construction of palafittic villages (Deák et al., 2019).

Further away, three treefall pits transformed to waste pits at Bevaix/Les Pâquiers site (Bednarz et al., 2006) are the only settlement type remains in the hinterland, which date from the Late Bronze Age. They contained an important concentration and variety of artefacts (pottery fragments, lithic artefacts, grinding material, burned soils fragments, Figure 5a,b), charcoal, and carpological remains. The latter are characteristic for Late Bronze Age habitat sites (Akeret and Geith-Chauvière, 2011). The ceramic assemblage is similar to the regional reference collections attributed to the HaB period and are identical to those found at the lake dwelling sites L'Abbaye 2 and Bevaix-Sud of bay of Bevaix (Figure 1). Although eroded, these waste pits are the only material evidence of a settlement in the hinterlands that existed during the same time as the lake-dwellings of the 10^{th} century BC. It is difficult to determine the exact nature/function of this habitat, but the available data suggest it was rather an isolated farm (specialised or seasonal) than an organised village/hamlet.

3.2. SHELTER OR WITHDRAWAL IN CASE OF LAKE-LEVEL RISE

In an abandoned channel located in the middle of the Areuse delta, at about 1 km from the lakeshores, a 40 m^2 large waste disposal was found (Elmer et al., 2016). It contained 15.000 pottery fragments belonging to at least 1.500 recipients, accompanied by quern-stones, lithic artefacts, clay fragments originating from around twenty firedogs and five spindle whorls, numerous burned stones, burned earth and wattle and daub fragments (Figure 6a,b). Interpreted as a domestic waste discard zone, this assemblage indirectly attests to a settlement composed of several buildings in proximity to this channel. Based on pottery typology, it has been attributed to the second half of the HaB2 phase (950-900 BC) of the Late Bronze Age. Based on regional archaeological data and on the evidence of a temporary break in the development of dwellings in the bays of Bevaix and Cortaillod, it is estimated that a short, but marked lake-level rise occurred during this period (Arnold and Langenegger, 2012). This lake-level rise did not denote the complete abandonment of

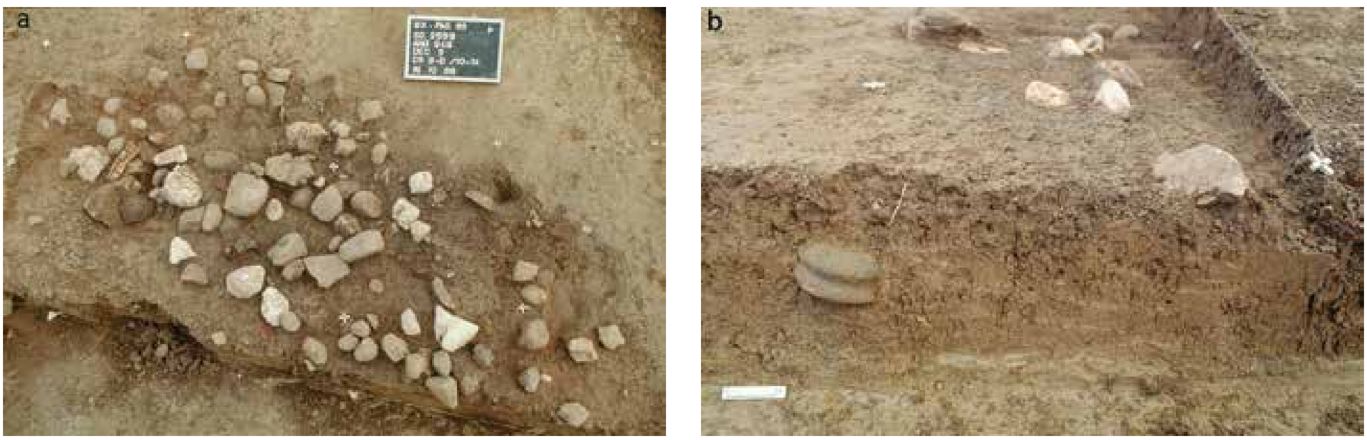

Figure 5. Treefall hollows transformed in wastepits, Bevaix/Les Pâquiers site:
a. Horizontal section.
b. Vertical section.
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the lake-shore: in the studied area it induced a temporary withdrawal of at least part of the population, while in the bay of Hauterive (Pillonel, 2007), which was located some kms North-East on the same shores of the Neuchâtel Lake, the houses were repaired or reinforced in order to resist more important hydrological trials.

3.3. TRACES OF CEREMONIAL COMMUNITY EVENTS AND BURIAL SITES

A few hundred meters inland from the lakeward boundary of the Bevaix Plateau, at the site of Bevaix/La Prairie-east (Figure 1), at the edge of a large marshy area, three very similar rectangular, flat bottomed hearth pits were discovered (Von Burg and Pillonel, 2003; Leducq et al., 2008). The bottoms are covered by a charcoal layer stemming from the combustion of oak wood, mainly slotted logs (up to 70 cm long). They contained, among others, a wide variety of burned cereal grains and a few pottery fragments, the latter attributed to the Late Bronze HB2 period. The dendrochronological analysis of one of these logs suggests its utilisation around 970 BC. These hearth pits of culinary vocation are common in the regional Late Bronze Age record (Mauvilly et al., 2003). They are placed outside of habitat areas, often clustered, functioning synchronously and for short periods of time, which is interpreted as reflecting festive or ceremonial community/

Figure 6. Domestic waste discard in an abandoned channel at Boudry/Chézard in the Areuse Delta:

a. Horizontal view during excavation.

b. Restored pottery (photos Thomas Jansen and Marc Juillard; copyright Laténium).

society events (Orliac and Wattez, 1989; Ramseyer, 2003; Mauvilly et al., 2003). These structures mentioned here are located upslope of the bay of Bevaix, at the edge of the marshy area, along the shortest possible circulation line between the lake-dwellings and the forests on the slopes of the neighbouring mountains. The wood used is oak, while the timing is around 970 BC, corresponding to the growth of the Bevaix-Sud satellite village (Arnold and Langenegger, 2012). All these elements suggest that certain activities or tasks of the lake-dwelling village planification could have been marked by festivities or rituals.

Only two burial sites dating back to the Late Bronze Age, more precisely to its final phase, thus corresponding to the phase of regrouped villages, have been documented so far in the Neuchâtel canton. One of them is situated in an abandoned channel of the Areuse delta at the site Boudry-Champs le-Sage-Centre (Elmer et al., 2016).

4. Soilscape and agricultural potentials of soils during the Late Bronze Age

4.1. SUITABILITY OF SOILS: WHY AND HOW

Since the Neolithic agricultural revolution, soils around settlements are part of the natural resources influencing, among others, the production of agropastoral goods and the nature and quantity of wood available for construction. The evaluation of suitability of soils for various land use in a given climate means the superposition of data concerning:

i. physico-chemical characteristics of soils;
ii. topographic data;
iii. edaphic requirements of plants for optimal growth and
iv. panoply of available agricultural tools and techniques.

Figure 6. Agricultural tools discovered at the Late Bronze Age site of Hauterive-Champréveyres:

a. Hoe made of beech wood.

b. Digging stick made of Cornelian cherry wood.

Photos Marc Juillard; copyright Laténium.

This way of inspecting the relationship between soils and potential land uses is borrowed from the Land Evaluation practices. These practices were initially constructed for present-day or future land uses and defined by the Food and Agricultural Organisation of the United Nations (FAO) in 1976 as an 'assessment of land performance when used for specific purposes'. In an archaeological context, land evaluation intends to define the potential suitability of ancient landscapes for ancient land uses (Van Joolen, 2003). In such a framework, many parameters of evaluation are unknown or approximatively extrapolated. For these reasons, we do not attempt to give quantitative indications on yields in this study, but we focus on a qualitative and comparative assessment of soils for specific purposes. In the last decades, several scientists attempted this exercise (ex. Borrello, 1984; Van Joolen, 2003; Louwagie et al., 2006; Baum, 2014) and gave interesting views on the potential relationship between soils, landscapes, and human activity. These above-mentioned studies are based on the characteristics of the present-day soils. In the case of the studied region, the present-day soil cover is considerably different from the past one, therefore in our study the first step was to distinguish and characterise the soils that possibly existed during the Late Bonze Age in the region surrounding the bays of Bevaix and Cortaillod.

Below we will focus on the suitability of soils for crop production, for meadows/pasturelands, and for forestry with particular attention to oaks that are used as piles for the houses. As for the agricultural tools, we assume the use of digging sticks, the hoe, and the plough, all of which have been available since the Neolithic (Jacquat, 1989 and Figure 7). The use of animal traction has also been attested since 2900-2500 BC (Jacomet and Schibler, 2006). In terms of crop production, implying ploughing and hoeing, the soil texture is a factor that influences the potential use of available tools. We estimate that:

i. sandy-silty soils can be easily cultivated with tools available during the Bronze Age;
ii. gravelly soils, depending on size and quantity of gravels, might present strong limitations;
iii. strongly clayey soils cannot be exploited for crop production during the Late Bronze Age.

Based on recent agronomic research concerning direct sowing and limited tillage (Labreuche et al., 2014), we assume that tillage was not systematically employed. Nevertheless, even in these conditions planting seeds and removing weeds were compulsory tasks. Taking into account that the agricultural tools were manufactured out of wood, in this work we estimate that strongly clayey soils were only marginally suitable or not suitable for crop production.

In order to evaluate the suitability of soils for the various land uses of the Late Bronze Age communities, first their physical and chemical fertility (Troeh and Thompson, 1993) was examined. The chemical fertility is in function of the quantity of organic matter available in the surface horizon and of mineralogical composition of the fine fraction throughout the soil. As for the physical fertility it is defined by:

i. granulometry, influencing the water retention capacity and workability;
ii. rooting depth;
iii. presence/absence, depth, and dynamics of the water table.

4.2. MOSAIC OF ORIGINAL SOILSCAPE

Today, the soilscape of the studied region is mostly composed of soils developed on more or less recent colluvial deposits of various thicknesses and thin soils formed on strongly eroded sediments of glacial origin (Figure 8). As for ancient alluvial and palustral settings, these areas nowadays are canalised (Figure 2) and/or intensively drained. As mentioned above, the examination of the ancient soilscape is possible thanks to the systematic geological and pedological documentation of archaeological interventions performed especially along the A5 highway, completed with observations done outside of it (see references above). Therefore, our study is focused on the original soils, i.e. the soils that covered the soilscape before important deforestations and major erosions took place. A brief characterisation of these soils is given below, but as a preliminary outline it is possible to say that on slopes and plateaus, these soils were more or less decalcified and were characterised by a thick, strongly humiferous surface (A) horizon and a more or less thick subsurface horizon. During Neolithic and earlier parts of the Bronze Age, these soils were already cleared and cultivated on numerous parts of Bevaix Plateau. Local reworking of the original surface horizon has also been retraced (Bednarz et al., 2006; Weber-Tièche and Sordoillet, 2008; Grau Bitterli and Fierz-Dayer, 2011). Nevertheless, with the available data we estimate that physical and chemical fertility parameters of the original soils were not significantly altered by this early and local erosion/sedimentation processes. Thus, they were also the soil resources during the Late Bronze Age.

After a first thorough examination of the collected data, it turned out that, for the original soils in the studied region, the soil's physico-chemical characteristics influencing past land use are primarily determined by the nature of the parent material and then by their landscape position. Therefore, the soils distinguished have been grouped, named, and characterised according to these criteria. This approach to sidestep the existing soil classification systems was chosen in order to cope with the nature of the data. In the archaeological contexts, the accurate physico-chemical parameters are not available because the soils are more or less eroded and sometimes even buried for several thousands of years. The soils differentiated are presented briefly below and in Figures 8 and 9, while Table 1 resumes the main parameters of their physico-chemical fertility that are decisive for their potential land use. The soil map (Figure 10) illustrates the original soilscape in the neighbourhood of the two bays. A comparative overview of potential land uses during the Late Bronze Age is presented in section 4.3 below.

Soils on glacial till deposits – A soils

The glacial till deposits form the parent material of a part of the ancient soils of the Bevaix Plateau. These deposits are strongly calcareous (30-45 %) and are rich in clay (30-60 %) and silt fraction; in general, they contain few coarse elements that can vary in size from small gravels to big blocs (limestones, magmatic, and metamorphic rocks). In some areas, the sandy fraction can be more important to the detriment of clayey components. This sediment is strongly compacted due to the weight of hundreds of meters of ice that passed over it.

On the well-drained slopes and on hilltops, the soil formed on this deposit (Table 1, A.1 soil, Figure 8a) was decalcified to depths of less than 1 m and its mineralogical composition was characterised by the presence of a high amount (50-70 %) of weatherable minerals and phyllosilicates. The surface horizon was considerably enriched in organic matter, as during thousands of years it evolved under forest vegetation. The initial compact character of the glacial till has been improved by soil forming processes, while the strongly compact parent material persisted to induce impeded drainage. The porosity of this soil was mainly related to bioturbation in its upper part and with swelling-shrinking processes in the subsurface horizon. Thus, in little perturbed conditions, it is assumed that it had a very good porosity in the surface horizon that decreased gradually towards the parent material. On foot slopes and in depressions, the decalcification and weathering of this sediment was less important, thus the soil (Table 1, A.2 soil) was much shallower.

In short, these soils had a good chemical fertility and a good water holding capacity. Nevertheless, these soils presented limitations for crop production due to their low permeability (A.1) and/or bad drainage condition (A.2). In addition, due to their clayey texture these soils were humid for longer, thus cold, hampering seed germination. Last but not least, the high clay content was certainly a limitation for the use of tools manufactured out of wood.

Soils on glaciofluvial and glaciolacustrine deposits – B soils

The glaciofluvial sediments are sandy and sandy gravelly (20 to 90 % coarse fraction) and strongly calcareous (20-60 % $CaCO_3$). Similarly to A soils, we estimate that the surface horizon of soils (Table 1, B.1 and B.2 soil) formed on these sediments contained high amounts of organic matter, at least at the onset of Late Bronze Age agropastoral activity. The mineralogical composition of the fine fraction was also characterised by high (30-70 %) weatherable mineral and phyllosilicate content. Their porosity was very important, permitting good root penetration and inducing a high permeability. On the well-drained slopes and on hilltops the depth of decalcification of soils formed on these sediments (Table 1, B.1 soil; Figure 8b) was more than 1 m thick. They were characterised by the presence of a clay illuvial subsurface horizon. On foot slopes and in depressions the decalcification was less deep and the soil (B.2 soil) did not have a clay accumulation horizon.

The glaciolacustrine sediments are composed of silty and clayey stratified, rather compact layers. In most part of the studied region they are intercalated with the glaciofluvial sediments, thus contributing to the variability of these soils. Nevertheless, relatively thick deposits of these sediments are present on the lake side edges of the Bevaix Plateau (Letessier, 2004). With the exception of its granulometry, the physico-chemical characteristics of the soil (Table 1, B.3 soil) formed on this well drained landscape position, presented strong similarities with the B.1 soil described above.

In short, these soils had good chemical fertility. The use of the wooden tool to cultivate the gravel rich facies (B.1 and B.2) was difficult or impossible. Nevertheless, overall observations indicate that in most areas, in the upper part of these deposits, the coarse fraction was less important, thus most probably permitting minimal soil tillage. The low fine material content of soil B.1 suggests that crop production could be disadvantaged during prolonged particular dry conditions. However, the presence of the clay illuviation horizon could compensate for this inconvenience. The B.2 soil located in more humid zones could have been an alternative soil resource in case of prolonged dry conditions. The sandy-gravelly facies were less vulnerable to erosion (B.1 and B.2), while the more silty textured soil (B.3) was strongly susceptible to this type of degradation. The B.3 soil was characterised by good water retention capacity and could be well cultivated with tools available during the Late Bronze Age.

Soils on tardiglacial slope and stream deposits – C soils

After the glacier retreat (at about 17 000 BP, Thew et al., 2009) and before the vegetation colonisation that occurred in the timespan Bølling-Allerød (14 700-13 900 BP,

Figure 8. Morphology of some of the components of the Late Bronze Age soilscape of the Bevaix Plateau:

a. Shallow and clayey soil formed on moraine (A.2 soil). The black layer corresponds to the surface horizon of this soil. This layer was at the surface during the Late Bronze Age.

b. Deep soil, rich in coarse elements, formed on glaciofluvial sediments at well drained topographic position (B.1 soil). The gravel rich layer is the original B_t horizon; it is covered by colluviums. The original surface and eluvial horizon have been eroded. For scale: the distance between two vertical lines is 1 meter.

c. Deep, fine textured soil, formed on tardiglacial sediments (C.1 soil). The black layer in the upper third of the image is the original surface horizon.

d. Lake marl (white sediment in depth) and peat (black layers) filling up humid depressions of Bevaix Plateau (D soil). (photos a, b, d, Marc Juillard; copyright Laténium; c – Roger Langohr).

Hadorn, 1994), thus during early parts of the Tardiglacial, the overland flows and slope processes have considerably reworked sediments of glacial origin, as well as the marls and sandstones of the Tertiary substratum. These tardiglacial deposits are usually heterometric, strongly resembling in granulometry to the reworked original sediments and contain between 20-50 % $CaCO_3$.

The soils formed on these sediments were rich in weatherable minerals. Compared to A soils they were characterised by a better permeability, while compared to B.1 and B.2 soils they contained less coarse elements. In well drained position the soil (Table 1, C.1 soil, Figure 8c) formed on this sediment was:

i. decalcified to more than one meter depth;
ii. often had a clay accumulation subsurface horizon and
iii. was characterised by an important porosity related to bioturbation and swelling and shrinking processes, permitting as such a good rooting penetration.

On foot slopes and in depressions, the soil developed out of these sediments (Table 1, C.2 soil) was also decalcified, but to depths of less than 50 cm, thus had a shallower rooting depth. Similarly to the soils described above, the mineralogical composition of these C soils and their evolution under forest vegetation during several thousands of years permitted to have an important nutrient reserve for plant growth. As for physical fertility, we can mention a good water holding capacity, but also the risk of slow water percolation (prolonged humidity) for the finer textured facies and those located in low landscape positions. The use of wood working tools must also have been difficult in the more clayey surface horizons.

Soils of humid depressions – D soil

In large depressions of the Bevaix Plateau located on the foot slopes and discharge areas of the neighbouring Boudry Mountain, lake formation and marshy waterlogged conditions existed, permitting the formation of marls, overlaid

Table 1. The soils composing the soilscape in the neighbourhood of the studied bays during Late Bronze Age and their physico-chemical characteristics influencing agropastoral and forestry activities

Geo-morphological position	Parent material	Topographic position	Soil type on Fig. 10	Chemical fertility	Rooting depth	Porosity	Water holding capacity	Workability	Erosion risks	Other
Bevaix Plateau	moraine	hilltops and gentle slopes	A.1	+++	< 100 cm	++	good	×	very low	cold soils with germination problems
		depressions and foot slopes	A.2	+++	< 50 cm	+	good	××		
	glaciofluvial and glaciolacustrine	hilltops and gentle slopes	B.1	+++	> 100 cm	+++	weak to good	✓	very low	
		depressions and foot slopes	B.2	+++	< 100 cm	+++		✓ to ×		
		edge of Plateau	B.3	+++	> 100 cm	++	good	✓ to ×	high	possible perched water-table
	tardiglacial alluviums and colluvial deposits	hilltops and gentle slopes	C.1	+++	> 100 cm	+++	good	✓ to ×	very low	germination problems in the clayey facieses
		depressions and foot slopes	C.2	+++	< 50 cm	+++	good	✓		
	lake marl and peat	large depressions	D	+	/	+	/	/	/	
ancient lake terraces and lake shore	laminities in alternation with with sandy-gravelly layers	steep slopes	E	+++ to ++	>100 cm	+++	weak to good	✓	high	possible perched water-table
	colluvial deposits	foot slope	F	++	> 50 cm	++	good	✓	exposed to lake level rise	fluctuating and regularly high water-table
	lake deposits	littoral platform	G	+ to ++	< 50 cm	+ to +++	good	× to ××	exposed to lake level rise	fluctuating and regularly high water-table
south-west zone of Areuse Delta	alluviums: channel and alluvial plain deposits	old levees and abandoned inundation plains	H.1	++	>100 cm	+++	++	✓ to ×	possible but rare	spring and autumn possibly high water-table
north-east zone of Areuse Delta		active and abandoned channels	H.2	++	/	/	/	/	high	active fluviatile dynamics
brooklets of Bevaix Plateau		at least temporarily active water courses	H.3	/	/	/	/	/	high and recurrent	high and lasting humidity

+++- high; ++-medium; + -low; ✓- no limitations to till or to work; × - difficult to till or to work; ×× -very difficult or impossible to work; /- not relevant parameter.

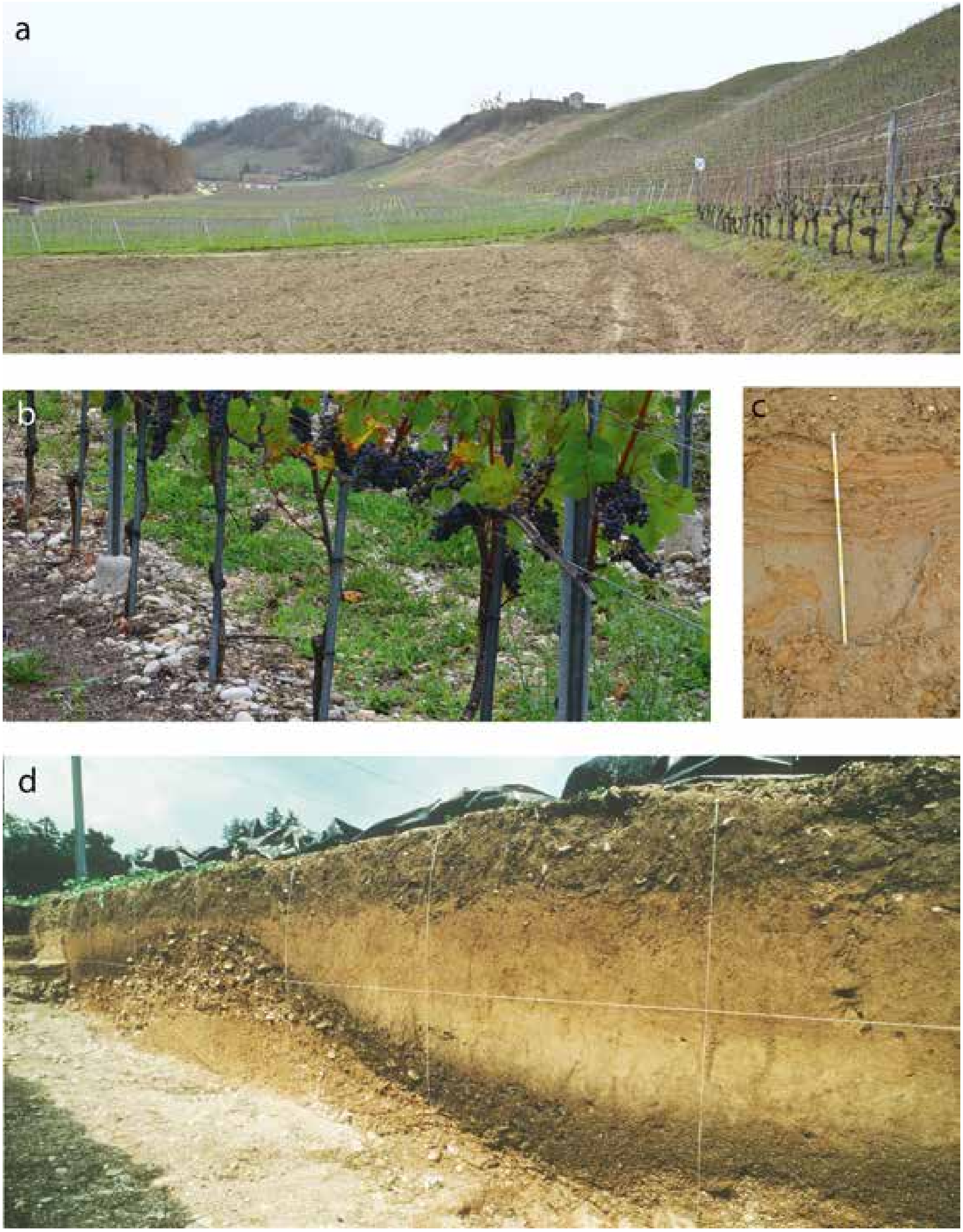

Figure 9. Morphology of soils, sediments and landscape adjacent of the bays of Bevaix and Cortaillod:

a. Colluvial sediments accumulated on the foot-slopes of the Bevaix Plateau. Taking in consideration their proximity to lake-dwellings, the F soil formed on these deposits was most probably used for both crop production (ex. pulses) and pastureland.

b. Vineyard on ancient lake-shore pebbles in the neighbourhood of bay of Bevaix. During Late Bronze Age the littoral-platform was covered by a patchwork of gravelly, sandy, chalky and peaty soils (G soil).

c. Alternation of clayey and sandy layers of ancient lake terraces that cover the slopes linking the Bevaix Plateau and the lakeshore. The involutions are related with cryoturbation processes. The E soil formed on this sediment has been largely eroded.

d. Sediments of the Areuse delta (H.1 soil). For scale: the distance between two vertical lines is 1 meter. (photos Judit Deák and Marc Juillard; copyright Laténium).

by peat. The sedimentological study of the swamplands crossed by brooklets of the Bevaix/Le Bataillard site, located upslope of the bay of Bevaix, showed the successive formation of marls and peat all through the first part of the Holocene, including the Neolithic (Tréhoux, 2008). During the Bronze Age, these sediments remained very humid, although clayey and organic rich colluvial deposits started to accumulate. The regulations of brooklets and drainage works took place progressively starting from the High Middle Ages, but these zones remain strongly humid until the massive drainage system installations during 19th and 20th centuries (Combe and Rieder, 2004; Leducq et al., 2008). In such conditions, during the Late Bronze Age, the waterlogged or strongly humid conditions were the parameters regulating plant growth and potential anthropic activities (Table 1, D soil; Figure 8d). To conclude, these areas were not suitable for crop production, but they could be used for pastureland, at least on the edges.

Ancient lake terraces – E soil

These rather compact sediments, composed of finely stratified silty and clayey deposits, sometimes with more sandy or more gravelly or more organic rich layers, have been identified on the steep slopes where the Bevaix Plateau and the lake shores or the Areuse Delta meet (Weber-Tièche, 1998). On the slopes overlying the bay of Cortaillod, they alternate laterally with coarser textured, gravelly glaciofluvial deposits (Letessier, 2004). These deposits, similarly to the above described sediments, are rich in $CaCO_3$ and their mineralogical composition is rich in weatherable minerals. Thanks to the topographic configuration, the soil formed on these sediments was decalcified with rooting depths of more than one meter and was characterised by a clay accumulation subsurface horizon (Table 1, soil E; Figure 9a,c). Thus, from a chemical point of view, this soil was also a highly fertile soil. Its considerable water retention capacity was surely an advantage, taking into consideration the excessively draining landscape position. After decalcification, the upper part of this soil must have been rather clayey, thus difficult to work. In addition, the silty textured facies might have been rather vulnerable to soil erosion. Last but not least, the lake-level fluctuations might have undermined the foot slopes, triggering mass movements. During the Late Bronze Age, the major advantage of this soil was its close proximity to lake settlements. It is likely that a terrace land management system for crop production has been set up. The soils of this landscape position, which was used as vineyards since a longtime, were strongly eroded and no material traces of this terrace type of land transformation could be unravelled so far.

Soils on slope deposits on foot slopes neighbouring the lake shore - F soil

Lake-level variations and agropastoral activities most probably triggered, at least locally, colluvial sediment deposition on the footslopes of the the Bevaix Plateau, at the contact with the littoral platform (Table 1, soil F; Figure 9a). These heterometric sediments, most probably rich in silt and clay, were non-calcareous originally, but they might have had calcareous components due to recurrent inondations at high lake-levels, which possibly added gravelly components, too. The potentially profound rooting depth was most probably affected by the ground-water fluctuations and this landscape position also presented inundation risks due to temporary lake-level rises. Its chemical fertility was high, while the use of a plough might have been difficult, either due to its fine texture or in some parts due to the presence of gravels. The main advantage of this soil was its close proximity to the habitat sites.

Soils on Holocene lake deposits – G soil

Towards 1050 B.C, the mean lake-level dropped to 426-427 m a.s.l. (Arnold and Langenegger, 2012), thus about 7 m lower than the levels reached during the preceding Middle Bronze Age (Deák et al., 2018). Behind the houses constructed from 1057-1054 BC onwards (Langenegger, 2016), the littoral platform was composed of former lake sediments, weakly transformed by pedogenetic processes and characterised by a very thin surface horizon. They were strongly calcareous, with finer granulometry towards the lake and a more gravelly one towards the shores (Table 1., G soil, Figure 9c). Areas of sediments rich in organic matter were also part of this soilscape. This soil, located in the close surroundings of the lake-dwellings, was affected by regularly high water tables and recurrent inundations due to temporary lake-level variations.

Soils on fluviatile deposits - H soils

These sediments are present in both of the main geomorphological zones studied, i.e. in the alluvial delta of the Areuse river and along the brooklets and small rivers that cross the Bevaix Plateau.

In natural conditions, the area of the Areuse Delta is composed of more or less active channels and their inundation plains, abandoned channels with oxbow lakes and with levees little affected by inundations. The archaeoenvironmental study of this area concluded that during the Bronze Age the channels were mostly active in the north-eastern part of the delta (Kraese et al., 2016). Thus, we estimate that during the studied period, the potential agricultural lands were located in the south-western part of the delta, close to the bay of Cortaillod, on relatively drained surfaces thanks to the considerable lake-level lowering that occurred at the beginning of the Late Bronze

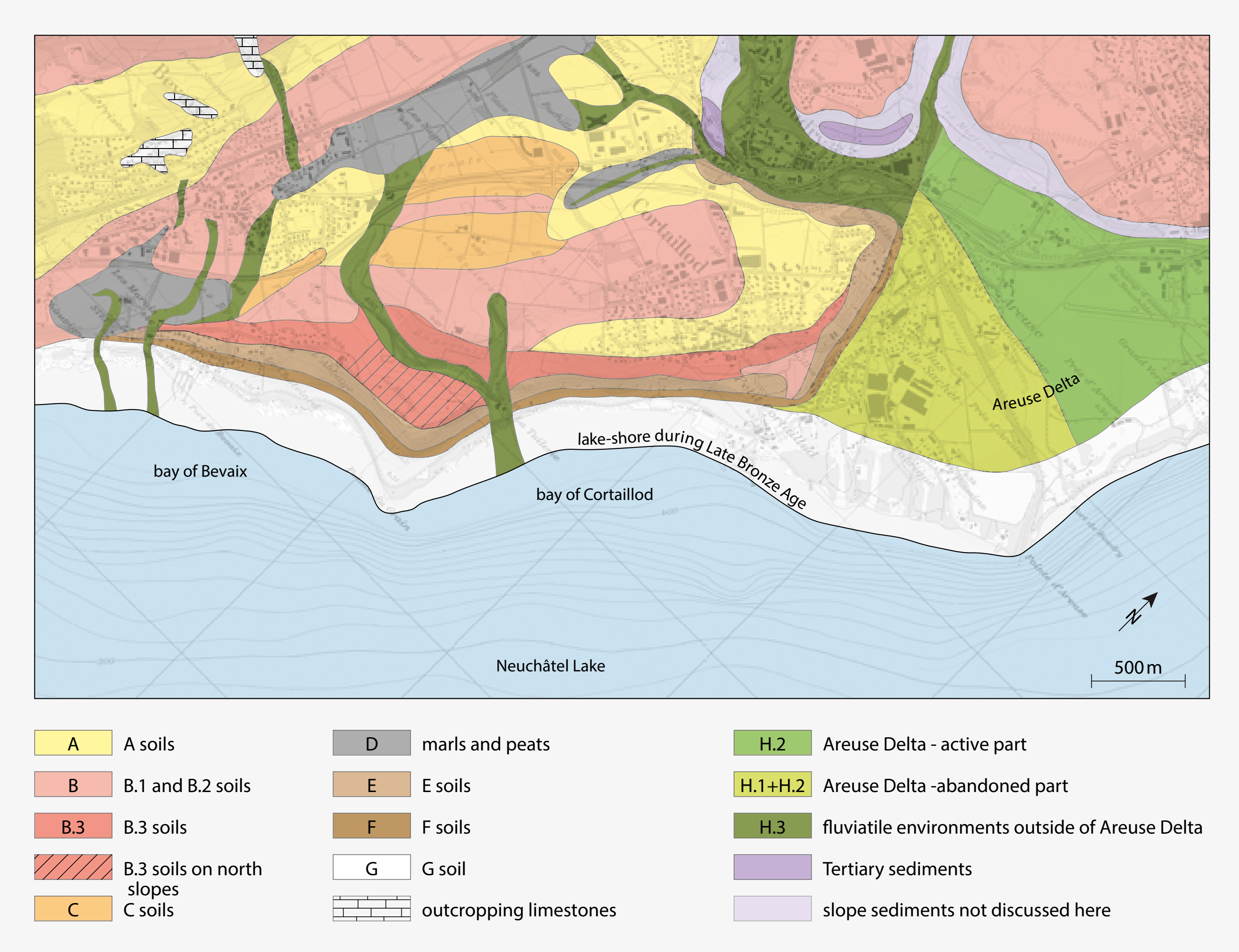

Figure 10. Soil map showing the mosaic-like soilscape of the hinterland of bays of Bevaix and Cortaillod. On this map only the major soil units could be illustrated. The hydromorphic facieses of several soils (A.2, B.2, C.2) were situated all around the major depressions and rivers. (CAD Philippe Zuppinger, OPAN).

Age. These ancient levee and channel deposits are sandy gravelly, while the ancient inundation plains are more sandy-silty (Table 1, H.1 soil and Figure 9d). Their mineralogical composition was dominated by calcite (about 59 % on average), completed by quartz (20 % on average) and phyllosilicates and several other weatherable minerals (Elmer and Adatte, 2016). This mineralogical composition and the possible high organic matter content supplied by the alluvial forest ecosystem provided a high chemical fertility. This soil was also characterised by a high porosity thanks to intensive biological activity of this ecosystem. Thus, with the exception of the temporary high water table, this soil did not have limitations for root penetration. Despite the fact that the water holding capacity of the sandy-gravelly facies is low, the water supply was most probably not a problem for plant growth thanks to the geomorphological position. On the contrary, the potential, even if occasional, flood events and water table fluctuations were the risk for yield loss. Last but not least, the silty facies were easy to work, while the use of mostly wooden tools was difficult on the gravel rich parts.

The north-eastern, active part of the Areuse Delta, was regularly inundated and eroded. As such, this soil (Table 1, H.2 soil) was not suitable for crop production. Nevertheless, this area could be used for pastureland and of course it was an important wood resource.

The Bevaix Plateau on the other hand, was crossed by numerous small, possibly temporarily, active brooklets. These channel deposits were humid and regularly subjected to erosion (Table 1, soil H.3). This implies that the only possible land use of these areas was as provisional pasturelands.

4.3. POTENTIALS AND LIMITATIONS OF THE SOILS FOR AGROPASTORAL ACTIVITY AND FOREST EXPLOITATION

The plants cultivated during the Late Bronze Age in the studied regions are known thanks to archaeobotanic studies carried out on both exceptionally well-preserved lake-dwelling occupation-layers (Jacquat, 1989) and on structures and occupation-layers of terrestrial sites (Akeret and Geith-Chauvière, 2011). They consist of cereals (barley, hexaploid naked wheat, known as bread wheat, einkorn, emmer, spelt, common millet and foxtail millet), pulses (garden peas, lentil and bread bean), and oil/fibre plants (flax, poppy). As for meadows/pasturelands, recent studies indicate that they were widely present north of the Alps during the Late Bronze Age (Kühn and Heitz-Weniger, 2015). In the studied region, the carpological assemblage of the Late Bronze Age site of Hauterive-Champréveyre, located a few kms north-east on the same shores of the Neuchâtel Lake, attests also to the presence of more or less humid meadows/grasslands; it is considered that they were integrated in alternating meadow-fallow land management (Jacquat, 1989). On the other hand, Bronze Age dated carpological assemblages of sites located on the Bevaix Plateau, contain very few plants indicating grassland; this confirms a meadow type land use without being able to tell anything about the importance of it (Akeret and Geith-Chauvière, 2011). Lastly, this study also considers the soil suitability for forests: the sessile oak (*Quercus petraea*) was being used for the construction of houses, while the wood stemmings from mixed and humid forests were used for all aspects of everyday live.

The edaphic requirements for optimal growth of the above-mentioned plants are summarized in Table 2.

Comparing these requirements with the soil characteristics of soils available during the Late Bronze Age in the surroundings of the two studied bays, allows us to evaluate their suitability for various crops and forests (Table 3). Taking into account the uncertainties of the various data, three suitability classes can be settled on: optimal, marginal (when one or several edaphic parameters are not optimal), and unsuitable when at least one parameter is strongly limiting.

The comparison of data presented in Table 3 with the soil map (Figure 10), shows that agronomic and forestry aptitudes of soils available for the communities living in the two bays were rather distinct. The exception to this was the littoral platform. Here, the soils facing a regular high water-table or even inundations, despite their high chemical fertility, were likely used as gardens for pulses, as these plants require regular care. In addition, this area was

Table 2. Brief overview of edaphic requirements for optimal development of crops and other plants discussed here

Plant considered	Rooting depth	Drainage	Granulometry	pH	Nutriment status	Others
Cereals	min. 50 cm	good	silty-clayey	neutral or slightly alkaline	high	
Pulses	min. 50 cm	good	heavy soils for lentils and broad beans; **n.l.** for the others	slightly acid to neutral; the lentils tolerate slightly alkaline soils	peas and lentils do not tolerate soils rich in nutriments	they need regular care, thus better cultivated close the habitats
Flax	**n.l.**	good	heavy	slightly acid to neutral;	high	
Grassland*	**n.l.**	*	**n.l.***	**n.l.**	**n.l.**	
Sessile Oak	deep	good	Silty, sandy	slightly acid	**n.l.**	tolerate temporary perched watertable, but sensible to long water saturation and anaerobic conditions

Based on FAO, 2000; Ducousso and Bordacs, 2004; Parent, 2008; Gibson, 2009.

n.l. - no limitation;

* Grasslands can be composed of a wide variety of plants adapted to all edaphic conditions available (Gibson, 2009).

As in the studied region the grasslands are by definition the result of anthropic activity we estimate that excepting the excessive drainage conditions, on soils with little water-holding capacity, no limitation applies for their optimal growth, as long as the reforestation is hampered.

also suitable for grazing and sheltering domestic herds.

Upslope of the littoral platform, the lands behind Cortaillod bay comprised well drained soils with several soil types (B.1, B.3, C.1, E) suitable for cereal production and some of them (B.1, B.3 and E) also suitable for sessile oak growth. Moreover, the better drained areas (levees for example) of the slightly active part of the Areuse Delta (H.1) permitted the cultivation of summer cereals. Such potential land use of little active alluvial plains has been described by Bogaard (2004). The more active part of the Areuse alluvial plain was suitable for meadows in addition to the natural presence of alluvial forest.

This wood possibly served to manufacture tools and objects necessary for everyday life.

The hinterland of Bevaix bay was markedly different. It was dominated by large areas with a constant high water-table or marshy conditions and soils characterised by heavy textures, inducing their low permeability and often located on poorly drained landscape positions (A.2, B.2, D and G soils). In addition, large surfaces covered by the well-drained B.3 soil were located on steep north/north-east oriented slopes. All these soils thus presented substantial limitations for crop cultivation, but they were suitable for grazing practices and meadowlands. These more or less humid, poorly drained soils were however forestry resources, with wood types other than the sessile oak. Only small surfaces covered by E soil and located on south oriented slopes and some parts of B.3 and C.1 soils, could be used for cereal production and were suitable for the oak trees used for the construction of houses. Therefore, we conclude that unless exchanges were carried out with the neighbouring bay, the community settled in this bay had to get construction wood from the secular forest located on slopes of the Boudry Mountain in the background of Bevaix Plateau.

Table 3. Land evaluation of the Late Bronze Age agro-forestry potentials of soils present in the neighbourhood of the bays of Bevaix and Cortaillod

Geo morphological position	Parent material	Topographic position	Soil type on Fig. 10	Suitability of soils for the growth of											
				Cereals		Pulses		Flax		Meadows		Oak forest		Flooded forests*	
				S_{ch}	S_{phy}	S_{ch}	S_{phy}	S_{ch}	S_{phy}	S_{ch}	S_{phy}	S_{ch}	S_{phy}	S_{ch}	S_{phy}
Bevaix Plateau	moraine	hilltops and gentle slopes	A.1	+	$-_{h,w}$	+	$(+)_{r}$	+	+	+	+	+	$(+)_{h}$	/	-
		depressions and foot slopes	A.2	+	-	+	-	+	-	+	+	+	-	/	(+)
	glaciofluvial and glaciolacustrine	hilltops and gentle slopes	B.1	+	$+_{w}$	+	+	+	-	+	$(+)_{h}$	+	+	/	-
		depressions and foot slopes	B.2	+	$(+)_{h}$	+	-	+	-	+	+	+	-	/	(+)
		edge of Plateau	B.3	+	$+_{w,e}$	+	+	+	+	+	$(+)_{h}$	+	+	/	-
	tardiglacial alluviums and colluvial deposits	hilltops and gentle slopes	C.1	+	$+_{w}$	+	+	+	+	+	+	+	+	/	-
		depressions and foot slopes	C.2	+	-	+	-	+	-	+	+	+	-	/	(+)
	lake marl and peat	large depressions	D	/	/	/	/	/	/	+	+	/	/	/	+
ancient lake terraces and lake shore	laminities alternating with with sandy-gravelly layers	steep slopes	E	+	$+_{w,e}$	+	$+_{e}$	+	$+_{e}$	+	$+_{e}$	+	$+_{e}$	/	-
	colluvial deposits	foot slope	F	+	$+_{h}$	+	+	+	$+_{h}$	+	+	+	$(+)_{h}$	/	-
	lake deposits	littoral platform	G	(+)	$(+)_{h}$	+	$+_{h}$	-	-	+	+	+	-	/	+
south-west zones of Areuse Delta	alluviums: channel and alluvial plain deposits	old levees and abandoned inundation plains	H.1	+	$(+)_{r}$	+	+	-	-	+	+	+	$(+)_{h}$	/	-
north-east zones of Areuse delta		active and abandoned channels	H.2	+	-	+	-	-	-	+	+	-	-	/	+
brooklets of Bevaix Plateaux		at least temporarily active water courses	H.3	/	-	/	/	/	/	+	+	/	/	/	+

S_{ch}- chemical suitability; S_{phy}- physical suitability; **+** = optimal ; **(+)** = possible/marginal ; **-** =unfeasible; **/** -not relevant parameter. In red final suitability, defined by the most limiting constrains. The green circles highlight the situations where certain crops/plants have optimal growth conditions. The dashed lined green circles indicate the marginal suitability cases.

Nature of limitations : **w**-workability ; **h**-humidity ; **e**-erosion hazard ; **r**-rooting depth;

*- The mixed deciduous forests are not included in this table. Indeed, except the long lasting water-saturated locations, in the bioclimatic condition prevailing during the Late Bronze Age, deciduous forest was the natural vegetation cover present all over the landscape at the studied altitudes.

5. Handling environmental challenges on the northern shores of Neuchâtel Lake: 200 years of history and interactions revealed by piles, (non)occupation of hinterland, and past soilscape

5.1. THE HINTERLAND AND ITS RELATIONSHIP WITH THE LAKE-DWELLING SETTLEMENTS

The narrow littoral platform could not provide all resources necessary to the subsistence of the population established in the villages of the bays of Cortaillod and Bevaix during the Late Bronze Age (HaB). Therefore, the hinterlands behind the bays were most likely used for agropastoral activity, raw material supplies, harvesting woods for construction purposes, tools, and heating. Surprisingly, it turns out that the traces of anthropic activity are rare in this area, despite the 200 years of intensive occupation of the bays. The thorough analyses of numerous excavation data indicate that the lack of more abundant human occupation traces is neither a consequence of research status, nor of erosion processes. The rare archaeological finds suggest that there was no intention of creating a long-lasting settlement in the hinterland. On the contrary, they suggest that these areas were the place of seasonal or occasional activities. Only one temporary habitat could be unravelled in the Areuse alluvial plain. This proved to be a refuge place during high lake-water periods.

All this leads us to conclude that the hinterland was not the territory of a 'terrestrial community' that evolved independently and synchronously with the lake-dwellers, as distinguished in other regions (Boisaubert et al., 2008, Néré and Isnard, 2012). It was rather the land of natural resources, fields and forest necessary to the subsistence of the lake-dwelling communities. Such use and exploitation of this territory leaves only scarce material traces and its importance cannot be measured by the quantity of archaeological finds.

5.2. LATE BRONZE AGE SETTLEMENT ORGANISATION ON THE LAKESHORE

The dendro-archaeological study of the piles of lake-dweller villages of the bays of Bevaix and Cortaillod, permitted to unravel the evolution of these villages and proposed a theoretical occupation model of the lakeshore for the Late Bronze Age HaB period. In each of these bays, a 'founding village' was built first, starting from 1060-1050 BC. These villages, constructed on land, close to the actual shoreline, lasted continuously for nearly 180 years and by the end of the occupation covered almost two hectares. They were shortly followed by a set of new villages constructed in both of the bays, called 'satellite villages'. The exhaustive study of the piles of the Bevaix-Sud and Cortaillod-Est satellite villages, constructed from 1010 BC onwards, indicates that the shoreward colonisation of the lake was carefully planned. The synchronous expansion dynamics of the satellite villages in the two bays has been interpreted as an indication of recurrent interaction between their populations. At the same time, the characteristics of the oak piles mostly used for construction of houses clearly suggest that forest resources used by inhabitants of the two bays were considerably different and as a consequence the working techniques had to be adapted. In the bay of Bevaix, old oak trees were used systematically, while in the bay of Cortaillod the majority of the piles were made of young oaks.

5.3. THE SOILS: POTENTIALS, LIMITATIONS AND IMPACT ON INTERACTIONS BETWEEN COMMUNITIES

As explained above, the lake-dweller communities of the bays of Bevaix and Cortaillod used very similar settlement dynamics strategies, but they exploited distinct forest resources. This can be well explained through the suitability analyses of soils in their neighbourhood. This investigation showed that all over the hinterland, chemical fertility of soils was suitable for all crops cultivated during the Late Bronze Age. On the contrary, for the physical fertility the situation was markedly different in various parts of the soilscape. In the hinterland in the neighbourhood of the bay of Bevaix, large surfaces were occupied by humid and marshy depressions, surrounded by strongly clayey or gravelly soils. In such conditions, cereal cultivation and/or tillage was difficult or even impossible. As such, besides the meteorological hazards, the damages caused by weeds, plants diseases or pests, the farmers here had also to handle the physical constraints of their soils: prolonged excess of humidity, low permeability, and low workability. The archaeological investigations indicate that the drainage techniques were not yet known. Indeed, in the studied region the first drainage ditches are dated back to the Iron Age (Bednarz et al., 2006; Leducq et al., 2008), while large-scale drainage works are only known to have started in the Roman period. (Bednarz et al., 2006). On the other side, the hinterland above the Cortaillod bay was composed of a patchy soilscape composed of alternation of drained and more humid lands. In addition, the light textured soils were more frequent as well. Last but not least, some parts of the neighbouring Areuse Delta might have been also used for crop production.

Based on these edaphic differences, it is possible to formulate some hypothesis regarding land use and subsistence strategies. On the one hand, it turns out that for the inhabitants of the bay of Bevaix, the deep and well drained soils required by cereals were restricted to the steep slopes at the rear of the habitat. These soils represented limited surface and might have been cultivated in the form of terraces. But, the major part of the hinterland, being very humid to marshy, most probably was covered by forest or possibly by meadows suitable for grazing. On the other hand, for the community living in the bay of Cortaillod, cereal cultivation was not only possible on the slopes overlooking the villages, but also on the plateau behind it. Indeed, this space contained significant surfaces of well drained soils, suitable for cereal production. Moreover, in the better drained areas (ancient levees) of the adjoining non-active part of the Areuse delta, summer cereal production was likely possible, especially in dryer periods, characterised by particularly low mean lake-water levels. Obviously, the active and non-active parts of this alluvial plain were also the place of growing of alluvial humid forests. Similarly to the humid areas of the overlaying plateau, these surfaces were also suitable for the grazing of herds.

The edaphic requirements for the optimal growth of sessile oak are comparable to the one of cereals, with a preference for sandy soils. These types of soils are very rare in the neighbourhood of the bay of Bevaix and as such, they most probably were used for crop production. As a consequence, the wood necessary for the house constructions most probably has been cut in the secular forest located on the bordering slopes of the Boudry Mountain. This matches the data issued from dendro-archaeological research. In contrast, the surfaces suitable for crop production were substantially larger for the community installed in the Cortaillod bay. Among others, the coarser textured soils were rather common compared to the lands close to the bay of Bevaix. This implies that for the community of the bay of Cortaillod, it was possible to have a cereal overproduction. Moreover, most likely it is possible that some parcels were left in fallow, which is where forest could regenerate. As such, with time, these younger forests could be used in function of construction and reparation needs. Once more the hypothesis of this land use matches the results of the dendro-archaeological study of piles.

Finally, despite the marked differences in the quality and potentials of available lands, the existing archaeological data suggest that the two communities kept close interaction throughout their development and in handling the lake-level variation challenges. Taking into consideration the agronomic aptitudes of soils in the surroundings, a regular exchange of agropastoral products and skills was most probably, part of the collaboration behaviours.

5.4. CLIMATIC AND ENVIRONMENTAL CONSTRAINTS: FROM SHIFTING VILLAGES TO THE ABANDONMENT OF THE LAKESIDE

To conclude, our interdisciplinary study allows us to formulate several hypotheses concerning the occupation dynamics and management strategies of the environmental challenges. In the early part of the Late Bronze Age (HaB), the parallel construction in both of the bays of 'founding villages' starting from 1050-1060 BC, followed by analogous construction of the 'satellite villages' starting from 1010 BC, could be unravelled. These facts suggest a regression of lake-level and significant interaction between the neighbouring populations. Indeed, a sustainable development in the context of significantly different land resources, implies a form of organised exchange of goods and/or skills in function of agricultural and forestry potentials of the hinterland. Between about 950-920 BC, all the 'satellite villages' were abandoned. The simultaneous establishment of a habitat in the hinterland close to the potential arable lands suggests temporary population flight, possibly related to lake-level rise. This was followed by a renewed expansion of the 'satellite villages' in both of the bays. Around 880 BC, a significant population movement occurred: all the 'founding' and 'satellite' villages were abandoned and replaced by one major agglomeration located on the lake-ward part of the Cortaillod bay and surrounded by a triple palisade. In the absence of meaningful data, several assumptions have been formulated to explain this notable change in the occupation strategy that obliged people to move and reconstruct on the lake at levels that are comparable to periods of low lake-levels; were they grouping together in order to face the approach of invading populations or because of natural (repeated landslides) or sanitary (epidemic) disasters? In addition, it turns out that this new settlement was located in a part of the landscape where most of the soils suitable for crop production were nearby. Finally, the lake-level showed more and more rising tendencies from 880 BC onwards and eventually in 850 BC this new village and the lakeshores were definitely abandoned as a reaction to the severe climatic deterioration that was recorded all over the lake-shores north of the Alps.

Authors contribution

Judit Deák studied the pedological data and performed the land evaluation analyses. Fabien Langenegger carried out the dendrochronological and dendroarchaeological study. Sonia Wüthrich examined and interpreted the archaeological facts situated in terrestrial context. The redaction of this paper is the result of close collaboration of the three authors.

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THE ABC SOIL TYPES: PODZOLUVISOLS, ALBELUVISOLS OR RETISOLS?

A review

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ABSTRACT
At an archaeological excavation site in central Belgium, we found whitish soil material interspersing a clay illuviation horizon under a Roman road. Starting from this case, we will illustrate how insights into soil formation and soil geography are relevant for understanding landscape evolution and archaeology. We do this by focusing on the 'Abc' soil types, which are silt-loam soils that are well-drained and have a mottled and discontinuous clay illuviation horizon. In Belgium, these soils are, almost exclusively, found under ancient forests. To explain their formation, two hypotheses have been proposed. A first assumes that chemical weathering leads to the degradation of the clay illuviation horizon, a process enhanced by the acidifying effect of forest vegetation. A second hypothesis explains their morphology as relict features from periglacial phenomena. We further review how views on their formation were reflected in Soil Taxonomy (*Glossudalfs*), the FAO legend of the soil map of the world (*Podzoluvisols*) and in the World Reference Base for soil resources (*Albeluvisols* and *Retisols*). If we accept the hypothesis that the morphology of the Abc soil types has to be attributed to periglacial phenomena, Abc soil types must have been more widespread before deforestation. Agricultural activities promoted the homogenisation of the subsoil and the fading of their morphologic characteristics. A Roman road would have prevented such a homogenisation process. These insights help elucidate the evolution of past and current landscapes.

KEYWORDS
soil formation, archaeology, Soil Taxonomy, World Reference Base, Belgian soil classification

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1. What got under a Roman road?

In the town of Asse, at an archaeological excavation site of the Roman Period (Magerman et al., 2013), we found a bleached and light-textured soil layer over a clay enriched horizon (Figure 1). The clay illuviation horizon was interspersed with clear whitish tongues, originating from the bleached horizon (Figure 1b). Strikingly, the light-textured soil material only occurred under the remnants of a Roman road and under a pile of Roman tiles. In contrast, a nearby soil profile under agricultural land did not have such bleached material (Figure 1c). Understanding the occurrence, or absence, of such soil patterns in both vertical and horizontal space, requires insights into soil forming processes. Why did this bleached soil only occur under the Roman artefacts? Did the Romans use such whitish soil material as a foundation for their construction works?

Insight into the genesis and the geography of the different soil types is crucial for understanding both current and past land-uses. This knowledge is particularly important when field soil scientists have to help explaining the palaeo-environment at archaeological excavation sites. Prof. em. Dr. Roger Langohr has greatly contributed to developing and spreading such insights. First, and foremost, by conducting detailed field research to elucidate the formation of soil types similar to those we encountered in Asse. Secondly, by his tireless dedication for teaching his insights to students and colleagues, both in Belgium and abroad. In his paper on the pedology and evolution of land-use in the silt-loam belt of Belgium, Roger Langohr concludes that a pedological approach for studying the evolution of landscapes can provide new data, complementary to those provided by other scientific disciplines such as forestry, archaeology, and history (Langohr, 1986).

The aim of this contribution is to illustrate the relevance of understanding soil formation and soil geography in relation to land-use, landscape evolution, and archaeology by focusing on the **'Abc** soil types' as defined by the legend of the soil map of Belgium[1]. First, we explain what the **Abc** soil types are and where they occur in Belgium. Secondly, we review the hypotheses that have been put forward to explain the formation of these soil types. We want to highlight how the views on their formation have influenced past and current international soil classification systems, particularly the American Soil Taxonomy system, the FAO-Unesco legend of the Soil Map of the World, and its successor the World Reference Base for soil resources. Finally, we reflect on the importance of understanding soil formation in relation to studying past and current land-uses. With these objectives in mind, an exhaustive review of the soil formation of silty-loam soils in Belgium is out of scope.

1 Codes (or symbols) from the legend of the soil map of Belgium are indicated in **bold**. Names from international soil classification systems, both of the Soil Taxonomy and the World Reference Base for soil resources are indicated in *italic*.

2. What is an Abc soil type?

The soil profile shown in Figure 2 illustrates the typical morphological characteristics of an **Abc** soil type. Soil surveyors (Baeyens, 1959a, 1959b; Louis, 1959) have described this soil type as having a thick forest litter covering a thin black mineral Ah horizon. The E horizon penetrates deep into the Bt horizon with very distinct grey and ochre coloured spots. Remnants of clayey silt appear isolated in a transition horizon (EB horizon), where clay coatings on the structural elements disappear and are replaced by a fine sandy, floury material. The cavities of the old roots – referring to the whitish tongues penetrating into the Bt horizon – are filled with material from the overlying E horizon. These morphological characteristics are ascribed not only to leaching of clay, but also to the very acidic nature of the soils resulting in the destruction of clay minerals. The process of acidification resulting into the destruction of clays has been referred to as 'podzolization' (Baeyens, 1959a; Louis, 1973) and has also been linked to the process of ferrolysis (Aurousseau, 1990; Bouma et al., 1990).

Following the definitions of the legend of the soil map of Belgium, soil types belonging to the soil series **Abc** have a silt or silt-loam texture (**A..**), are well-drained (**.b.**), and have a clay illuviation (Bt) horizon in the subsoil (**..c**) that is strongly mottled and discontinuous (Maréchal and Tavernier, 1974). Maréchal and Tavernier further clarify that it corresponds to the sols *podzoliques* of the French authors, the *Pseudogleye* and the *Fahlerden* of the German authors, and, in part, with the 'Gray Brown Podzolic soils' of the American authors or according to the then-new American Soil Taxonomy classification system, the order of the *Alfisols* such as *Glossudalfs, Ferrudalfs* and *Aqualfs*.

In general, the soils of Belgium were mapped following the standard soil classification system explained below. Only the soils of the coastal plain were mapped according to geomorphological and lithostratigraphic criteria (Dondeyne et al., 2014; Maréchal and Tavernier, 1974). As the definition of the **Abc** soil type illustrates, the standard Belgian soil classification system is based on morphogenetic properties readily identifiable in the field. A three-letter code allows representing a soil series: the first letter corresponds to the soil textural class, the second to the drainage status, and the third to the soil profile development. Variants are recognised based on (i) the occurrence of lithic discontinuities forming a substratum, (ii) the admixture of parent materials, e.g. limestone

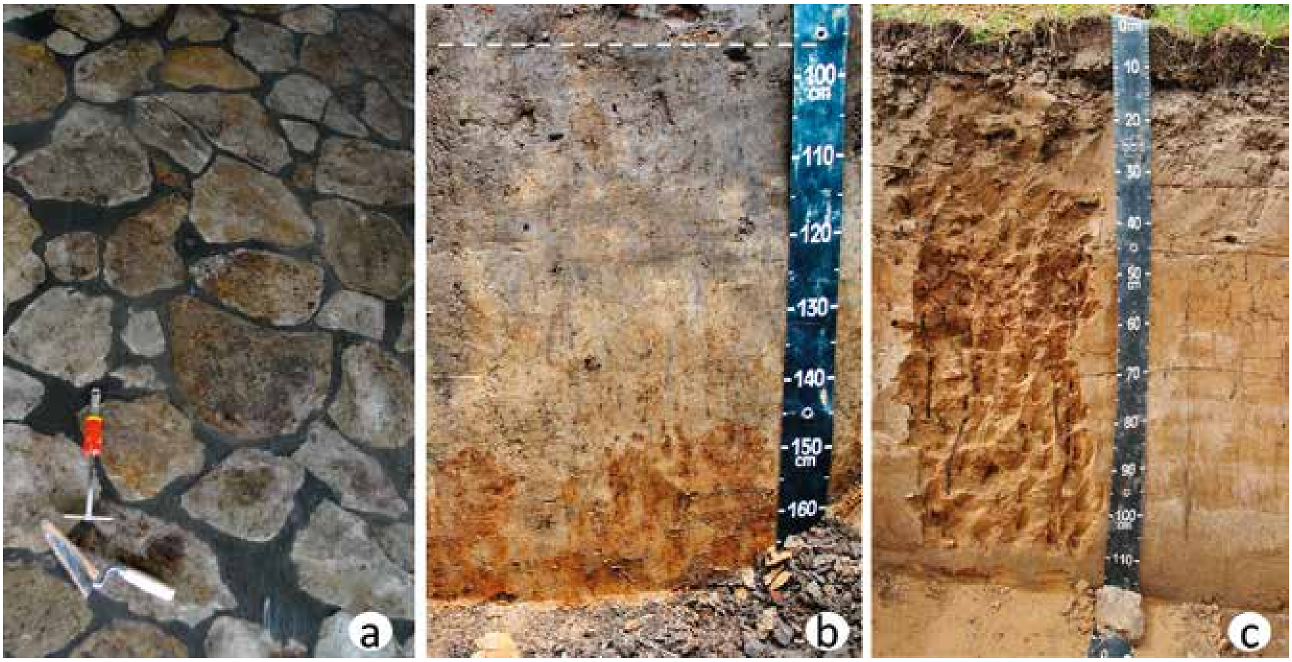

Figure 1.
a. Reconstructed Roman road excavated in Asse (Belgium).
b. Bleached soil material (115-150 cm) occurred under a pile of Roman tiles found at the level of the dashed line. The bleached soil material interspersed an underlying clay illuviation horizon (>150 cm).
c. A nearby profile under agricultural land did not have such bleached soil material, nor did it have any whitish tongues. Photos: S. Dondeyne.

in a soil otherwise derived from loess, and (iii) variations in the profile development, e.g. the occurrence of a *Fragic* horizon. Variations in the depth or thickness of particular characteristics are indicated as soil phases. Codes for variants and phases are indicated with a prefix or suffix code to the series code. Hence, a soil type is defined by the code for the soil series and either explicitly combined with a code for a particular variant or phase, or implicitly by the absence of such a code. For example, by adding the code **...0** to the series code **Abc**, soil type **Abc0** is explicitly defined for having a strongly mottled Bt horizon occurring at a depth greater than 40 cm (Dondeyne et al., 2014), but implicitly the information is also conveyed that it does not have a lithic discontinuity within the first 120 cm. If such a substratum would occur, it would be indicated explicitly with a prefix code.

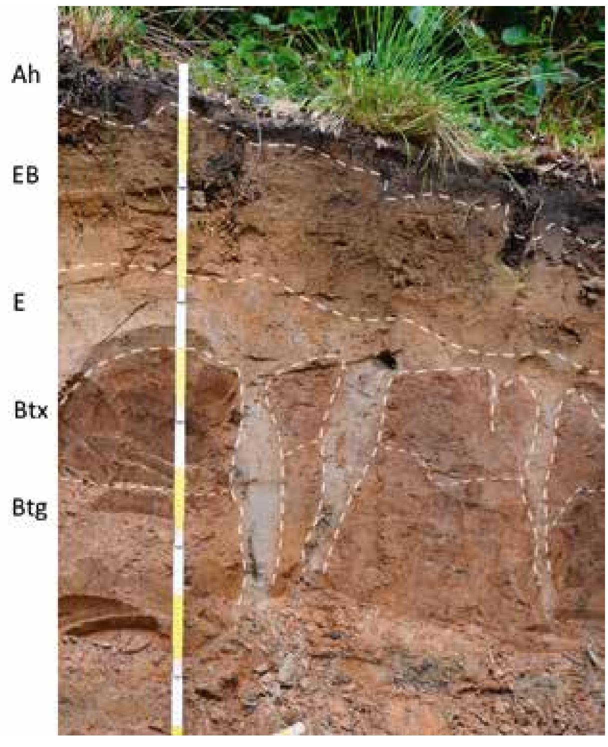

Figure 2. Example of the Abco soil type from the Sonian Forest (Belgium). Below a thin humus rich Ah horizon is a yellowish brown intermediate EB horizon. It has a weakly developed soil structure and a silty-loam texture. The subsequent bleached E horizon has been affected by clay eluviation and dissolution of Fe oxides. In the upper part, the clay illuviation horizon is compact, but non-cemented (Btx), impeding water and plant roots from penetrating; in the lower part oxido-reductimorphic mottles are prominent (Btg). Photo: S. Dondeyne.

3. Where do Abc soil types occur?

While soils with mottled and discontinuous clay illuviation horizons are widespread in Belgium, the particular **Abc** soil types are almost exclusively mapped in the Sonian Forest south-east of Brussels and the Meerdaal Forest, somewhat more to the east (Figure 3). They have, however, also been reported to occur in the Bertem Forest, which is a small forest north-west of Meerdaal Forest (Brahy et al., 2000; Vancampenhout and Deckers, 2010). These are all ancient forests, as the 18th century topographic map of Ferraris indicates (Figure 3b). In the northern part of the country, soil types with mottled or discontinuous clay illuviation horizons are mostly formed in loamy-sandy soils (textural class **L..**, and **P..**) or even in sandy soils (textural class **S..**). In the southern part of the country, vast areas with silt-loamy soils (textural class **A..**) have weakly expressed mottled or discontinuous B horizon and have been mapped as soil type **Aba(b)**.

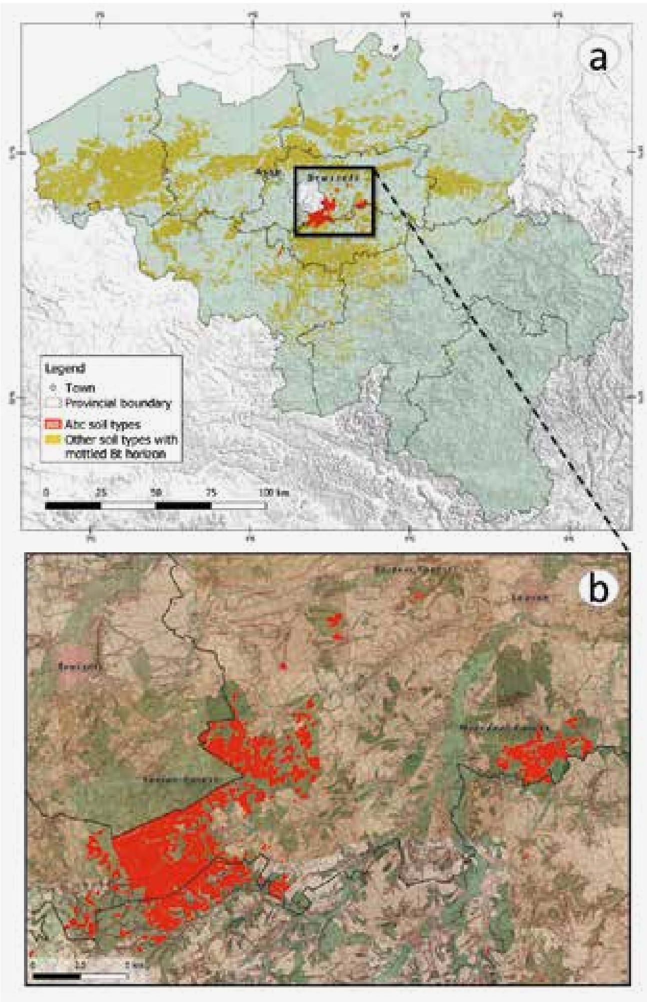

Figure 3. Distribution of Abc soil types:

a. in Belgium with the indication of other soils with mottled Bt horizons;

b. within the ancient Sonian and Meerdaal forests as shown on the 18th century Ferraris map. Note, the Region of Brussels is not covered by the digital soil map.

Data sources: https://dov.vlaanderen.be/ & http://geoportail.wallonie.be/.

4. How are Abc soil types formed?

Two hypotheses have been put forward to explain the formation of the enigmatic soil patterns found in **Abc** soil types. The first hypothesis assumes that a chemical weathering leads to a dissociation of clay and iron oxides under temporary reducing conditions, and a mobilisation of clay by the leaching and degradation of the clay itself. A second hypothesis postulates that the whitish tongues are relicts of glacial or periglacial phenomena.

4.1. DEGRADATION OF THE CLAY ILLUVIATION HORIZON

The synthesis we present here largely draws on Schaetzl and Thompson (2015). The hypothesis assumes that in a first stage of soil profile development the clay illuviation (Bt) horizon thickens and gets ever more clayey with time. Whereas in warm, humid climates the Bt horizon clay mineralogy can become dominated by low-activity clays, in temperate climates most Bt horizons develop to a certain point, after which they begin to degrade as the upper part of the soil gets increasingly acidic and leached. Subsequently, it is assumed that a process of ferrolysis sets in, causing clay minerals in the upper part of the Bt horizon to become unstable. The ferrolysis process is seen as the driving force behind the degradation of the Bt horizon (Bartelli, 1973; Schaetzl and Thompson, 2015). Initially, the Bt horizon degrades at the top and along permeable ped-faces and pores. The secretion from plant roots, which are preferentially located at these sites, enhance the degradation of the clays by acidifying these areas (Louis, 1973). The clays, their weathering products, and Fe-oxides are then leached and translocated, resulting in a pattern of whitish tongues penetrating the clay illuviation horizon (Hardy et al., 1999). Ultimately, this process leads to the formation of a degraded Bt horizon with an irregular upper boundary marked by narrow to broad penetrations of tongues of the bleached material (E horizon) into the Bt horizon (Figure 4). Often, the upper part of the Bt horizon is very dense and firm, but brittle when taken out and put under moderate pressure, and is referred to as a *fragipan*. The extraordinary compactness of the fragipan makes it very easily recognisable, both while augering and in a soil profile. Its consistency is very firm and its plasticity reduced; its structure is roughly flaky or platy and very clearly developed (Tavernier and Maréchal, 1957). In general, fragipans are considered pedogenic horizons, though their formation is not well understood (Bockheim and Hartemink, 2013; Soil Survey Staff, 1975). At least there seems to be some consensus that the formation of the fragipan requires a stage whereby the soil structure collapses under the influence of loading and wetting (Bockheim and Hartemink, 2013). Finally, the hypothesis assumes that the degradation process of the clay illuviation horizons also affects the fragipan as illustrated in Figure 4 (Schaetzl and Anderson, 2005; Smalley et al., 2016; Szymański et al., 2011; Smalley et al., 2016).

In the 1950s, when the standard legend of the soil map of Belgium was developed, the hypothesis of the chemical degradation of the clay illuviation horizon was generally accepted. Figure 5, adapted from one of the explanatory notes of the soil map, illustrates how the development of soil profiles with strongly mottled or discontinuous clay illuviation horizons **(..c)** was seen as an intermediate between a soil with a homogenous clay illuviation horizon **(..a)** and a Prepodzol **(..f)**, which would ultimately develop into a Podzol **(..g)**.

As indicated in Figure 5, soils with profile development **..c** are correlated with *Glossudalfs*. These are soils belonging to the Soil Taxonomy order of the *Alfisols* with an *Udic* moisture regime and with a *Glossic* horizon. In the most recent edition of the Key to Soil Taxonomy, the Glossic horizon is still seen as a result of the degradation of a clay illuviation horizon in which clay and free iron oxides are removed (Soil Survey Staff, 2014). In the FAO-Unesco legend of the Soil Map of the World, these soils were named *Podzoluvisols* (FAO, 1988). The name *Podzoluvisol* reflects the view that these soils have a clay illuviation horizon akin to the *Luvisols*, but that have been subjected to a ‘podzolization’ process (Driessen and Dudal, 1991).

4.2. RELICTS OF GLACIAL OR PERIGLACIAL PHENOMENA

Early on, as an alternative hypothesis to the process of chemical degradation due to ‘podzolization’ and/or ferrolysis, several authors have argued that the formation of fragipan soils could be linked to the permafrost (Fitzpatrick, 1956; Grossman and Carlisle, 1969; Lozet and Herbillon, 1971). Roger Langohr, with his co-authors, has been a leading scholar documenting and explaining how soil-forming processes under periglacial conditions may have led to the formation of the morphological characteristics typical for the **Abc** soil types. Through detailed field studies in the Sonian Forest, Roger Langohr and co-workers demonstrated that the bleached tongues form a typical polygonal pattern that can reach up to a depth of 120 cm (Figure 6). The fragipan is consolidated to such an extent that tree roots cannot penetrate through it. Contrary to the belief that roots formed the tongues, it is rather the roots that follow the polygonal cracks. The most compelling case for this argument is made in the paper by Brigitte van Vliet-Lanoë and Roger Langohr published in Catena,

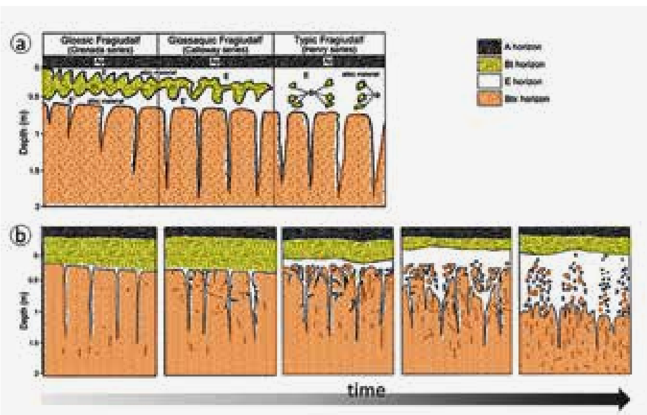

Figure 4. Two schematic representations illustrating the assumed degradation process of the clay illuviation (Bt/Btx) horizons due to acidification of the soils under a humid-temperate climate and leading to the formation of discontinuous Bt horizons.

a. Development and degradation sequence of fragipan soils developed in loess in the lower Mississippi Valley as proposed by Bartelli (1973).
b. Profile scale degradation of a clay illuviation horizon with a fragipan as proposed by Lindbo et al. (2000). Source: adapted from Schaetzl and Anderson (2005).

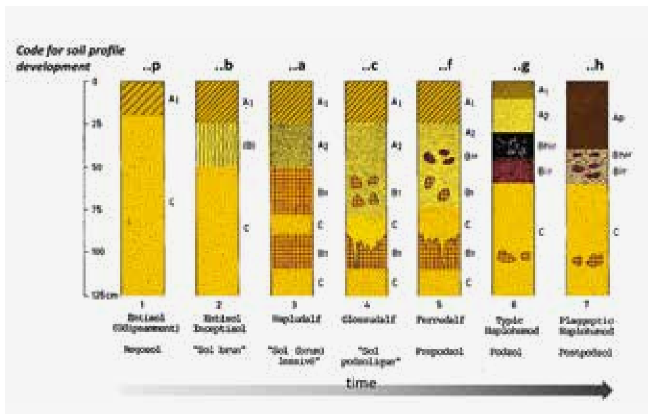

Figure 5. Stages of soil profile development in chronologic order. The code for soil profile development as used in the Belgian soil map legend is given on the first line. On the two lowest lines, correlations are given with the American and the French classification systems. Soil profile development ‘..c’ is seen as an intermediate stage between soil with a clay enrichment horizon and a Prepodzol. Note that following the FAO designations for horizons (FAO, 2006), the A1 horizon corresponds to Ah or Ap, A2 to E, (B) to Bw, and Bir to Bs. Source: adapted from Ameryckx and Leys (1960).

where the authors compare typical permafrost features with the distribution and the physical, macromorphological, and micromorphological properties of fragipans (Van Vliet and Langohr, 1981). The common oxido-reductimorphic features must be regarded as relicts, as these soils are nowadays well-drained (Langohr, 1986; Langohr and Sanders, 1985). The assumption that clay minerals in soils with textural contrast and *Albeluvic* properties would be destroyed through a process of ferrolysis has been debunked by Van Ranst and De Coninck (2002), who show that the formation of the bleached E horizon is due to clay translocation.

Ampe et al. (2015) explain that during the last glaciation eolian loess was deposited in central Belgium until about 15,000 years BP. Later, under subarctic vegetation and during the relatively warm and humid Bølling-Allerød interstadials (ca. 14,700 – 12,800 years BP) *Chernozem*-like soils developed with a thick organic matter-rich surface horizon. The leaching of carbonates was then initiated and clay migration resulted in the formation of a clay illuviation horizon (Bt). Subsequently, during the permafrost of the Younger Dryas (ca. 12,800 to 11,500 BP), polygonal patterns of desiccation cracks developed that extended into the Bt horizon. Fragipans were formed through freeze-drying and due to the pressure from ice on the prismatic soil structures. Stagnation of water above the permafrost layer, as well as during the very humid Atlanticum period (ca. 7500 to 5000 years BP), led to the formation of oxido-reductimorphic mottling that persists until today. Decalcification, clay migration, and bioturbation continued during the Holocene. The process is illustrated in Figure 7 and shows that where forests prevailed, soils with leached tongues were preserved. Soils under agriculture were subjected to erosion and had their profile homogenised as a consequence of agricultural activity and bioturbation.

This hypothesis is fundamentally different from the hypothesis of chemical degradation of the clay illuviation

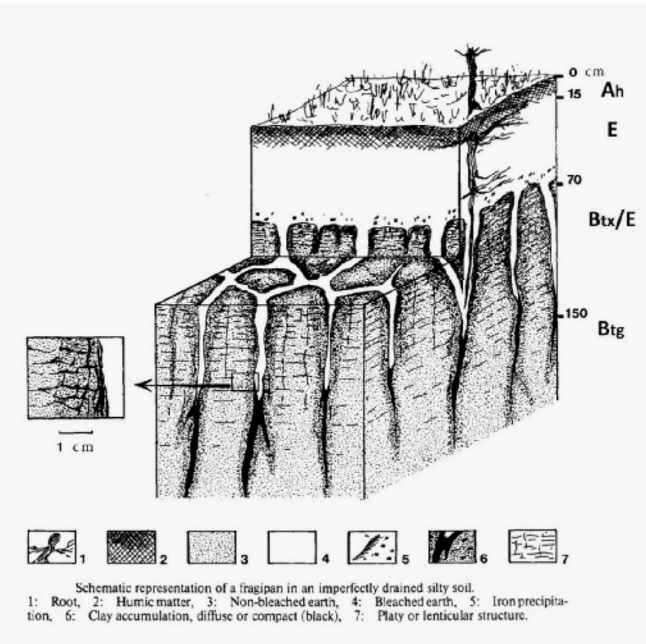

Figure 6. Schematic representation of a soil with a pronounced bleached (E) horizon interspersing a clay illuviation with a fragipan in the upper-part (Btx/E) and with oxido-reductimorphic features (Btg). The polygonal pattern of bleached material – defined as Albeluvic tongues – and the presence of a fragipan are best explained as remnants of periglacial process, whereby a prior formed clay illuviation horizon (Bt) was subjected to freeze-drying, leading to the formation of desiccation cracks. The clay minerals and Fe-oxides leached in permafrost conditions, leading to the formation of the E horizon, which, upon thawing, slid into the polygonal cracks. Source: adapted from (Van Vliet and Langohr (1981).

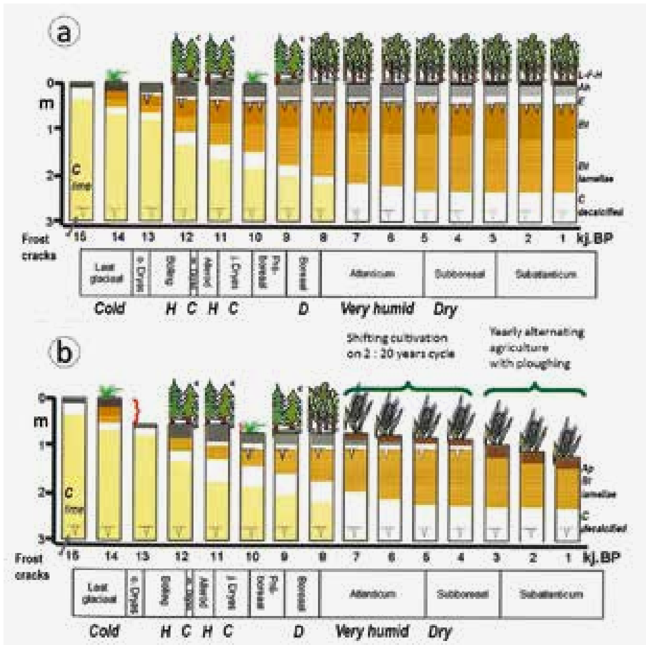

Figure 7. Soil formation in eolian loess deposits starting from the late glacial period to the present. (a) Evolution under a forest on a plateau position (b) and under agriculture on a sloping position. Legend: H = humid period; C = cold period. Source: adapted from: Ampe et al. (2015).

horizon by 'podzolization' and/or ferrolysis processes, even though it still entails a physical degradation of the Bt horizon during a period of permafrost. Given these new insights, in the first edition of the World Reference Base for soil resources (ISSS–ISRIC–FAO, 1998) – i.e. the international soil classification system that evolved from the FAO-Unesco legend of the soil map of the world – the *Podzoluvisols* were redefined as *Albeluvisols*. *Albeluvisols* have, within 1 metre from the surface, a clay illuviation horizon with an irregular or discontinuous upper boundary, due to deep tonguing of bleached soil material into the illuviation horizon. *Albeluvisols* are required to have *Albeluvic* tonguing starting at the upper boundary of the clay illuviation horizon. The *Albeluvic* tongues consist of whitish (i.e. *Albic*) soil material with the tongues having greater depth than width. In clayey Bt horizons they need to be at least 5 mm wide, in silty Bt horizons at least 10 mm wide, and in silt-loam or loamy Bt horizons they need to be coarser than 15 mm. They also must occupy at least 10 percent of the volume in the first 10 cm of the

Figure 8. Example of a soil under pasture (Dilbeek, Belgium) with a strongly mottled Bt horizon (Btg/E), but which does not meet the characteristic polygonal pattern of Albeluvic tonguing. This reticular pattern can however also be attributed to periglacial phenomena. In the 3rd edition of the World Reference Base for soil resources, it qualifies as a *Eutric Stagnic Retisol* (*Siltic*), in the Belgian classification system it is a *Acco* soil type. Photo: S. Dondeyne.

Bt horizon, measured on both vertical and horizontal sections. However, during field testing in Norway, Poland and Russia of the 2nd edition of the World Reference Base (IUSS Working Group WRB, 2007), it became evident that the definition of the *Albeluvisols* was too restrictive. The requirement for having *Albeluvic* tonguing resulted in the exclusion of a wide range of soils that do have clay illuviation horizons with reticular patterns of bleached material and which can equally be attributed to relict features from periglacial conditions. When comparing the soil profile in Figure 8 with the example in Figure 2, or with the scheme in Figure 6, it is clear that it lacks the typical *Albeluvic* tonguing in a polygonal pattern. It, however, has a clear pattern of coarser textured *Albic* material within the clay illuviation horizon (Btg/E). The interfingering coarser-textured *Albic* material is found both as vertical and horizontal whitish intercalations on the faces and edges of soil aggregates. This feature corresponds to what has been defined as *Retic* properties in the 3rd edition of the World Reference Base (IUSS Working Group WRB, 2015).

Hence, in the latest edition of the World Reference Base, the *Albeluvisols* have been replaced by the broader group of *Retisols*. Many soils that had been mapped as *Podzoluvisols* in Russia also fit the definition of the *Retisols*. In the Belgian soil classification system, such soils are indeed also recognised for having a mottled Btg horizon **(..c)**. Concerning the **Abc** soil type presented in Figure 2, following the 3rd edition of the World Reference Base for soil resources, this soil is a *Dystric Glossic Fragic Retisol* (*Siltic*). With the qualifier *Dystric* standing for the low level of exchangeable basic cations linked to the acidic nature of the soil; *Glossic* for the clear bleached tongues interspersing the clay illuviation horizon, *Fragic* for the fragipan, and *Siltic* for the silt-loam texture.

5. What do we learn from this?

If we accept the hypothesis that the morphology of the **Abc** soil types has to be attributed to periglacial phenomena, what does this tell us about the enigmatic soil pattern found under a Roman road in Asse? We found that the *Dystric Glossic Fragic Retisol* (*Siltic*) of the **Abc** soil types is well preserved in the ancient forests of central Belgium, as these areas have never, or hardly ever, been under agriculture. Reciprocally, it means that before deforestation, the **Abc** soil types must have been more widespread. Buried *Albeluvisols* have indeed been found in central Belgium in a study of Holocene dry valley sediments (Rommens et al., 2007). It is only through human agency that these soils developed a homogenous clay illuviation horizon. Liming and manuring promoted the activity of earthworms and particularly of *Lumbricus terrestris*. Earthworms are favoured by the European mole (*Talpa europaea*) and their combined actions will have contributed to the homogenisation of the E and the Bt horizons. Following Langohr (2001), we can thus conclude that the *Haplic Luvisols* (soil types **Aba**) have been formed as a consequence of human alteration of the landscape. In Asse, the remnants of the Roman road, as well as the pile of Roman tiles, must have obstructed earthworms and moles from homogenising the soil. The observations in Asse confirm that in pre-Roman and Roman times the **Abc** soil types must have been much more common than they are today. In Asse, we did not only learn about a Roman settlement and Roman infrastructural works, but we also found a window into what the soils and landscapes were like 2000 years ago. The case thus illustrates how understanding soil formation processes helps to understand the evolution of the landscapes as well as past and current land-uses. Such insights are indeed complementary to what we can learn from ecology, forestry, archaeology, and history.

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THE BYRE'S TALE

Farming nutrient-poor cover sands at the edge of the Roman Empire (NW-Belgium)

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ABSTRACT
Prior to the construction of a high-speed railway track (TGV) between Antwerp (Belgium) and the Dutch border, archaeological and geoarchaeological research was conducted at several archaeological sites. All are situated in the northern Campine, a region characterised by quartz-rich, nutrient-poor cover sands. On the site of Brecht-Zoegweg, two well preserved deepened byres (*'potstallen'*) were uncovered in Roman stable-houses. Stables with sunken floors are commonly recorded on Roman-period farms in the sandy part of northern Belgium. Following medieval to sub-recent parallels in the area, they are considered to be features serving agricultural fertilising purposes through the intentional accumulation of dung and the creation of manure by mixing with added organic matter (sods or 'plaggen'). This archaeopedological research investigates several questions concerning the origin and the infill process of these remarkable features. Field observations, analytical and micromorphological data point to a gradual succession of events leading to a byre with a sunken floor, rather than an intentional digging out of the floor concomitant with the house construction and a post-occupational filling or levelling. It is furthermore suggested that plaggen fertilisation could indeed have been applied, at least in some of the phases of the byre use.

KEYWORDS
byre, *potstal*, cover sands, Gallo-Roman period, northern Belgium, soil micromorphology, archaeopedology

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1. The Roman byre on the cover sands

Late prehistoric and Roman period farm construction in the Northwest European plain was essentially characterised by the dominance of the so-called stable house: a timber-framed construction in which humans lived together with their animals under the same roof, with the stabling part generally taking up one third of the total floor surface, often over the total width of the house. Several studies have pointed to the importance of this *Hauslandschaft* for the socio-economic and cultural understanding of these early farming societies living on the poorer, sandy soils (Haarnagel, 1979; Zimmermann, 1999; Roymans, 1996, and De Clercq, 2012). It appears that the household, the house, and cattle were closely intertwined elements in rural society, even on an ideological level (Roymans, 1999; Roymans and Gerritsen, 2002). Notwithstanding the swift introduction of various new aspects of farming techniques, these century-old local housebuilding traditions continued to be applied during the Roman period. In fact, in the middle Roman period (ca. 70-270 AD) and, more specifically, on the cover sands of NW-Belgium and SW-Netherlands, the tradition was even intensified (De Clercq, 2011). Probably following economic pressure on the acid, gradually depleting sandy soils (Groenman-Van Waateringhe, 1983), timber farmhouse architecture was modified, giving way to the construction of larger stable-houses from the 2nd century to the late 3rd century AD and onwards. This increase in surface, however, was not related to the space covered for human housing, but to the area used for (cattle) stabling (byre) and storing (attic) purposes (De Clercq, 2011: 245). More importantly, the concept of the stable itself seems to also have been altered. Whereas before the floor levels for human and animal parts were equal, after ca. 150 AD the stabling areas became deepened.

Morphological identical stabling features with a sunken floor called ‘potstal’ are common to the north of Belgium and other rather poor areas more to the northeast from the middle ages up until quite recent periods (Lindemans, 1952, 349; Spek, 2004).

The term *potstal* (byre) (Domhof, 1953; Zimmerman, 1999) in itself is not precisely defined. It is a Dutch word that refers to a stable with a floor lower than the rest of the farmhouse and where animals were kept overnight and/or during winter (Mücher et al., 1990). The concept in itself occurs in various regions, periods, and cultures throughout the NW-European cover sand plains. Importantly, the presence of a byre is usually linked to an agricultural management system, carried out to improve soil fertility in oligotrophic sandy heathlands. Turf sods, or plaggen, are collected from the outfield areas (heather, forest, marshy areas) and spread out at the bottom of the byre where they function as an absorbent bedding and become mixed with urine and excrements of the stabled animals, hence increasing the sheer volume of organic matter (manure) to be spread on the arable infields as a fertiliser. By penning the animals in deepened stables, not only can the direct access and safety to them be better controlled, but also the spatial concentration of their excrements and therefore, even enhanced in volume. Furthermore, a sunken byre filled with manure provides good insulation against frost, which came in through the floor more than through the walls and roof (Zimmermann, 1999). This is similar to a soil management technique known from India, where potassium and nitrogen rich soil from underneath the stable is dug out and is used to fertilise fields (Chiel, 2012, 19).

While the occurrence of a field management system using a sunken floor, byres, is suggested for the Roman period in the Campine region, based on the morphological similarities with more recent parallels, it has never been demonstrated from an analytical point of view (Leenders, 2003).

This study investigates for the first time archaeopedologicaly, if such a similar management system could have been applied in the Roman period and if the deepened stabling parts are indeed related to such a system. The investigation approach presented here completes already existing research methods used to unravel parts of buildings, dwellings, etc. Perhaps the best-known example is the application of phosphate analysis. Well planned, thoughtful and focused research during the excavation often gives clear insight into whether a certain structure was used as a stable. The approach developed in northern France can serve as an example (Broes et al., 2012). It is also clear that this approach is complementary to the one presented here.

2. The Roman stable-houses at Brecht-Zoegweg

During the preliminary field investigations preceding the construction of the railroad track between Antwerp and the Dutch border, it became clear that at four locations further archaeological excavations were necessary to document the Iron Age, Roman and Medieval settlements present underneath the future track. The excavations were conducted on behalf of the Belgian Railroads and co-ordinated by the Province of Antwerp (Delaruelle et al., 2004). At three of the sites, Ekeren-Het Laar, Brecht-Hanenpad, and Brecht-Zoegweg plaggen soils were present widespread (De Coninck, 1958, 1959a, 1959b, 1960a, 1960b). On these three sites (Figure 1) thorough archeopedological research was carried out (Mikkelsen et al., 2002a, 2002b, 2002c,

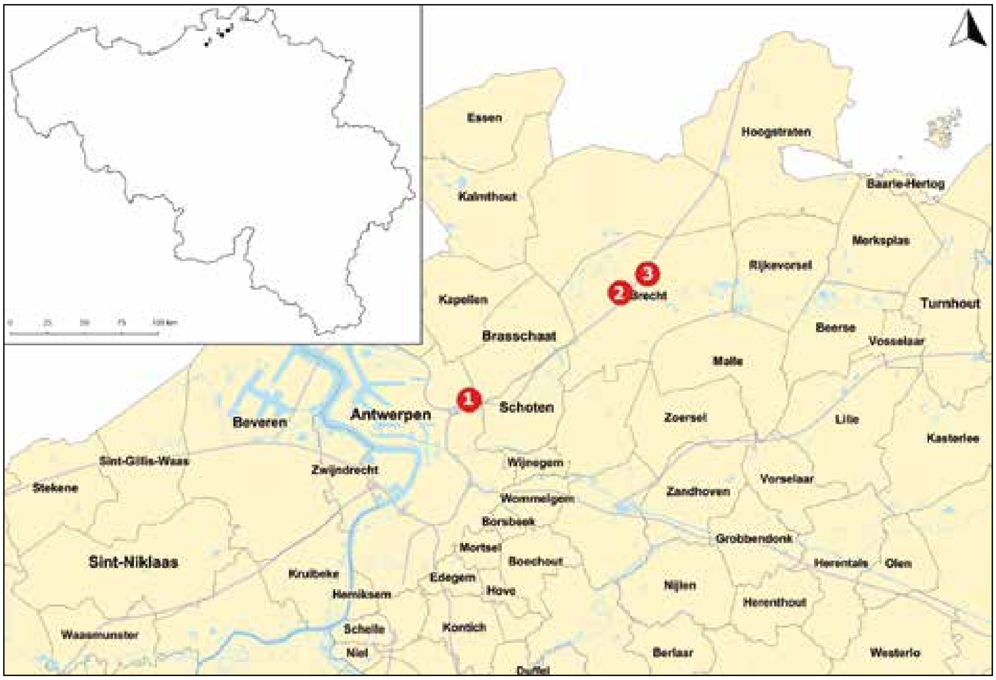

Figure 1. Map northern Belgium with the location of the three archaeological excavations:
1. Ekeren-Het Laar
2. Brecht-Zoegweg
3. Brecht-Hanenpad

2002d). Together, the sites form an almost continuous rural settlement landscape from the early Iron Age onwards.

One site, Brecht-Zoegweg, is particularly interesting due to the presence of stables with a sunken floor. At this site, the first settlements in the form of a few isolated buildings could be dated to the middle Iron Age (475/450-250 BC). From the early Roman period, a farming community settled and occupied the site until the last quarter of the 3rd century. Traces from the early (402-900 AD) and high medieval period (900-1200 AD) were excavated as well (Bungeneers et al., 2004).

At the site, 17 main buildings could be identified (Delaruelle et al., 2004). In six of these stable-houses, all belonging to the later occupation phases, a dark greyish-brown soil infilling was delineated. These humus-rich deposits were observed in the north-eastern part of the houses and covered the full width of 4-8 m. They are characterised by a 60-80 cm deep sunken floor covered by a thick fill of largely homogeneous, humus-rich greyish-brown earth. The humus-rich soil corresponds to the farmsteads' stable and would as such be called a '*potstal*' or a byre.

The two best preserved byres were selected for more detailed archaeopedological studies (Mikkelsen et al., 2002d). The large farmstead (S14) is approximately 28.5 m long and 7.5 m wide (Figure 2; Figure 3). The stable may be up to 18 m long and includes two large postholes. Based on ceramic finds, the building was dated to 175-225 AD. The slightly smaller byre S47 is 27 m long and 6 m wide and is ceramic-dated to 80/90-150 AD (Figure 2).

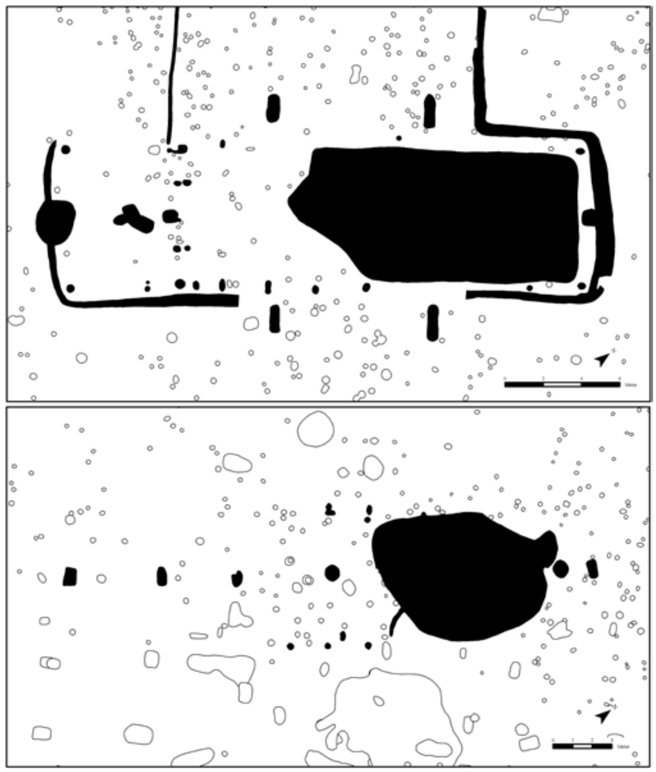

Figure 2. Excavation plan of the large byre S14 (above) and the slightly smaller byre S47 (below). © Heritage Service, Province of Antwerp.

Figure 3. View on byre S14 from the Brecht-Zoegweg excavation. Notice the thick humiferous horizons. A small brook running into the Weerijsbeek is located about 50 m to the right of the structure.

3. The present day soilscape

At the central part of the site Brecht-Zoegweg, the soils are composed of light sandy loam and are characterised by humus-iron B-horizons with a gley horizon starting between 80-120 cm depth and a clayey substrate starting at less than 125 cm depth. Secondary loamy sandy plaggen soils are present with a moderate dry to moderate wet drainage class (De Coninck, 1959a, 1959b). During the archaeological excavation, it was noted that the plaggen soils were heavily influenced by levelling and deep ploughing. Particularly on the original higher landscape positions, significant parts of the archaeological record were destroyed through deep ploughing.

The region is composed of flat to gentle sloping interfluvia, alternating with very gentle valley slopes and meandering rivers and tributaries. With the intensification of agriculture and the introduction of a plaggen infield-outfield management, the landscape was partly levelled and organic-rich soil material was brought onto the fields as fertiliser. This offered some protection to the archaeologically interesting layers that occur today, buried below two to four plough layers of up to 80 cm cumulative thickness. Considering that the original A and E/B horizons are locally preserved, the soil surface was raised before the first ploughing. The introduction of the plaggen infield-outfield management in general has been suggested from the 6th to the 8th century AD and onwards (Von Fastabend and von Raupach, 1962; Von Mückenhausen et al., 1968).

Due to a relatively high groundwater table, widespread oxido-reduction is observed as rusty mottles and concretions. In the deeper structures excavated, such as the water wells, the Campine Clay and peat layers could be observed, possibly belonging to the late Pleistocene Formation of St.-Lenaarts (De Ploey, 1961, 57).

4. Methodology

During the fieldwork, lateral and vertical soil variability and the presence or absence of special soil characteristics were recorded. Field sketches were made of the profiles, indicating horizons, positions of sampling, and special characteristics. The site, archaeological structures, and soil profiles were described and sampled according to the Handbook for Comprehensive and Adequate Field Soil Data Bases (Langohr, 1994) and the Guidelines for Soil Profile Description (FAO, 2006). More specific archaeopedological field checklists were used when needed (Fechner et al., 2004).

In the laboratory, texture was determined by Robinson pipette (<50 μm) after dry sieving (>50 μm) and the destruction of organic matter. Bulk density is the calculated average weight of 4-7 samples of each 100 cm^3, dried for 24 hours at 105 °C. pH: is the water/soil ratio of 1/1. For organic matter we used the method of wet combustion, applying potassium dichromate and H_2SO_4. Total Nitrogen: according to the Kjeldahl method of wet oxidation, using sulphuric acid and K_2SO_4. Extractable basic cations: Na, Mg, Ca and K were measured with an atomic absorption spectrophotometer. Cation Exchange Capacity (CEC): by adding ammonium acetate and using spectrocolometry. Citrate-bicarbonate-dithionite (CBD) extractable Fe and Al were obtained following the method of Mehra and Jackson (1960). Organic, inorganic, and total phosphor were analysed by adding H_2SO_4 and subsequently ammoniummolybdate and ascorbic acid, thereby measuring the blue colour in an unburned (inorganic P) and a burned (total P) sample (Mikkelsen et al., 1996).

Special undisturbed samples were impregnated with polystyrene resin (Stoops, 2003). Soil thin sections, 30 μm thick, were studied under the petrographic microscope, and descriptions followed the international guidelines of Stoops (2003). Detailed micromorphological descriptions were effectuated, though only the elements useful for the discussion are highlighted. A more systematic presentation of this micromorphology data is the object of a paper to be published in a subsequent research phase.

5. Physical and chemical aspects of the byre sediments

5.1. Byre S14, profile P1

Byre S14 was divided into 17 squares, each measuring 2 m by 3.5 to 4 m. This provided approximately 75 m of vertical soil profiles that were all examined. A detailed sampling strategy for laboratory analyses and a micromorphological study were performed on three soil transects.

Profile S14-P1 is a 2 m wide soil transect studied centrally in the byre (Figure 4). The particle size distribution divides the soil horizons (H) into three units: H1-2, H3-7, and H8 (Table 1), suggesting a difference in deposition. The organic carbon content is stable throughout H1-6, with a peak in the dark brownish H7. The nitrogen-carbon rate increases with depth, possibly because the deeper horizons are more liable to nitrogen leaching if reducing conditions prevail at the base for some time every year; the organic matter content remains stable throughout. Very low values of dithionite extractable iron suggest that

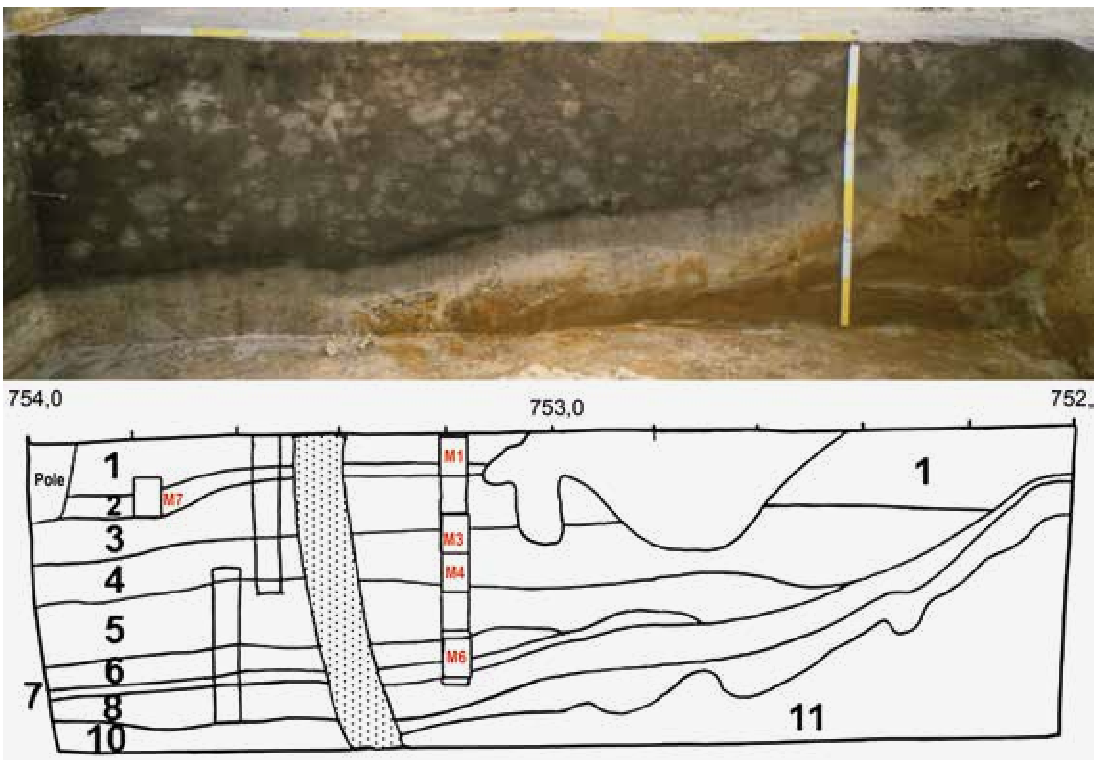

Figure 4. Photo and sketch of profile S14-P1. In the deepest part of the byre, the thin black layer (H7) was interpreted in the field as a wooden floor. The sketch indicates the horizons (black numbers), the micromorphology samples (red numbers), and the sampling zone for laboratory analyses (dotted).

Table 1. Analytical data for byre S14, profiles P1, P2 and P4a

Profile	Horizon	Depth (cm)	Particle size (µm, %)[a] <2	2-20	20-50	50-100	100-200	200-500	500-1000	1000-2000	Org. C. (%)	Total N. (%)	C/N[b] (%)
S14-P1	1	0-4	4.5	7.1	7.9	14.5	33.7	30.9	1.1	0.3	0,43	0,035	12
	2	5-8	4,8	8,0	8,0	14,3	36,0	27,9	0,9	0,1	0,62	0,043	14
	3	12-17	5,8	4,6	13,4	19,1	36,0	20,3	0,8	0,0	0,29	0,021	14
	4	20-26	5,9	5,6	11,9	17,2	37,9	20,5	0,8	0,2	0,55	0,033	17
	5	28-34	5,9	6,1	12,4	19,3	35,2	19,8	0,8	0,5	0,56	0,036	16
	6	38-43	6,1	4,7	11,5	18,0	38,5	20,0	1,0	0,2	0,54	0,032	
	7	44-47	6,6	6,2	11,7	18,1	35,4	20,9	0,9	0,2	1,24	0,074	17
	8	49-54	3,6	4,7	9,2	16,5	40,9	23,6	1,3	0,2	0,24	0,012	20
S14-P2	1	1-8	5,2	5,4	11,8	19,1	35,6	22,0	0,8	0,1	0,39	0,030	13
	3	10-17	4,2	3,9	10,8	17,5	40,5	22,2	0,9	0,0	0,25	0,015	16
	5	40-47	7,2	6,5	13,0	19,3	34,3	18,7	0,8	0,2	0,72	0,044	16
	Pole-1	36-44	4,7	3,4	8,4	15,5	39,0	27,1	1,5	0,4	0,17	0,015	12
	Pole-2	48-56	4,7	3,2	3,5	11,0	34,8	40,6	1,8	0,4	0,09	0,009	10
	Pole-3	64-72	7,3	4,3	12,3	18,3	36,4	20,5	0,8	0,1	0,16	0,017	9
	11	81-89	6,7	0,4	0,1	19,6	55,4	17,1	0,5	0,2			
	10	32-39	9,2	5,2	4,3	22,1	42,5	16,7	0,0	0,0	0,06	0,012	5
S14-P4a	SS										5,27	0,082	64
	3b	0-10	6,9	6,2	12,6	20,2	34,1	19,2	0,8	0,0	0,43	0,029	15
	4b	10-17	7,3	6,4	11,4	18,6	33,2	18,8	2,3	2,0	0,58	0,027	22
	25	17-26	5,2	4,8	11,1	18,2	34,0	24,9	1,5	0,3	0,23	0,015	16
	8	26-32	3,1	2,5	4,4	9,7	32,9	44,3	2,9	0,2	0,07	0,006	11

Profile	Horizon	Exch. basic cations cmol(+)/kg soil by NH_4OAc Ca^{++}	Mg^{++}	K^+	Na^+	CEC/ soil	BS[c] (%)	Dith. Cit. Fe_2O_3 (%)	P_2O_5 (%) Organic	Inorganic	Total	pH H_2O (1:1)	Thin section no.
S14-P1	1	0,6	0,08	0,083	0,016	2,8	28	0,07	0,002	0,064	0,065	6,0	M1, M7
	2							0,07	0,017	0,045	0,062	5,9	M1, M7
	3	0,9	0,16	0,130	0,021	2,6	47	0,02	0,028	0,014	0,041	6,0	M3
	4							0,03	0,039	0,032	0,071	5,8	M3, M4
	5	0,7	0,12	0,146	0,026	3,4	29	0,03	0,005	0,048	0,053	5,6	M4
	6							0,04	0,003	0,017	0,020	5,6	M6
	7							0,06	0,021	0,014	0,034	5,5	M6
	8	0,6	0,10	0,098	0,018	2,2	37	0,03	0,001	0,009	0,010	5,5	M6
S14-P2	1							0,03				5,9	
	3							<0,02				5,9	
	5							0,02				5,0	
	Pole-1							0,11				5,4	M9
	Pole-2							0,28				5,0	
	Pole-3							0,04				4,7	M11
	11							0,28				5,5	
	10							0,04	0,005	0,068	0,011	4,8	
S14-P4a	SS							1,93	0,010	0,842	0,852	5,9	M28
	3b	0,5	0,09	0,261	0,069	3,4	27	0,07	0,023	0,045	0,069	5,1	
	4b	1,0	0,16	0,270	0,025	5,6	26	0,41	0,020	0,141	0,161	5,3	M29
	25	0,8	0,12	0,155	0,011	2,9	37	0,07	0,013	0,062	0,075	5,9	
	8							0,03	0,009	0,005	0,014	6,2	

[a] % of fine earth fraction [b] Ratio carbon-nitrogen [c] Base saturation

iron has been leached out of the soil, possibly related to a fluctuating water table, although it cannot be excluded that the accumulated earth was poor in iron. The lowest level of phosphorus is found in H6-8 and the highest in H4. Despite the observed peaks, the concentrations of phosphorus are, in general, remarkably low.

5.2. BYRE S14, PROFILE P2

Profile S14-P2, 2.5 m long, is situated perpendicular to S14-P1. It offers insight into the sedimentary characteristics from one of the central postholes towards the northern house wall (Figure 5).

The three humiferous horizons (1, 2, 3, Fig. 5) have a uniform texture, but show little similarities with the texture of the posthole (sandy texture) and the parent material (sand to loamy sand). Their loamy sand texture is comparable with the humiferous horizons of the previous profile. This suggests that the earth material had a similar source, different from what is found in the immediate vicinity of the byre. The content of iron oxides is very low in the humiferous horizons, slightly higher in the upper part of the posthole and in a part of the parent material.

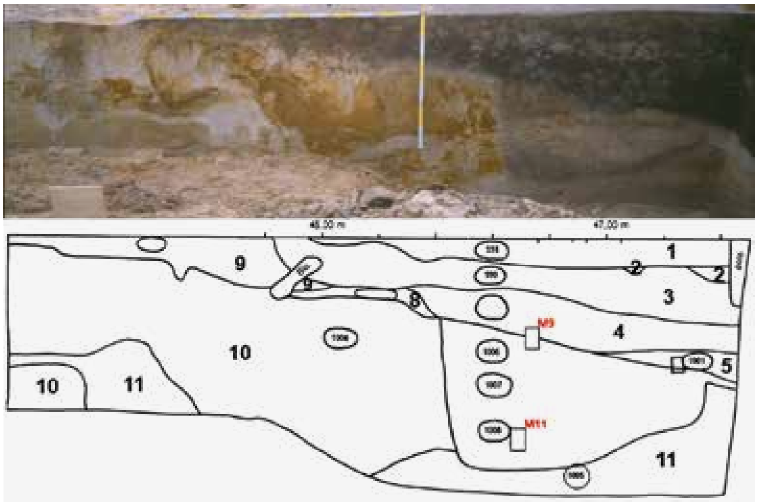

Figure 5. Photo of profile S14-P2, with the dark greyish brown humiferous horizons on top (H1-4) covering the central posthole (PH). The sketch indicates the horizons (black larger numbers), the samples for laboratory analyses (smaller black numbers in circles), and the micromorphology samples (red numbers).

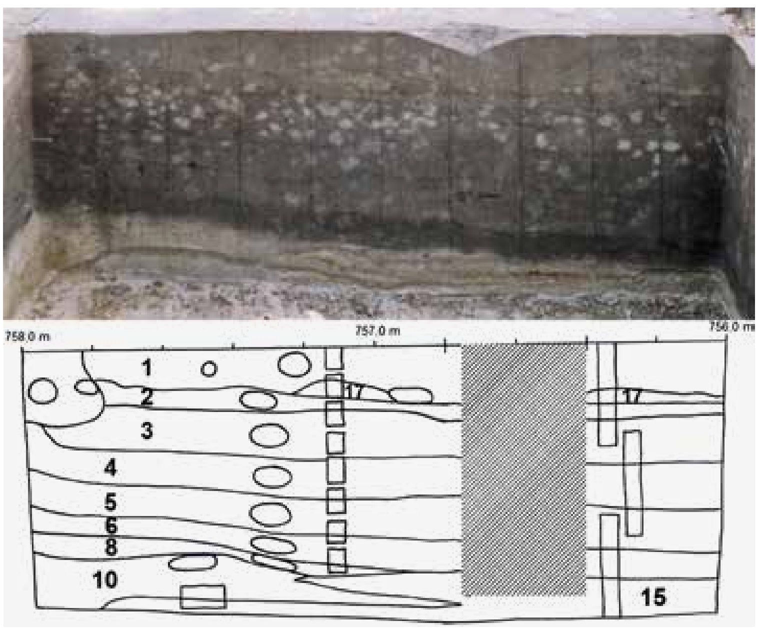

Figure 6. Photo and sketch of S14-P3. The sketch indicates the horizons (black numbers) and the zone where samples were taken for determining the bulk density (hatched).

5.3. BYRE S14, PROFILE P3

For profile S14-P3, bulk density measurements provides an insight into the soil density in function of the depth. A relatively higher density in H6 (62-67cm) may reflect a more intense phase of trampling in the byre (Figure 6 and 7). A rather high bulk density, just below the humiferous horizon (H15), cannot be explained entirely by the higher clay content. Trampling, with reduction of the original soil porosity (Rentzel et al., 2017) before the stable was enriched with soil clods, could explain the denser structure.

5.4. BYRE S14, PROFILE P4A

Profile S14-P4a, 3.5 m long, is located towards the south-western limit of the byre (Figure 8). At this location, the humiferous horizons merely reach 30 cm thickness and are characterised by a peculiarly high concentration of charcoal and pinkish-reddish soil material. The horizons H3b, H4b and H25 have a similar texture (loamy sand), while H8 is significantly different, with less clay, silt and fine sand, and considerably more medium sand. The fraction coarser than 2 mm is composed of iron concretions, charcoal, and burned soil aggregates. One sample, collected explicitly in the central part of the remains of a possible fire pit, contained a high amount of organic carbon, iron oxides, and extremely high concentrations of phosphorus (0.85 % P_2O_5). This suggests that bones have been burned.

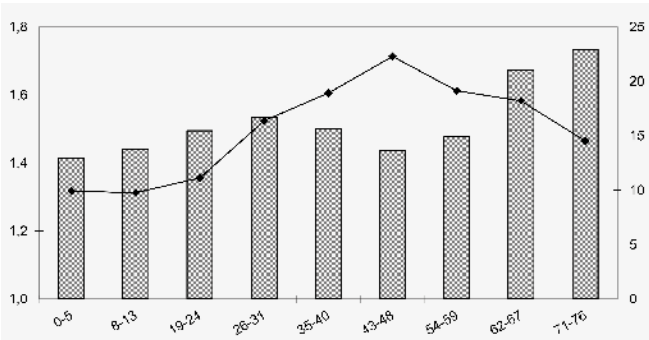

Figure 7. Bulk density (black line) and actual water content (dashed line) for profile S14-P3. Left: bulk density in g/cc, right: % water. Below: depth in cm.

5.5. BYRE S47, PROFILE P2A

This reference profile of the smaller byre S47-P2a is 4 m long and 57 cm deep (Figure 9). The profile is built up of, more or less, horizontal horizons that disappear towards the walls of the building. Interesting are the whitish sandy spots in H4 and H5. They are remains of individual soil clods. Based on bulk density measurements, it seems the soil is most compacted at a depth between 23-32 cm (Figure 10). Possibly, this is due to trampling by animals, or it is a buried living floor (Rentzel et al., 2017). The texture of H1-5 (humiferous horizons) is very different from that of H10-11 (parent material). The distribution of organic matter is relatively homogeneous, suggesting a good mixing of the upper humiferous horizons, which again, may be the result of animal trampling. Very high C/N (Table 2: H5) ratios at the bottom of the byre, where very little or no mixing has occurred, provide arguments for a vegetation of sods from a heathland or a coniferous forest. Organic matter accumulation as a result of *in situ* vegetation development cannot be invoked as no evidence of meso or macrofauna was found in the horizontal sections made during the fieldwork.

The C/N ratio together with the physical and chemical parameters of S47-P2a suggest an interesting interpretation concerning the field observed morphology of the soil horizons. It seems that the deeper part of the byre was filled with soil fragments from various soil horizons. This filling was sufficiently thick so that the deeper part of

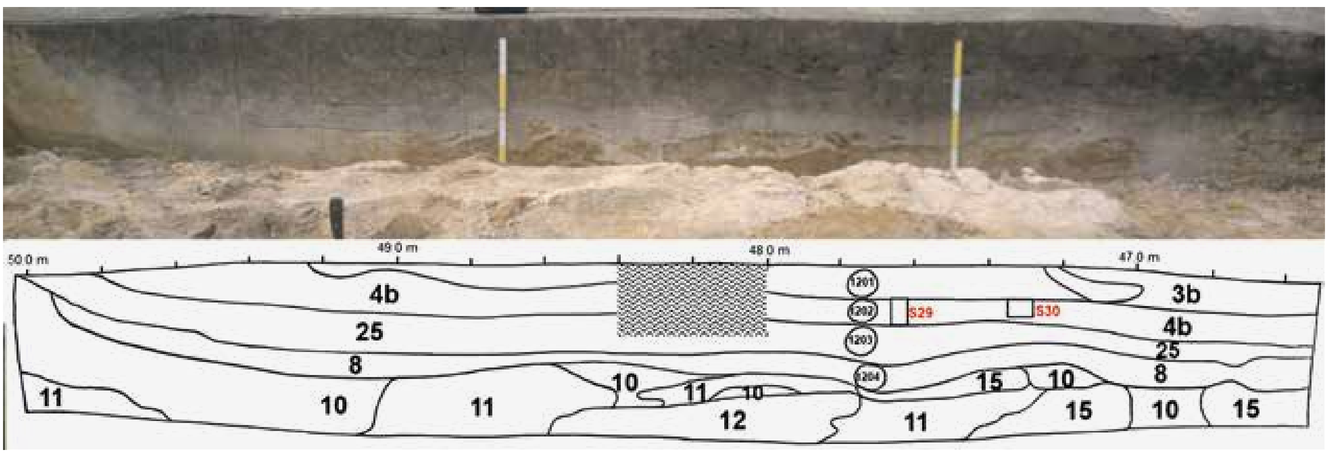

Figure 8. Photo and sketch of profile S14-P4a. The sketch indicates: the horizons (black larger numbers), the samples for laboratory analyses (smaller black numbers in circles), the two micromorphology samples (red numbers), and the special samples for analyses of the fraction coarser than 2 mm (dashed surface).

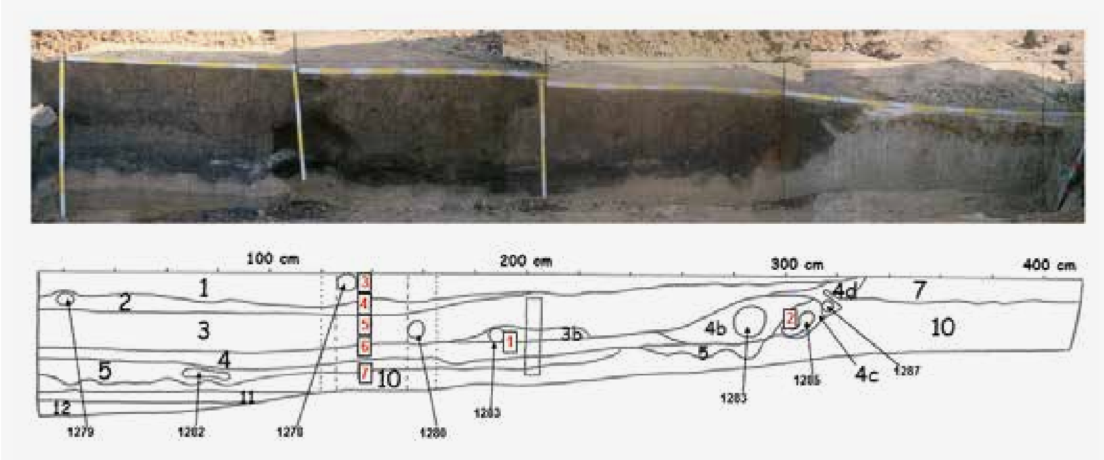

Figure 9. Photo and sketch of profile S47-P2a. The sketch indicates the horizons (black larger numbers), the sampling for laboratory analyses (smaller black numbers associated to circles), and the micromorphology samples (red numbers).

the byre was never homogenised. Here, we still find remnants of the original material of Podzol horizons like the Bs, Bh, and even E-horizon material. The high C/N ratio in the deeper part of the byre also indicates a soil that would typically form under heathland (Rove et al., 2006). In the upper horizon, the mixing was much better. Here, no fragments of the original soil are visible and the C/N ratio is much lower.

H5 is not part of the humiferous horizons, but is part of the parent material, enriched by accumulation of organic material. It is possible that a certain degree of anthropic mixing occurred when the byre was emptied. Then, a first layer of material was added (H4) and shortly afterward, possibly in different phases, H3 was accumulated. This occurred while the animals had ample time to accumulate 0.5 % phosphorus. Towards the surface, H1 and H2 contain significantly lower concentrations of phosphorus. This could be related to a younger phase of the building, but with a different use than cattle housing.

5.6. BYRE S47, PROFILE P3B

The posthole in S47-P3b (H6) cuts through H3 (Figure 11), indicating that this and the underlying horizons are older than the posthole and that the posthole is older than H1 and H2. Whether this means that the byre has gone through at least two life cycles remains an open question. This seems quite possible when we look at the phosphorus concentrations in function of depth (S47- P2a, P2b, P3b) (Table 2). In all vertical sequences, H1 and H2 contain considerably less phosphorus than H3 and H4. This seems to imply that the original byre starts from H3 and downwards. Later, the building was reconstructed (posthole 81/462) and humus-rich material accumulated inside again (H1-2). This time, however, it may not have functioned as a byre. In any case,

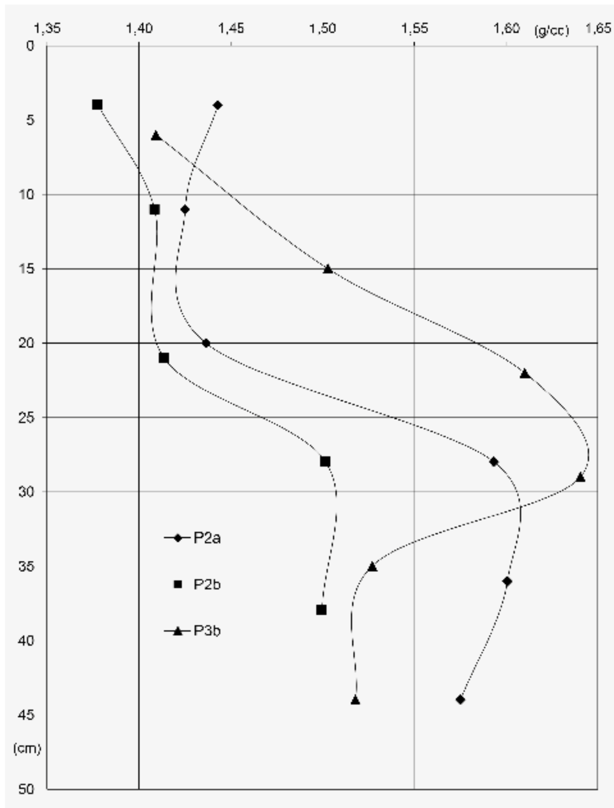

Figure 10. The bulk density in function of depth for byre S47, profiles P2a, P2b, and P3b.

Table 2. Analytical data for byre S47, profile P2a

Profile	Horizon	Depth (cm)	Particle size (µm, %)[a] <2	2-20	20-50	50-100	100-200	200-500	500-1000	1000-2000	Org. C. (%)	Total N. (%)	C/N[b] (%)
P2a	SS										0,50		
	1	0-10	5,8	7,4	13,7	19,2	36,1	16,7	1,0	0,1	0,45	0,038	12
	2	10-16	7,0	12,2	14,0	19,3	33,7	12,9	0,6	0,3	0,44	0,035	13
	3	16-30	4,2	9,6	13,2	20,0	34,7	16,5	1,3	0,5	0,52	0,035	15
	3b	20-26	18,9	14,5	8,9	16,5	21,6	8,9	5,7	5,0	0,31	0,039	8
	4	30-36	3,0	7,9	13,2	20,7	38,5	16,0	0,6	0,1	0,70	0,035	20
	5	36-40/45	2,6	4,7	6,7	14,6	55,7	15,4	0,3	0,0	0,55	0,015	37
	4b	9/22-25	3,7	7,9	12,2	19,0	39,6	16,2	1,1	0,3	0,99		
	4c	13-19	5,2	6,3	11,8	16,4	43,6	15,4	0,9	0,4	0,43		
	4e	18-23	2,7	2,5	2,7	8,6	72,3	10,6	0,4	0,2	0,33		
	4d	7-13	4,6	5,1	9,3	15,9	49,4	14,6	1,0	0,1	0,43		
	10	40/45-47	0,7	0,1	0,1	2,9	77,4	18,4	0,2	0,2			
	11	47-52	0,8	0,1	0,1	1,9	78,7	13,1	3,9	1,4			

Profile	Horizon	Exch. basic cations cmol(+)/kg soil by NH_4OAc Ca^{++}	Mg^{++}	K^+	Na^+	CEC/soil	BS[c] (%)	Dith. Cit. Fe_2O_3 (%)	P_2O_5 (%) Organic	Inorganic	Total	pH H_2O (1:1)	Thin section no.
P2a	SS							0,05				5,9	
	1	0,6	0,09	0,26	0,02	3,3	29,2	0,12	0,058	0,027	0,085	5,7	M3, M4
	2	1,5	0,24	0,25	0,10	4,5	46,4	0,18	0,023	0,140	0,163	5,9	M4
	3	1,5	0,20	0,18	0,02	4,7	40,5	0,23	0,033	0,511	0,544	5,9	M5
	3b	9,9	1,80	0,36	0,11	15,3	79,5	1,38	0,022	0,133	0,155	5,9	M1
	4	2,2	0,23	0,11	0,02	4,5	56,7	0,14	0,013	0,047	0,060	6,1	M1, M5-6
	5	2,6	0,27	0,06	0,01	4,5	65,4	0,12	0,011	0,060	0,071	6,1	M7
	4b								0,024	0,236	0,260	5,8	M2
	4c							0,10	0,012	0,116	0,128	5,6	M2
	4e							0,29	0,003	0,230	0,233	5,6	
	4d								0,005	0,084	0,089	5,5	
	10												M7
	11												

[a] % of fine earth fraction [b] Ratio carbon-nitrogen [c] Base saturation

no clear phosphorus peak was measured. A change from cattle to sheep breeding does not explain for the decrease in phosphorus. In cattle dung, the average concentration of phosphorus (P_2O_5) is 2.9 kg per ton of manure and for sheep and goats the concentration is 3.5 kg per ton, which is very similar (Vlaamse Landmaatschappij, 2016, Table p. 7). It should be noted that the measurements are based on present day cattle and sheep breeding, where cattle are kept inside year-round and sheep are usually not.

5.7. BYRE S47, THE SLOPING BYRE FLOOR

Sunken byres frequently occur with flat bases, but locally deepened areas within the byre, (shallow) pits and sloping levels, also occur (Laloo et al., 2008). S47-P3b shows a slightly sloping byre base, where the thickness of the humiferous horizons is reduced over several meters. In S47-P2a, the outer profile boundary shows a more average degree of steepness. This can be interpreted in various ways. While the boundaries of the stable to the exterior walls of the house are fixed, those inside the building may have varied from time to time. It is quite possible that the byre was larger during the years when the herd was more extensive, and vice versa. As a result of such a flexible boundary between the inside space dedicated to the byre versus the living space, a less steep slope developed. Another suggestion is that the deeper part was used for large cattle, and the shallower part - approximately from the posthole in P3b and towards the boundary of this profile - for smaller animals, such as goats and sheep. A last

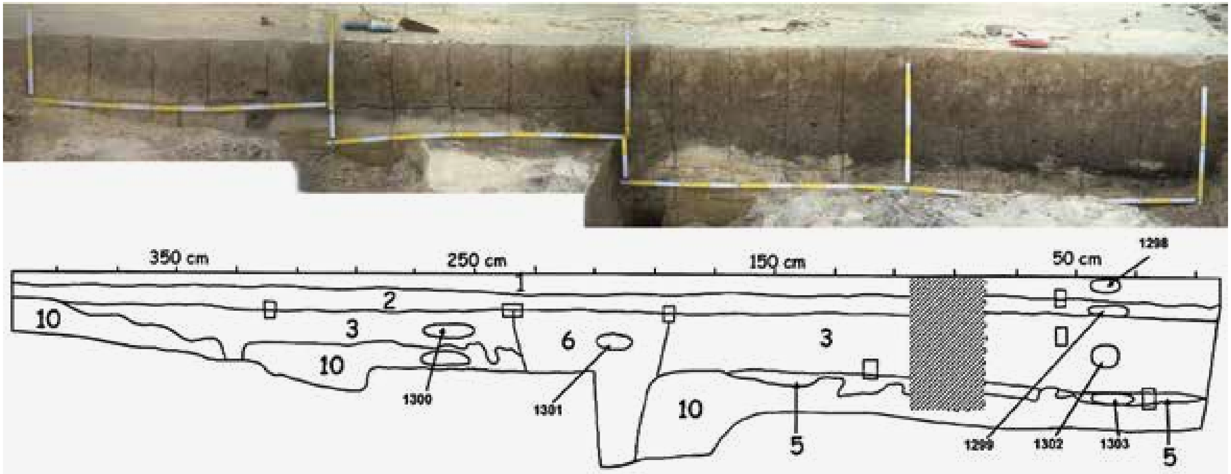

Figure 11. Photo and sketch of byre S47 profile P3b. The sketch indicates the horizons (bigger black numbers), the samples for laboratory analyses (smaller black numbers), and where samples were taken for bulk density (hatched zone).

interpretation, adopted by the authors of this paper, is that the sunken floor of the byre is the result of the regular recovering of manure whereby small quantities of bottom sand of the byre were removed to leave a clean floor. By this process, a gradually deepened section of the house is created. Close to the walls of the building, where less manure can accumulate and where the soil is less intensively trampled, less soil material was removed. The result is a shallower floor towards the byre walls versus the more intensively used central part of the house. Similar observations were made during the excavation at Gent-Kluizendok (Laloo et al., 2008).

6. Soil micromorphology of the byre sediments

6.1. BYRE S14, PROFILE P1

The soil material consists mainly of quartz sand. In addition, sub-rounded to rounded, un-weathered to slightly weathered glauconite grains are also present. In the deeper horizons, the glauconite is more weathered. This indicates a possible 'profile inversion' whereby the current deepest soil material originates at least partly from surface horizons that have undergone stronger weathering.

Many angular to sub-angular flint fragments are observed, ranging from 0.2 to 0.5 mm, with a few up to a few mm in size. It is practically impossible to distinguish between debris of flint artefacts and artefact production (chips) and natural flint (Angelucci, 2017).

Opale phytoliths occur in all horizons, except H6 and H7. They do not seem to have been burned. This is a typical characteristic of grasses such as cereals and other

Table 3. Phosphorus data for byre S47, profiles P2b, P3b and posthole 82/462

Profile	Horizon no.	symbol	Depth (cm)	P_2O_5 Organic (%)	Inorganic	Total
P2b	1		1-7	0,030	0,118	0,148
	3		13-19	0,029	0,582	0,610
	4		26-33	0,008	0,320	0,328
	5		35-40	0,016	0,219	0,235
	7	C2	4-9	0,003	0,123	0,126
	10	C1	22-28	0,001	0,000	0,001
P3b	1		1-7	0,037	0,106	0,142
	2		12-18	0,028	0,095	0,124
	3	left	14-22	0,018	0,410	0,428
	3	right	23-30	0,020	0,202	0,222
	5		40-43	0,010	0,899	0,909
81/462	6	upper	20-25	0,018	0,254	0,271
	6	central	42-52	0,004	0,134	0,138
	6	lower	66-76	0,012	0,062	0,074
	10	below	90-100	0,004	0,039	0,042

plants with high silicate content. The floor of a stable can be characterised by a thick layer of large phytoliths (Courty et al., 1989, 115-125; Vrydaghs et al., 2017), which are part of the manure and urine when the organic material is digested by oxidation.

Sclerotia (remains of certain fungi, Chet et al., 1969) occur in most horizons of the byre. They are all fragmented, indicating that the soil has moved and became disturbed, possibly when the sods were cut on the heathland and transferred to the byre. It may also be the result of trampling in the byre.

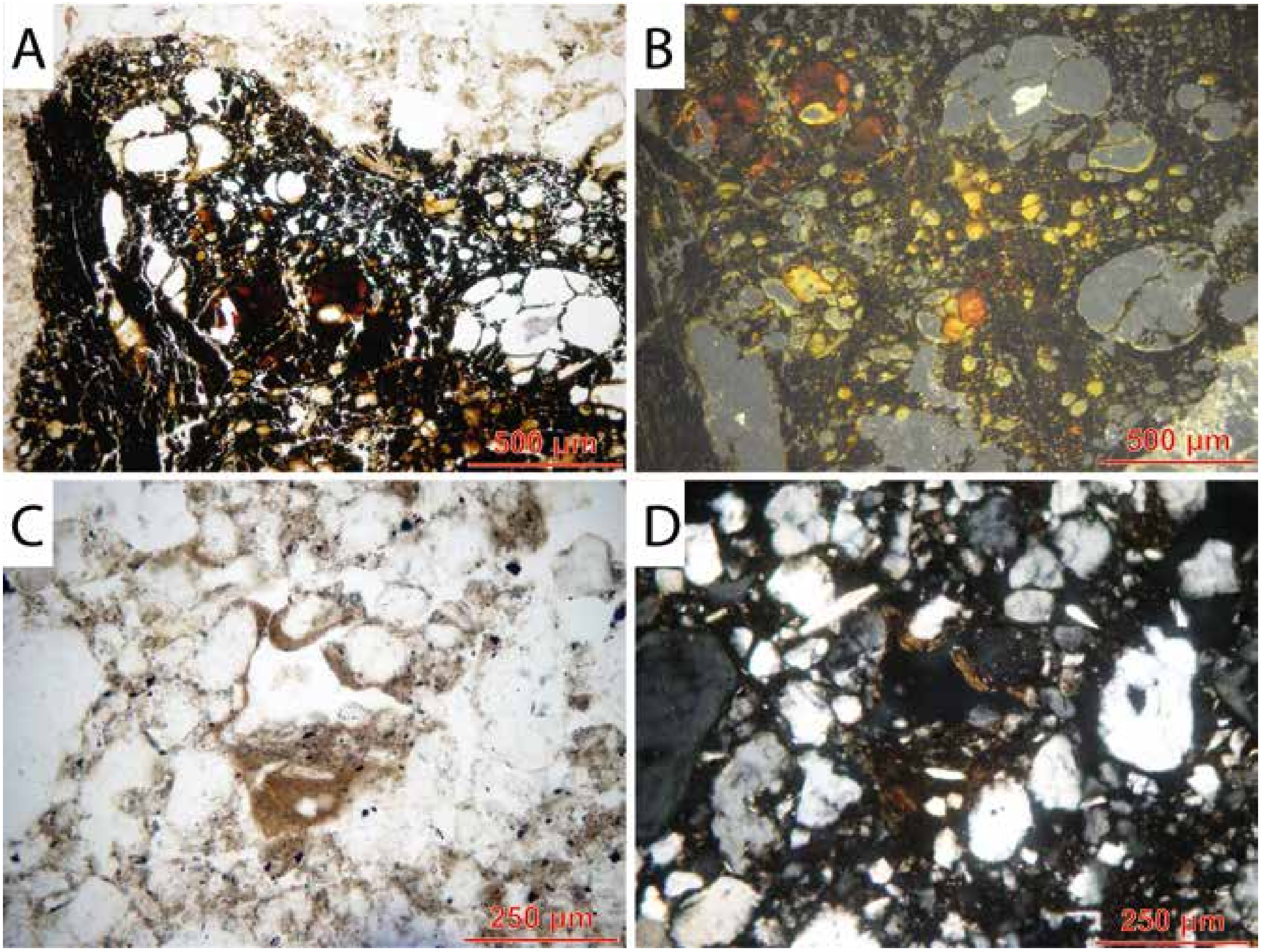

Figure 12. Soil micromorphological photos from byre S47, profile P2a. **A**: Charcoal filled with iron-rich limpid clay (H1, 0-7 cm; PPL + OIL). **B**: Same pedofeatures as photo A (XPL+OIL). **C**: Present-day incomplete dusty clay and silty coating with sandy top coating. (H1-2, 9-16 cm. PPL). **D**: Same pedofeatures as photo C (XPL). Silty parts slightly birefringent. PPL: plane polarized light. XPL: crossed polarizers. OIL: oblique incident light.

Charcoal is observed throughout the humiferous horizons, except in H3 and H7. The absence of charcoal in H7 is interesting. Already during the field research, the origin of this horizon was questioned, as it occurs as a thin black line in the soil sequence. Charcoal was found in the thin sections both above and below H7, but not in the horizon itself. It is suggested that H7 could be the remnant of a wooden floor. If this is the case, the planks have not been burned. However, there are no micromorphological pedofeatures that confirm or reject the theory of the wooden floor. The charcoal is scattered over several horizons and does not occur in large concentrations. It occurs usually in the shape of small pieces of less than one mm. This distribution pattern can suggest three hypotheses. Firstly, the stable burned down. This is unlikely given the size and distribution of the charcoal throughout the soil. Secondly, the charcoal was already present in the field, due to the deliberate or accidental burning of the vegetation. This would imply that this vegetation would have consisted largely of shrubs and trees, since heather and grasses produce mainly ashes and only small amounts of charcoal when burned. In acidic soils, ash weathers relatively quickly, unlike charcoal (Courty et al., 1989, 113; Canti, 2017; Canti and Brochier, 2017). The third, and the most likely, explanation is that the charcoal was added regularly to the byre, as for example after cleaning the fireplace used for cooking. This waste was probably thrown between the animals, that, with time, would mixed it with the humiferous material. At the site Brecht-Ringlaan, located 3.5 km to the northeast of Brecht-Zoegweg, several byres were excavated (Bracke et al., 2015). One byre was studied more in detail, including sieving bulk samples of the byre fill. This revealed a large fraction of micro waste. Dumping the household waste in the byre was given as an explanation

(Van Quaethem, 2016). Indeed charcoal, just like bark, has a very high C/N ratio so when it is added to a nitrogen-rich environment, it will immediately adsorb nitrogen and potential smells.

Dusty coatings are observed in all studied profile horizons except H1. Such dusty coatings are often associated with agricultural activities because of the presence of bare soil with increased water infiltration. However, it is known that the presence of dusty coatings alone is insufficient to conclude that the soil has undergone agriculture (Macphail et al., 1990; Deák et al., 2017). The observed coatings often are not only very dusty, but also contain loam and even visible grains of sand (Figure 12: photo C and D). The development of such coarse coatings requires a soil environment characterised by a strong sudden infiltration of liquid. One of which is indeed inside a byre, where the soil is unprotected by vegetation and the animals urinate regularly. This can result in a relatively concentrated amount of liquid that infiltrates and penetrates the soil in a short period. Horizontal dusty crusts (Figure 13: photo G) are described for H3-4 (common), H4 (few), H6 (very few) and H8 (even fewer). As they are often associated with open spaces and as they are still in their original horizontal deposition, it indicates that the soil didn't become mixed after the development of these pedofeatures. The described crusts are an indication of a vegetation-free sedimentation environment, where the soil builds up in horizontal layers that always fossilise and protect the underlying crusts. Crusts can form on the soil surface through splash if little or no vegetation grows on it, but as soon as the soil is tilled, they become fragmented and lose their orientation.

In H2, H4, H7, and H8 cross-layered clayey pedorelicts were observed. It is assumed that this originates from the deeper geological layers, possibly the Campine Clay. Clay was used for many household purposes: for walls, floors, and kitchen equipment. The fragments were not burned, so they are not ceramic fragments. In H2 and H3-4 ceramic fragments were observed under the microscope.

6.2. BYRE S14, PROFILE P2

In the upper part of this profile, sampled at the edge of the posthole and H4, glauconite, flint, phytoliths, charcoal, dusty coatings, dusty crusts, iron, and clayey pedorelicts were observed. The discussion and interpretations made for S14-P1 also apply to these thin sections. In addition to the pedofeatures already mentioned (glauconite, sclerotia, charcoal fragments, few dusty clay coatings), a flint fragment that may have been cracked by fire and many thin limpid clay coatings were described in the thin section from the deeper part of the posthole. The limpid clay coatings are in situ.

6.3. BYRE S14, PROFILE P4

One thin section was sampled in H4b. It is very heterogeneous and polygenetic. Dusty clay coatings can be associated with cattle trampling. The frequent concretions cemented with iron-rich clay clearly do not originate from the soils of the surrounding area. Some concretions may contain iron phosphate, but this was not analysed further. Embedded in the larger charcoal fragments are secondary iron and dusty coatings (Figure 12: photo A and B). In the soil's fine material, clay phosphate coatings occur (Figure 13: photo H). Both types of coating indicate that the soil has undergone a period of highly active iron phosphate and clay migration. This was probably due to an increase in pH when ash and charcoal were added to the soil. Furthermore, there are many pedorelicts. Some have been burned, others not, but they all consist of the same clayey soil material. These may be the remains of a clay floor or walls that were burnt down.

6.4. BYRE S47, PROFILE P2A

Mineralogically, the soil material consists mainly of unweathered quartz, sub-angular and never rounded. Glauconite is also very common, slightly weathered to weathered. In H3 the glauconite is weathered with a reddish-brown colour, but some grains are also un-weathered. In situ weathering of glauconite seems excluded. Probably, the glauconite has its origin in the variety of soil materials that have been mixed in the byre.

Opal phytoliths occur in H1-5 and H7-8. In H1-2 the concentration is high. Such phytoliths are common in 'grasses'. These may have ended up in the byre with the soil material or as hay used as winter fodder.

Flint occurs in H3-8. It is typically angular in shape, but semi-rounded fragments were also observed. The very large (up to 2.5 mm diameter) fragments are interesting. These fall completely outside the textural pattern of the soil. The most logical explanation is that the flint was among the materials that were brought into the byre by man, possible from material brought from the nearby brook valley.

Charcoal occurs in all horizons, except in H8. It is generally larger than that observed in the larger byre (S14), although the large fragments are often broken. Considering the variation in size and the in situ breaking of the larger fragments, it seems most plausible that the charcoal here is originating from the cleaning of a fireplace. One piece of charcoal (Figure 13: photo A and B), with a size of 2.4 mm, is interesting as it is filled with limpid clay. Such a process takes place in a very stable environment, such as a soil under a forest cover. In a byre, clay and humus migration resulting in dusty coatings would be more likely. This fragment is, therefore, a pedorelict that was brought into the byre.

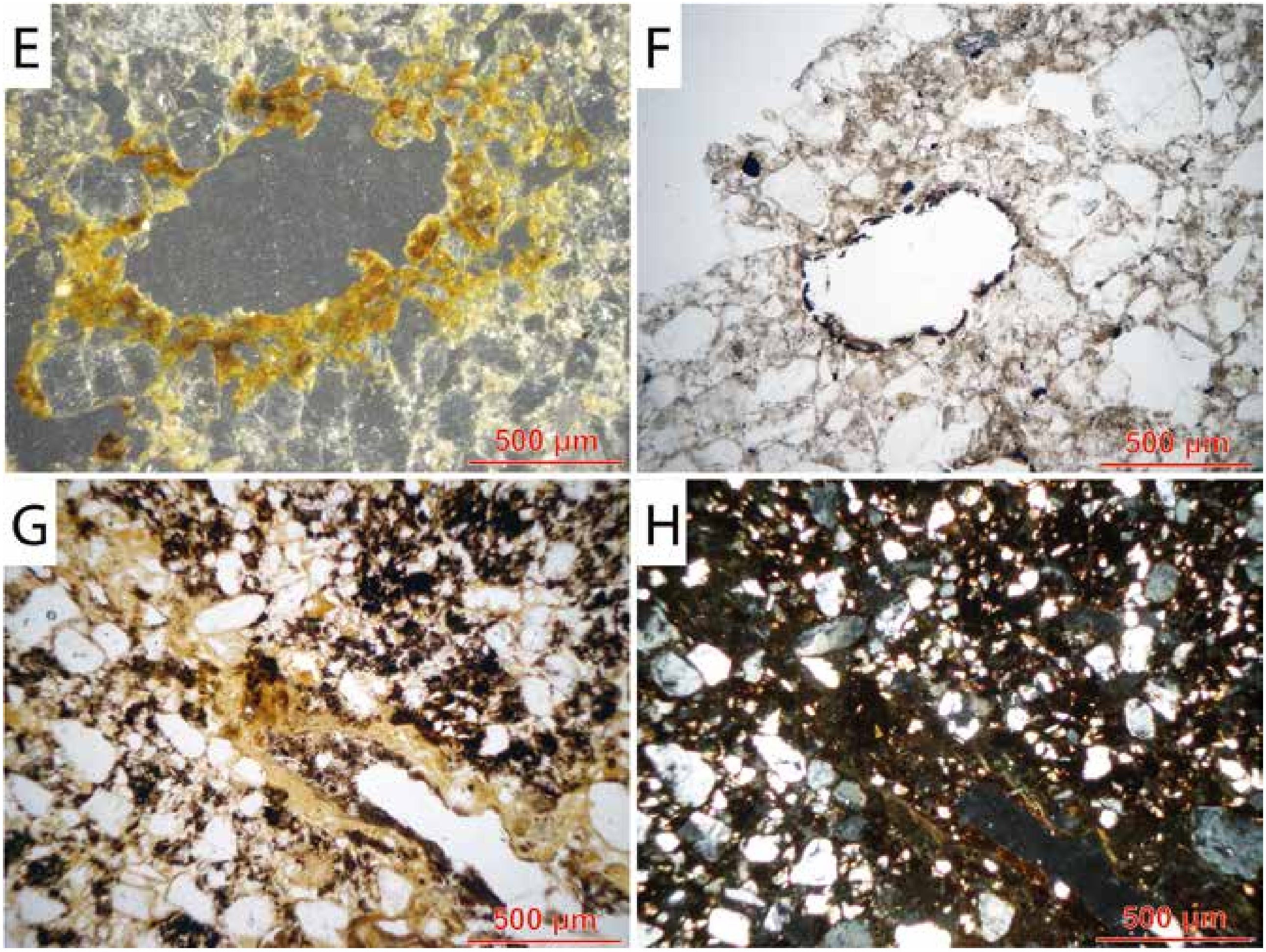

Figure 13. Soil micromorphological photos from byre S47 profile P2a. **E**: Iron stains around the open space indicate an environment with oxido-reduction. In addition, the iron is mobilised from the matrix and deposited around the open spaces where oxygen is available, indicating a strongly reduced environment of the "gley" type (cf. marsh soils). (H1-2, 9-16 cm: XPL+OIL). **F**: Broken, non-birefringent coating of organic material in open space, (H1-2, 9-16 cm; PPL). **G**: Phosphorous-rich clay coating. No birefringence. (H3-4, 26-33 cm; PPL). **H**: Same clay coating as for photo G (XPL).

Sclerotia occur in H1, H3, H4, H6, and H7. They are fragmented, indicating a certain degree of transport and/or trampling.

One pedorelict, 7 mm in size, was observed in H1; this pedorelict has a fine texture, suggesting that it stems from the geological substrate. That such a large fragment has been preserved indicates that H1 was not bioturbated by trampling of cattle and has not been homogenised by any other process since this relic was introduced into the byre sediment. This is an additional argument for interpreting H1 as a levelling layer after the demolition of the building.

Dusty coatings are particularly common in H3, but also occur in several other horizons. They have various forms such as typical coatings, crescentic coatings, capping in macropores, and dusty coatings. They indicate that the soil has been subject to rapid infiltration/percolation of liquids mixed with loose soil on an exposed surface. Some coatings contain coarse loam and sand particles (Figure 12: photos C and D), which is exceptional. A byre floor on which urine is released by the cattle could produce such coatings.

The crescentic shapes of some coatings indicate that they are still in situ. As the macropores are still open, it suggests that they are related to the deeper part of the byre which was no longer trampled by the animals.

The dusty coatings probably developed during the period when the byre material accumulated. It is assumed that those that were found deepest, migrated first. When new sods were added, the depth of the dusty coatings gradually shifted upwards.

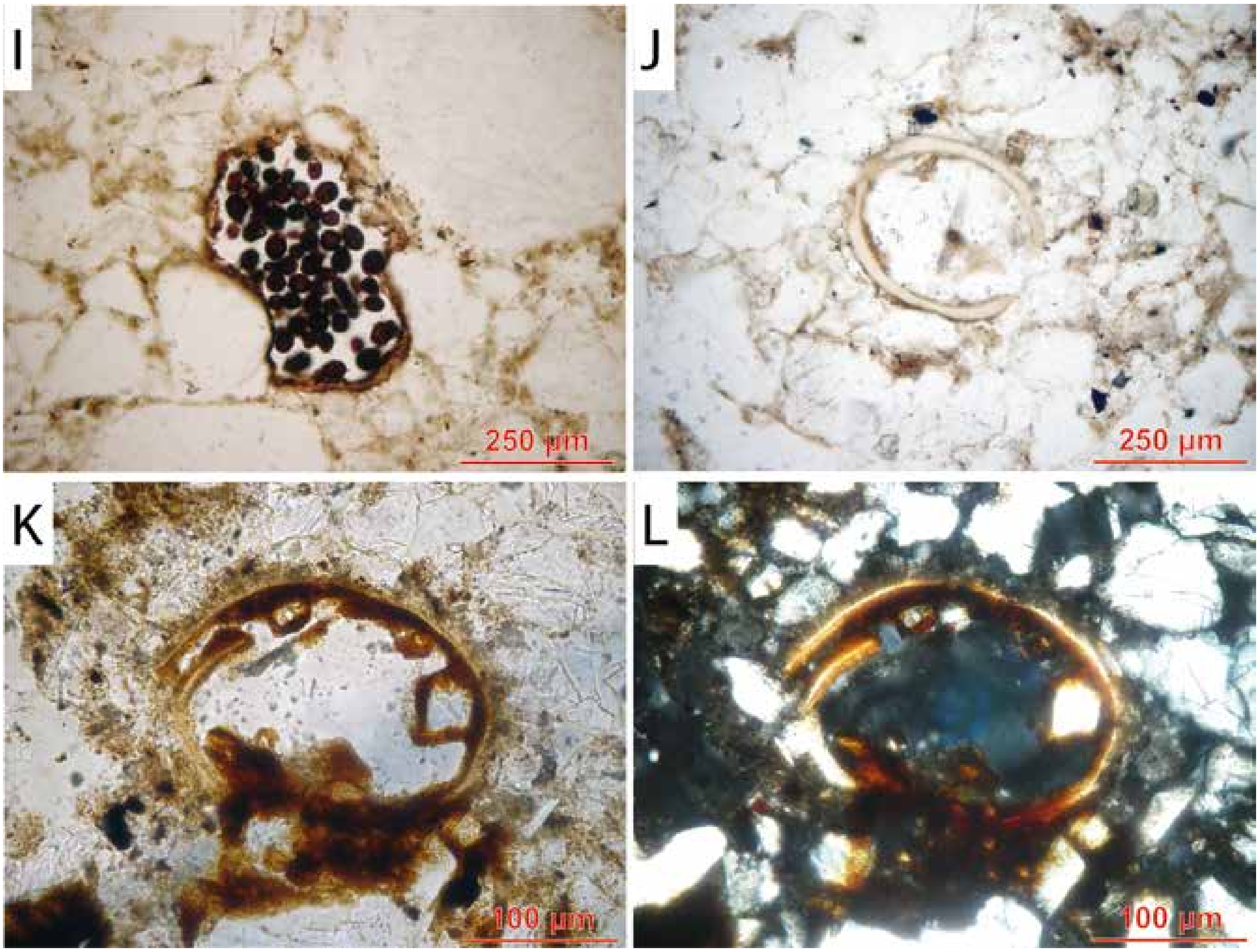

Figure 14. Soil micromorphological photos from byre S14 profile P1. **I**: Organic tissue with spores and iron stains. (PPL). **J**: A well-preserved bright ring, which is a spore form of vesicular arbuscular mycorrhizae. (lower part of H2; PPL). **K**: Bright ring (impregnated by iron and filled with grains of clay and fine sand size. (lower part of H2; PPL). **L**: same bright ring as photo C (XPL).

Broken coatings were described in several thin sections (Figure 13: photo F). They contain an important amount of amorphous organic material, but in some cases, they are also of the dusty type.

In the thin sections of H1, 2, 3 and 6, iron and manganese accumulations are observed. They occur as hypocoatings or as soft concretions (Figure 13: photo E). This type of soil characteristic is related to oxido-reduction, probably in the form of a high groundwater table or when the soil is within range of the capillary ascent of the groundwater table during the wetter periods of the year. In H6, two types were described: one type consists of orange-light-brown concretions, interpreted as probably being brought into the byre with the soil clods. Another soil characteristic are the dark blackish red pedofeatures. This type (Figure 13: photo G) forms under rather strong reducing conditions of the gley type (cf. marshy soils). This may well correspond to the period when cattle were penned in the byre, producing large amounts of manure and urine, creating an environment with high bacterial activity. In such conditions, the soil may, at least temporarily, have been oxygen depleted.

Yellowish isotropic coatings are observed in the last two horizons (H3 and H7) (Figure 13: photo H). They are an additional indication of intensive accumulation of manure. This corresponds well with the high phosphorus content in H3, and to a lesser extent in H7.

6.5. THE BRIGHT RINGS

Several circular rings were observed in the thin sections. They are not damaged or deformed, are almost perfectly circular, and are all birefringent. These pedofeatures are

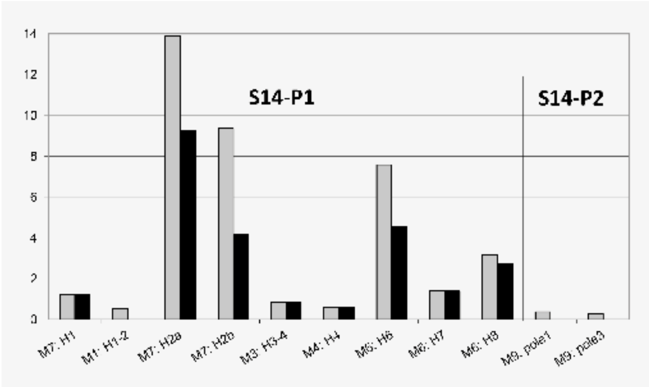

Figure 15. Number of bright rings per thin sections (counted for surfaces of 10 cm²). Data from byre S14, profile P1 and P2. Grey bars: total number; black bars: complete rings.

extensively discussed by Romans and Robertson (1983). These scholars interpret these as remnants of fungal tissues (moulds) that are associated with cattle and/or sheep excrements. In addition, this study reveals that in soils buried for more than 900 years, these features are birefringent.

These bright rings are frequently found in the thin sections of byre S14, but with a somewhat uneven distribution pattern. No rings were observed in byre S47. The total quantity observed, either as fully preserved rings or as fragmented or collapsed rings, was counted (Figure 15). Firstly, and probably most essential, is the fact that these rings are completely absent in profile S14-P4a and S14-P4b, both of which are a part of what is the heterogeneous part in the byre. Secondly, only two fragments of bright rings were found in the posthole of profile S14-P5, and none in the horizon just above the posthole (H4). Thirdly, the rings were frequently observed in profile S14-P1.

It is important to distinguish between complete bright rings and fragmented rings. It can be assumed that the complete rings are in situ. When the rings occur fragmented, they may have been transported over a short distance. It should be noted, however, that most of the samples consisted of more than 50% of complete rings, and none of them consisted of less than 25 %. The rings that were not fragmented, but appeared collapsed, were included in the fragmented rings, although this could have happened in situ. It should also be mentioned that fragments that were observed close to each other and that came from the same ring, were counted only once. The rings were never found in clusters but were scattered throughout the respective horizons. There were some small differences between the rings. For example, some were a bit darker brown, while most had a beige colour. The dimensions could also vary a little and were typically around 150-200 µm. Most fragments (partly) retained their round shape (Figure 14: photo I, J and K). One exception is the fragment from the deepest part of the posthole in profile S14-P2. In this case, it is doubtful whether it is part of a bright ring. Evidently, the calculated density per surface of the thin section (Figure 15) is too small to have any statistical value concerning the involved horizons, but it provides a good idea of the concentrations throughout the byre horizons. For example, they are nearly absent in the posthole and just above it, and the greatest concentrations occur in H2, and to a lesser extent in H6 and H8.

According to the above presented data, the following interpretations can be made:

- The bright rings possibly accumulated in the byres more than 900 year ago, thus indicating this particular stabling practice during the 12th century or earlier; this is in good agreement with the chronological setting established by the archaeologists.
- Most of the rings are still in situ, either as well-preserved rings or as in situ collapsed ones. This indicates that these deposits represent the original byre material and that trampling or any other kind of deep disturbance can be excluded.
- Their presence indicates that the house was used for sheep and/or cattle stabling.
- The higher concentrations of bright rings observed in P1H2 and P1H6-8 of byre S14 indicate that the byre was used more intensively for cattle, at least for two periods. It is also possible that during these two periods the animals stayed longer in the byre before new earth was added. This would provide more time for the accumulation of the rings.

7. Discussion

During the fieldwork on the site of Brecht-Zoegweg, special attention was paid to the two best-preserved byres: S47 and the much larger S14. These two archaeological structures were immediately identified as excellent cases for further detailed archaeopedological research.

Both features are characterised by a deeply incised floor which, according to soil surface reconstruction based on the soil maps, may have been between 70 and 120 cm below the original soil surface of the site. The byre is at its deepest in the central part and gently slopes towards the outer walls. Black horizontal bands are observed in the central part of both byres. They are probably the remains of a wooden floor that was used to prevent the cattle from sinking too deeply into the ground. This process of puddling can become a problem if the level of the deep byre floor comes within range of the fluctuating water table.

There are strong indications that at least part of the humus-rich soil in byre S14 represents the material that accumulated when the stable-house was in active use. An argument for this hypothesis is the presence of bright organic rings in the larger byre. These are produced by moulds that occur in places where cattle excrements occur. The brightness of the rings indicates that they have reached an age of at least 900 years. The heterogeneous soil material observed around profile S14-P4a however, does not show any indication for the presence of cattle, but contains numerous fragments of charcoal and fire structures, including clay-rich elements. Most probably, the charcoal and burned soil came into the byre as household waste. Undoubtedly, the byre fill would show seasonal differences. In the summer, the input of household waste upon manure would increase. In the winter, when the cattle would stay in the byre, manure would dominate the fill.

In the smaller byre S47, the very high concentration of phosphorus in multiple horizons matches the history as a byre with long periods of cattle raising. The upper horizons contain considerably less phosphorus, but cover the central post hole. It seems that they are of a more recent date and hence post-date the actual use of the stable-house and its byre.

The high content of phosphorus in certain horizons indicates that these were at the surface of the byre for longer periods, allowing more phosphorus to accumulate.

The earth that was brought into the byre most likely came from a forest or heathland, as suggested by the relatively high C/N ratio, still present today in the deeper horizons of both byres. In comparison with the surrounding soil, the byre material is enriched with organic carbon, nitrogen, alkaline cations, and phosphorus. In addition, the pH was increased, but this may be due to recent agricultural practices.

In byre S14, we find indications that iron and phosphorus were largely leached out after the burial of the occupation surface. This byre is close to the local brook, in a lower and wetter landscape position than byre S47, which may explain the leaching. During longer periods of reduction conditions, the Fe in iron-phosphate bonds is reduced from Fe^{3+} to Fe^{2+}. This makes phosphorus much more mobile (Brady and Weil, 1999, 560-561). On the other hand, iron and phosphorus have been conserved in the somewhat drier byre S47.

Several characteristics of the humiferous fill of the byres can be related to post-occupational processes and point to the discarding of the structures. Concerning the difference in phosphorus content between the two byres, it could be argued that the function of the two stables was different. The small byre, relatively rich in phosphorus, would have been a byre, and the large one, with little phosphorus, would have had a different function. A more likely explanation is that the large byre, was constructed in a lower landscape position and therefore more liable to a fluctuating groundwater table with associated reduction processes and leaching of iron phosphate compounds.

After the sites were abandoned, it seems that the large wooden central posts were recovered, and the site was levelled to a certain extent with soil from the surroundings. It is not excluded that the site continued to be used as agricultural land. The heterogeneous filling in the upper horizons of the southwestern part of S14 can be related to the utilisation, after its abandonment, as a waste pit. A similar interpretation was proposed for a byre in Scotland (Guttmann et al., 2003, 18).

A remarkable feature of the humiferous horizons are the numerous lighter coloured patches, most of them with a sub-rounded contour. This is related to a post-occupation process of organic matter consumption by microbiological activity, a process accelerated in recent decades since the high increase of nitrogen-rich substances (mainly nitrate). The input can come from both the direct application of fertiliser and by air-born input.

While the use of the byres for stabling cattle could be demonstrated, from the data of this study it cannot be concluded with certainty that farmers were already using plaggen farming techniques in this region during the Roman period. The archaeopedological characteristics of the byres however, point to a complex use-sequence exemplified by three successive management phases.

The first phase starts with a byre bottom that is at the same level as the rest of the sandy farm floor. It is not clear if sods or plaggen were applied in this phase. However, each time when collecting the manure, some earth of the byre floor was scraped away. As a result, the byre bottom became gradually deeper. This process was less intensive near the wall of the byre because of a building stability risk and was more pronounced towards the centre. Possibly, the scraping of the underlying soil was intentionally done, after all the underlying soil was trampled and soaked with nutrients after a season of manure and urine deposition.

In a second phase, the lowest part of the byre floor became so deep that it reached the influence of the groundwater table. This could be related to particularly rainy period(s). The water-saturated soil created a risk for the stability of the building and provided problems of poaching of the cattle. In order to face these difficulties, the floor was raised. Soil clods and pottery fragments were dumped in the deepest positions and the whole layer was covered by a wooden floor. Consequently, this bottom horizon was not disturbed further by cattle trampling.

During the third phase, presumably each time after collecting the manure, some earth, possibly soil clods, were deposited on the byre bottom. This earth became mixed with the manure by the animal trampling. Keeping in mind the problems experienced towards the end of phase 1, care was taken to leave at least some of this earth during the next extraction phase. Consequently, the byre bottom gradually moved up and over the years a characteristic thick, relatively homogeneous humiferous soil sediment accumulated. Whether the extra earth was only spread over the floor after the extraction of the manure or if soil clods were regularly dumped in the byre during the cattle stabling such as in the plaggen type of management, is not sure and can only be checked by studying the Roman period infield plough layers. At the time of this research there is no reliable information about this subject available in the studied region.

The succession of interventions proposed here, and based on two cases, supports the theory that the sunken floors were not excavated during the construction phase of the building. The regular input of earth, probably soil clods, along phase 3, resulted in the thick humiferous horizon that fills the byre. This is the item that received the most attention from the archaeologist and that has been investigated in more detail in this archaeopedological research.

Another interpretation would be that the byres were indeed intentionally dug out in the soil, but only in a shallow way during or soon after the stable house was built. Following intensive use and repetitive emptying of the stables throughout time, the original floor level got scraped away and the stable gradually deepened, taking away evidence of its very first phases of use. In any case, both interpretations demonstrate the byres' complex biography of use and discard, only leaving us with the sediments of the last phases of use and the discard of the structure.

8. Conclusions

The study of two byres, dating back to the Roman period, provided valuable information on the complex life-history of the use and discard of stables with a sunken floor, also known as byres of the *potstal* type. Detailed field observations of 75 m of soil profiles in a grid of two by four m, in combination with physical and chemical laboratory analyses and an extended soil micromorphological study have supplied valuable insights into the life cycle of such byres.

The importance of a combined field strategy to assess these remarkable structures is evident, where the archaeological and archaeopedological investigations are united. In future research of byres from poor sandy cover sands, we recommend the analysis of the byres for phosphorus, carbon and nitrogen (C/N ratio), and to combine this information with a soil micromorphological study. In the ideal case, this research would be expanded with studies of the agricultural infields, where the byre manure was applied. Only then we will be able to fully understand the nutrition cycle of the Gallo-Roman farmers.

Although the study was unable to document that a plaggen infield-outfield farming system was carried out in the region during the Roman period, the study did reveal a system where manure and soil nutrients were carefully collected and, at least to some extent, mixed with soil material.

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Natural and anthropogenic soil forming factors and processes

SOILS AS RECORDS OF PAST AND PRESENT
FROM SOIL SURVEYS TO ARCHAEOLOGICAL SITES:
RESEARCH STRATEGIES FOR INTERPRETING SOIL CHARACTERISTICS

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DRIFT SAND-PODZOL HYDROSEQUENCES IN THE MOL-DESSEL AREA, NE BELGIUM

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ABSTRACT
This paper explores the concept of drift sand-Podzol hydrosequences, based on recent observations (exposures and hand augerings) at a small interfluve in the Mol-Dessel area, NE Belgium. It shows that drift sand characteristics and the soil horizon morphology of the buried Podzols covary in a slightly undulating landscape, according to their vertical position with respect to an assumed palaeogroundwater table. Notwithstanding the fact that several issues still need to be resolved, the investigated sequences have great potential as a palaeohydrological archive.

KEYWORDS
soil horizon morphology, Podzol, drift sand facies, palaeohydrology, groundwater table, Holocene

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1. Introduction

Podzol horizon morphology is strongly dependent on the hydrological conditions during soil development. The average highest and average lowest groundwater tables have an impact on the distribution of Fe in the soil profile and the morphology, thickness and nature of the transition between the B- and E-horizons (Buurman, 1984; Buurman and Jongmans, 2005; Buurman et al., 2013). De Coninck (1980) distinguishes four types of B-horizons, and thus Podzols. The first, Friable Podzols have loose B-horizons, which are characterised by high biological activity. Drainage conditions may vary from poorly drained to well drained. The second, Cemented Podzols have partially or completely cemented B-horizons which are characterised by less biological activity (e.g. as a result of a shallowing groundwater table or changing vegetation). Again, drainage conditions may vary from poorly drained to well drained. The third, Nodular Podzols have a gley horizon in the shallow subsurface, which is characterised by iron nodules and mottles. The B-horizon then develops around the iron nodules. Finally, Placic Podzols have an orange-red iron pan directly underneath the B-horizon. The iron-pan develops as a result of stagnant conditions on top of a cemented B-horizon.

In general, soil development in the sandy parent material of the Campine area (NE Belgium) started after the stabilisation of the landscape due to vegetation development at the beginning of the Holocene (see references in Beerten et al., 2014). Subsequent land use and socio-economic changes were responsible for increased pressure on the landscape (deforestation, grazing, development of road track networks, heather sodding practices in agriculture) that caused wind deflation of the previously developed Podzols and parts of the parent material. Episodes of decreased landscape stability and sand drifting are known to have occurred during several stages in the Holocene, but it was not until the late Middle Ages (AD 1050-1500) and the Modern Period (from AD 1500) that sand became massively mobilised which led to the development of the characteristic micro-topography in many regions in the European sand belt (Figure 1; Koster, 2009; Tolksdorf and Kaiser, 2012; Küster et al., 2014; Pierik et al., 2018). Gradually, during the course of the 19th century, the landscape became stabilised again. The thus fossilized drift sand landscape shows characteristic alternations of deflation hollows (usually around 1-2 m deep) and shallow (1 m up to several m high) irregularly shaped drift sand dunes. Very often drift sand is found on top of (partially eroded) Podzols, in which case the podzolization process is no longer active and the soil turns into a palaeosoil. Typical features in drift sand landscapes are table-shaped mounds, showing an alternation of elevated areas consisting of buried Podzols, and deflation areas where the Podzol has been completely removed (Castel, 1991). In some regions, sand is still drifting today, such as in the Veluwe area in the central Netherlands (Koster, 2009).

Logically, similar to the Podzols that developed prior to landscape instability, deflation hollows and drift sand deposition patterns are expected to have been influenced (or not influenced) by the contemporaneous groundwater table. For example, a rising groundwater table may cause groundwater to outcrop in a deflation hollow that developed during an earlier episode of deeper groundwater tables. Drift sands that are subsequently caught in a body of standing water or on a saturated surface are expected

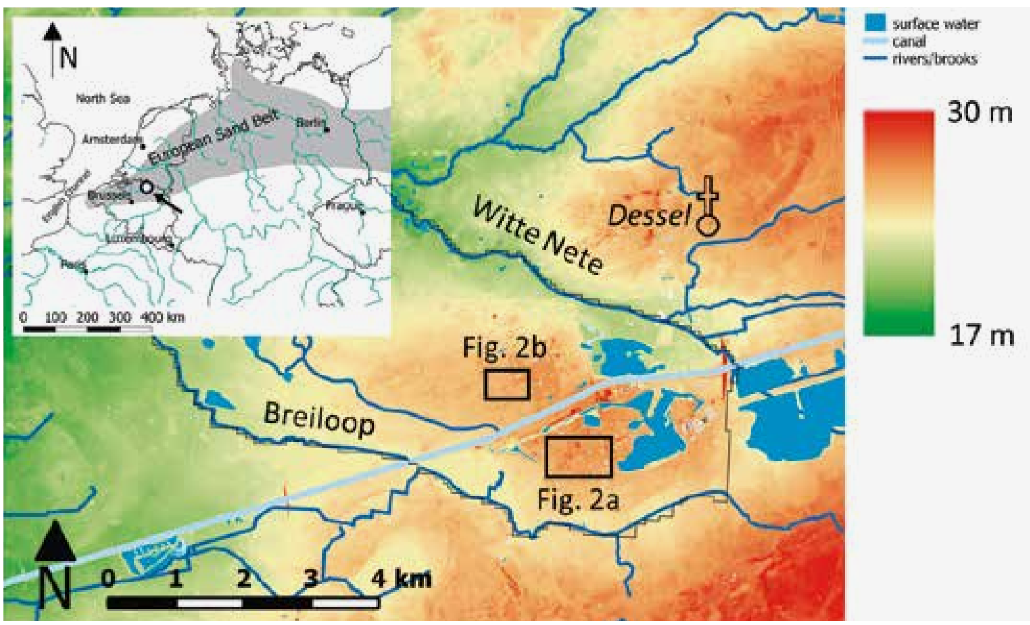


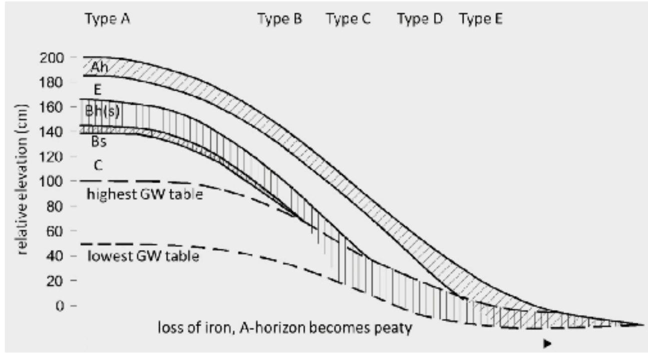
Figure 1. Location of the study area. See Figure 2 for a detailed DTM of the area covered by the two rectangles (AGIV, 2006).

to exhibit distinct sedimentological features compared to their purely aeolian counterparts. Beyond doubt, such sequences, if studied in sufficient detail, may evolve into valuable palaeohydrological archives. Therefore, the aim of this paper is to explore the concept of drift sand-Podzol hydrosequences in the Mol-Dessel area (NE Belgium), based on earlier work in the region (Beerten et al., 2012 and 2014; Beerten and Leterme, 2015) and new field observations (exposures and hand augerings) in view of their palaeohydrological significance.

2. Materials and methods

During the past few years, temporary exposures became available on the interfluve that is bordered by the Breiloop in the south and the Witte Nete and Kleine Nete in the north (Figure 1 and Figure 2). The exposures typically display soil-sediment profiles consisting of a (partially eroded) Podzol buried underneath drift sand deposits. Two soil profiles were previously investigated in detail and serve as the basis for the current work. Profile BP (Figure 2b) was studied in Beerten et al. (2012) and profile GKD (Figure 2a) was studied in Beerten et al. (2014). Additionally, the following characteristics of the newly observed profiles were described in detail: soil colour (Munsell Soil Color Book, 2009), soil horizon morphology, and macroscopic sedimentology. Furthermore, hand augerings were done in the vicinity of profile GKD, in order to map the pre-drift sand landscape (see Figure 2a). Podzol soil morphology was interpreted in terms of (palaeo)hydrological conditions using the concepts developed by Buurman (1984), Buurman and Jongmans (2005), and applied in, e.g. Buurman et al. (2013) and Martinez et al. (2018). The concept is visualized in Figure 3 and summarized in Table 1. Well-drained Podzols, in which the groundwater table never reaches the B-horizon, retain Fe in the profile and usually show clear horizon differentiation (hydrosequence type A). The E-B transition is clear and wavy. A typical feature in these Podzols is the presence of thin bands of organic matter near the transition from the B- to C-horizon. Moderately drained Podzols, in which the groundwater table occasionally would reach the B-horizon, usually show a clear differentiation in horizons and the presence of iron concretions and/or mottles in the B-horizon (type B). Poorly drained Podzols, in which the B-horizon is permanently saturated by groundwater, usually are depleted in Fe and show vague horizon differentiation (type C). The E-horizon in particular becomes very thin (type D) and even disappears (type E) when the groundwater table becomes shallower.

Figure 3. The concept of a Podzol hydrosequence in a slightly undulating landscape (modified from Buurman (1984)). Podzol hydrosequence types A-E are explained in the text.



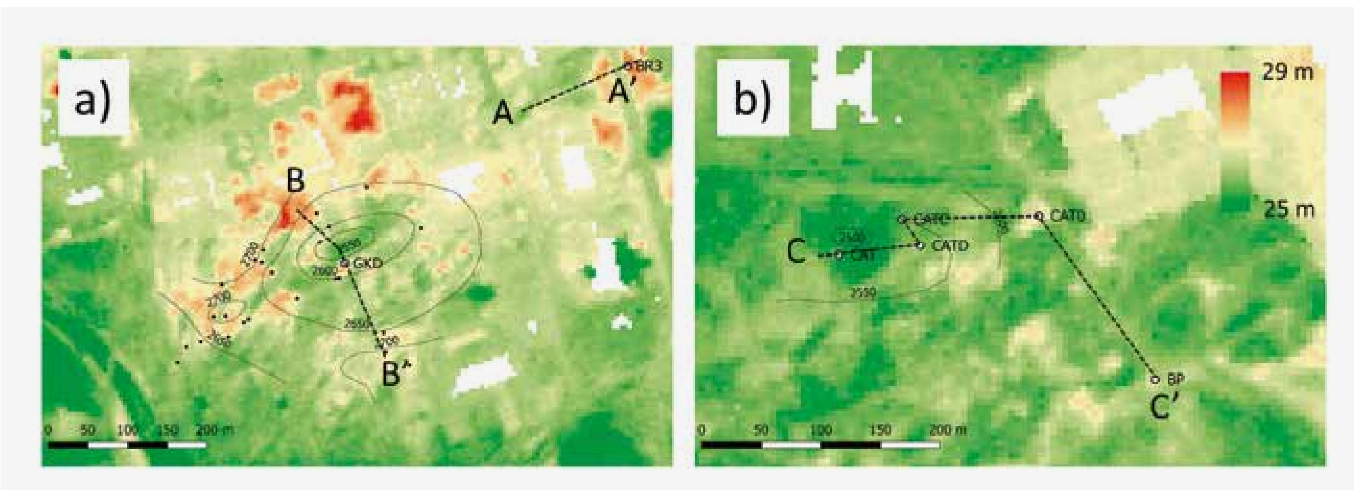


Figure 2. DTM of the study area. Thin black lines are isolines representative of the top of the Podzol soil (i.e. the top of the A-horizon). Numbers give the altitude of the top of the Podzol in cm a.s.l. (TAW). (a) See Figure 7a and b for cross-sections A-A' and B-B'. Black dots indicate hand augering locations. (b) See Figure 7c for cross-section C-C'.

Table 1 Diagnostic criteria to determine the position of the groundwater table with respect to the contemporaneously formed Podzol soil

Podzol morphology	Well-drained (I)	Moderately drained (II)	Poorly drained (III)
Fe distribution	Mottles of Fe oxyhydrates or no Fe in C horizon	Fe concretions/mottles in lower B horizon	Depleted in Fe
B horizon colour and morphology	Thin, black, wavy and well-pronounced with thin humus bands in BC-horizon	Black to dark-brown (sometimes with humus bands)	Less pronounced and black or brownish
E horizon morphology	Thickness depends on time, parent material and speed	Thickness and depth limited by GW table; may be thick	May still be present, usually very thin
E-B transition	Clear and wavy	May still be clear	Diffuse (vertical water movement) to abrupt (lateral water movement)

(based on Buurman et al., 2013). I = GW table permanently saturates C-horizon. II = GW table sporadically saturates B-horizon. III = GW table regularly saturates B- and E-horizon.

Drift sand depositional facies were interpreted using diagnostic criteria to distinguish structures that are produced by aeolian deposition in a dry environment, on a wet (saturated) surface, and/or in standing water (Schwan, 1991; van Huissteden et al., 2001; Koster, 2009; Brookfield and Silvestro, 2010; Van Loon and Pisarska-Jamroży, 2014). In this work, four different facies are distinguished. Facies 1 is an aeolian sand sheet facies and consists of homogeneous massive drift sand deposited in dry conditions from grain fallout. Facies 2 is also an aeolian sand sheet facies, but there is a slight alternation in grain size between cm-dm thick laminae, mainly deposited in dry conditions or a damp surface from grain fallout. Facies 3 is similar to facies 2, but the cm thick laminae contain more organic material as a result of slightly wetter conditions. Finally, facies 4 consists of finely and irregularly laminated sand with traces of wavy and flaserlike bedding, which suggests deposition in a shallow pool.

3. Results and discussion

3.1. DESCRIPTION OF THE INDIVIDUAL SOIL-SEDIMENT PROFILES

The location of the studied profiles is shown in Figure 2 and their main characteristics are summarized in Table 2 and Table 3. Based on colour characteristics, soil-sediment profile BR3 (Figure 4a, green bar) shows a clear differentiation in Ah-, E-, Bh- and Bs-horizons (see Figure 3). The B-horizon is relatively loose and thin humus bands are present in the BC-horizon. It is interpreted as hydrosequence type A. The overlying drift sands (yellow bar) are organised in thick laminae of slightly alternating grain size (facies 2) and are interpreted as grainfall laminae resulting from sustained wind gusts (Brookfield and Silvestro, 2010). They are covered by massive and homogeneous windblown sands which may also be the result of sustained wind patterns (facies 1). The granulometric differentiation in the laminae (facies 2) is very weak, and only accounts for a 5-10% change in grain size, the darker horizons being slightly finer and containing a very small amount of organic carbon. These may reflect very short periods of landscape stabilisation and vegetation development in otherwise dry conditions and/or the final phase of an individual aeolian event (Beerten et al., 2012).

Soil-sediment profile GKD (Figure 4b and c) is a complex profile that shows a clear differentiation in Ah-, E-, Bh- and Bs-horizons. The Bh-horizon is directly underlain by an iron pan, which reflects stagnant conditions above the Bh-horizon. According to De Coninck (1980) this Podzol can be classified as a Placic Podzol. The Fe-content underneath this iron pan is still relatively high, such that it can be qualified as a Bs-horizon (Beerten et al., 2014). Below the Bs-horizon is a C-horizon with abundant oximorphic mottles but without thin humus bands. As these mottles may reflect temporary saturation of the C-horizon, up to the transition to the B-horizon, this soil is interpreted as soil type B (Figure 3). As can be seen in Figure 4b on the left side, the soil is eroded, presumably by aeolian deflation (Beerten et al., 2014). The erosional surface and the Podzol are covered by drift sand facies 1 and 2.

The next profile, BP (Figure 4d), again shows an eroded Podzol. In this Podzol, horizon differentiation is slightly less well expressed, and the typical colour of iron (as observed for BR3 and GKD) is lacking in the profile. The B-horizon is cemented and poorly developed humus bands are present. This Podzol marks the transition from a moderately drained soil to a poorly drained soil (soil type C; Figure 3). The overlying drift sands are again organised in thick laminae of slightly alternating grain size (facies 2) and become massive and homogeneous towards the top (facies 1).

Table 2 Summary of field observations for the various profiles

Profile	Altitude (m a.s.l.)	Alt. of podzol top (m a.s.l.)	Drift sands				A-horizon		E-horizon			Bh(s)-horizon		Bs-horizon		C-horizon	Type
			Thickness (cm)	Type	Colour (facies 1 and 2)	Colour (facies 3)	Thickness (cm)	Colour	Thickness (cm)	Colour	E-B transition	Thickness (cm)	Colour	Thickness (cm)	Colour	Colour	
BR3	28.1	27.5	60	1 and 2	7.5YR8/1 5Y6/1	n/a	5-10	5B4/1	10	N9-N10	Clear	5	N0-N2	5-10	7.5YR4/6	10YR7/2	A
GKD	27.7-27.3	26.7	60-100	1 and 2	10YR8/1 10YR7/1	n/a	5-10	10BG2/1	10-15	5BG8/1	Rather clear	5-10	N4	>5	10Y8/1 7.5YR5/2	10YR8/1 10YR7/8	B
BP	27.0	25.7	130	1 and 2	10YR8/1 5Y6/1	n/a	Eroded	n/a	>10	5B6/1	Rather vague	5-10	10B3/1	0	n/a	10YR6/7	C
CAT0	26.8-26.7	26.3	40-50	2	10YR8/1 5YR8/1	n/a	5-10	10BG6/1	10	N9-N10	Very clear	5-10	N0-N2	>10	10YR3/3	10YR7/4	A
CATC	25.6	25.8	0	n/a	n/a	n/a	5	10BG4/1	15	N9-N10	Rather clear	10-15	N0-N2	5-20	10YR5/4 10YR7/6	n/d	B
CATD	26.2	25.4	80	1, 2, 3 and 4	10YR7/1	10GY8/1	5	N0-N1	5-10	10B7/1 5BG6/1	Rather vague	>10	N0-N2	?	n/a	n/a	D
CAT	25.7-25.2	25.1	10-50	2 and 4	10YR8/1 10YR7/1	10G8/1 10YR8/1 N5	0-5	10B2/1	0-5	10B8/1	Vague	10 upper (h) 15 lower (hs)	5PB2/1 (h) 5YR5/1 (hs)	0	n/a	7.5YR3/2	E

Altitude of the terrain (m a.s.l. *Tweede Algemene Waterpassing*), altitude of the top of the Podzol soil, drift sand thickness, colour and facies (facies 1, 2, 3 or 4), thickness and colour of the Ah-, E-, Bh(s) and Bs-horizons, and hydrosequence type (A-E) are given. n/a = not applicable. n/d = not determined.

Table 3 Summary of field observations

Profile	Alt. of podzol top (m a.s.l.)	Bh-horizon	Humus bands in BC-horizon	Type
BR3	27.5	Weakly cemented	Yes	A
GKD	26.7	Cemented with placic horizon	No	B
BP	25.7	Cemented	Yes	C
CAT0	26.3	Weakly cemented	Yes	A
CATC	25.8	Cemented	No	B
CATD	25.4	Cemented	n/a	D
CAT	25.1	Cemented	Yes	E

Bh-horizon characteristics (according to De Coninck (1980)) and presence or absence humus bands. n/a = not applicable.

Profile CAT0 (Figure 5a) shows a soil with clear horizon differentiation, similar to profile BR3, and is covered by drift sand facies 2. The B-horizon is weakly cemented and there is some accumulation of organic matter in thin humus bands below the B-horizon. The soil is interpreted as belonging to type A. The next profile, CATC (Figure 5b), again shows a soil with clear horizon differentiation. The Bs-horizon is well developed, but thin humus bands are absent. This soil is interpreted as belonging to type B, towards the well drained end-member of the hydrosequence (Figure 3).

Profile CATD (Figure 5c and d) is very different from the previous profiles, both in terms of soil development and drift sand characteristics. Though the C-horizon of the profile could not be observed, it is clear that horizon differentiation in this soil is less well developed. The E-horizon is vaguely defined and shows a vague transition towards the B-horizon underneath. This soil is interpreted as a Podzol with features that typically belong to the poorly drained end-member of the full hydrosequence, type B (Figure 3). The drift sands that overlay the Podzol are very different from what can be observed on top of well drained Podzols. Near the bottom they are organised in very thin laminae (several mm thick) of contrasting grain size (facies 4; Figure 5d). White laminae consist of sand, while the amount of fines and organic matter increases when the colour darkens. The laminae are irregular, i.e. cannot be followed over a large lateral distance and sometimes show wavy bedding (white arrows in Figure 5d) and flaserlike features (black arrows in Figure 5d). Wavy bedding is thought to be the result of waves acting upon the surface of stagnant water. Similarly, flaserlike features develop when slightly finer material fills in shallow troughs that result from weak wave action. The thin irregular laminae may reflect very short wind gusts (Brookfield and Silvestro, 2010) from which the resulting sedimentological product (a thin lamina) would have been blown away during the next event unless it is protected by a wet surface and/or a shallow column of standing water. The laminae are slightly better expressed towards the top and then alternate with mm-cm thick dark layers enriched in organic matter. This layer of drift sand is overlain by drift sands that are interpreted as belonging to facies 3. They mark the transition from the top of facies 4 to facies 2, as the laminae become thicker and the amount of organic matter declines. The top of the profile consists of drift sand facies 1. The full drift sand accumulation can be interpreted as a drying-upward sequence in which the

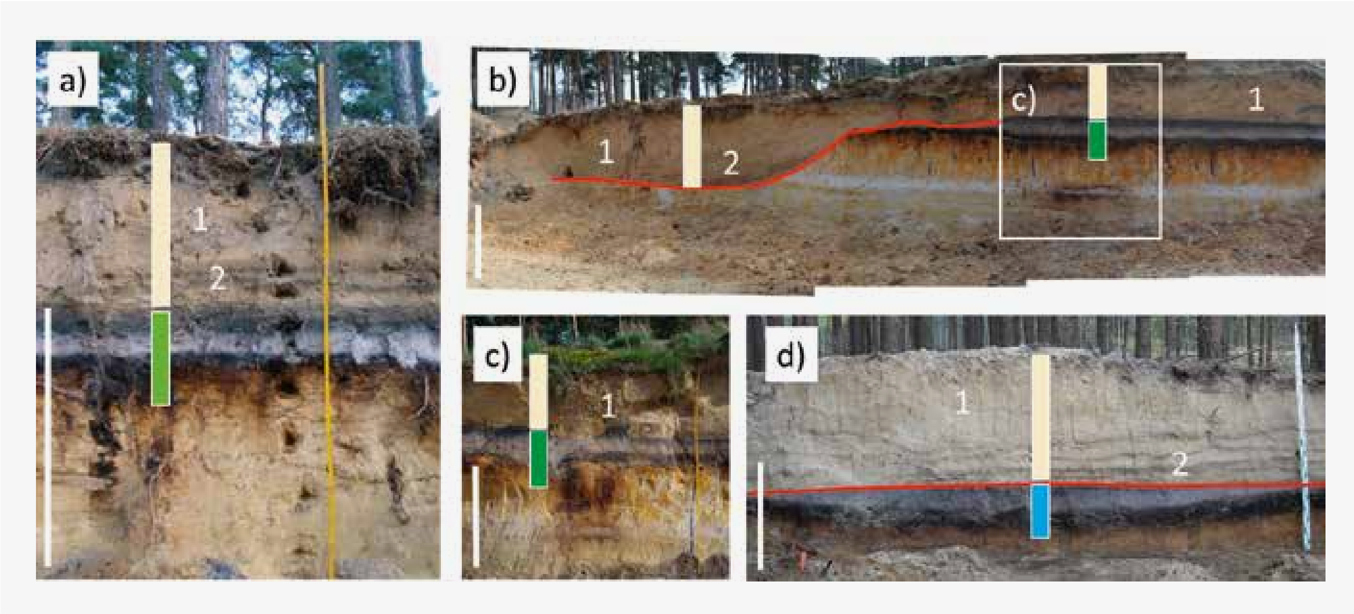


Figure 4. (a) Soil-sediment profile BR3. (b) Soil-sediment profile GKD. (c) Detail of the image shown in Figure 4b. (d) Soil-sediment profile BP. Vertical line = 50 cm. See Figure 7 for colour legend. Green and blue bars refer to the Podzol hydrosequence type, the yellow bars indicate the overlaying drift sands. Red line shows the position of the deflation horizon. Numbers denote the drift sand facies (1 and 2).

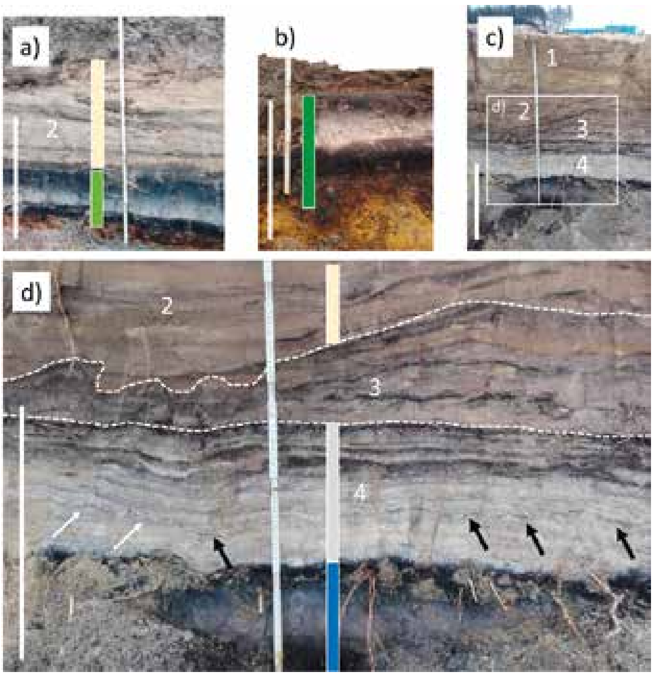


Figure 5. (a) Soil-sediment profile CAT0. (b) Soil-sediment profile CATC. (c) Soil-sediment profile CATD. (d) Detail of the image shown in Figure 5c; wavy bedding is indicated by white arrows and flaser structures are indicated by black arrows. Vertical line = 50 cm. See Figure 7 for colour legend. Green and blue bars refer to the Podzol hydrosequence type, the yellow and grey bars indicate the overlaying drift sands. Numbers denote the drift sand facies (1, 2, 3 and 4).

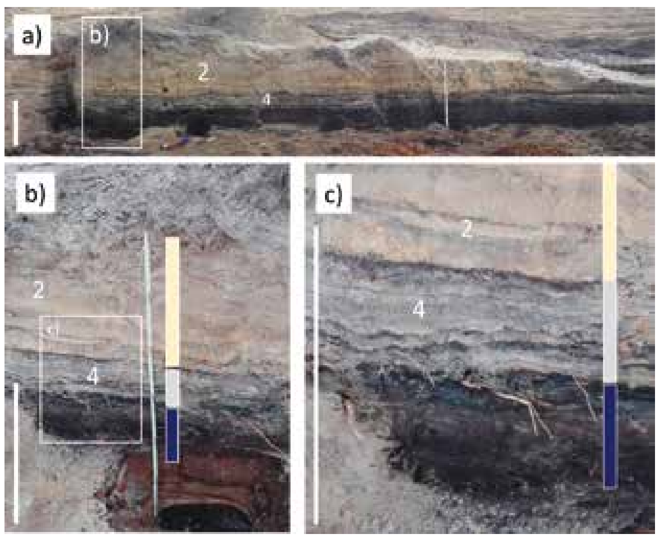


Figure 6. (a) Soil-sediment profile CAT. (b) Detail of the image shown in Figure 6a. (c) Detail of the image shown in Figure 6b; note the wavy lamination in drift sand facies 3. Vertical line = 50 cm. See Figure 7 for colour legend. Blue bars refer to the Podzol hydrosequence type, the yellow and grey bars indicate the overlaying drift sands. Numbers denote the drift sand facies (2 and 4).

build-up of the groundwater table could not keep pace with the accumulation of drift sand. Profile CAT (Figure 6) shows similar features as the previous one (CATD). Podzol horizon differentiation is even less well expressed, with a peaty A-horizon, a very vague E-horizon and a cemented B-horizon (Figure 6a, b and c). The soil is interpreted as belonging to type E. There is some accumulation of organic matter in thin humus bands in the Bhs-horizon. The palaeosoil is overlain by drift sand facies 4 and 2, similar to profile CATD.

3.2. PODZOL MORPHOLOGY, AEOLIAN DEFLATION AND DRIFT SAND CHARACTERISTICS IN RELATION TO THE PALAEOGROUNDWATER TABLE

Whereas there might be some uncertainty regarding the interpretation of the individual soil-sediment profiles, their relative elevation and their absolute position in the landscape strongly suggest they are genetically related with respect to a first-order long-term groundwater table elevation.

Profile BR3 is schematically positioned in a topographical cross-section in Figure 7a (see Figure 2a for the location of the cross-section). As there were no indications of groundwater table features in this particular soil-sediment profile (hydrosequence type A and drift sand facies 1 and 2), the groundwater table must have been far below the soil forming depth during soil formation and subsequent drift sand deposition, as tentatively illustrated by the sine-wave in Figure 7a. The sine-wave is meant to illustrate the variation of the average highest groundwater table in a given timeframe.

Next, Figure 7b shows the position of soil-sediment profile GKD (see Figure 2b for the location of the cross-section). Here, the position of the groundwater table is assumed to have been permanently below the deflation horizon. Prior to the formation of the latter, the groundwater table may have reached the B-horizon during some episodes (hydrosequence type B). The top of the Podzol soil as reconstructed from hand drillings (see also Figure 2b) gives an indication of the palaeotopography prior to aeolian deflation and sand drifting. Apparently the

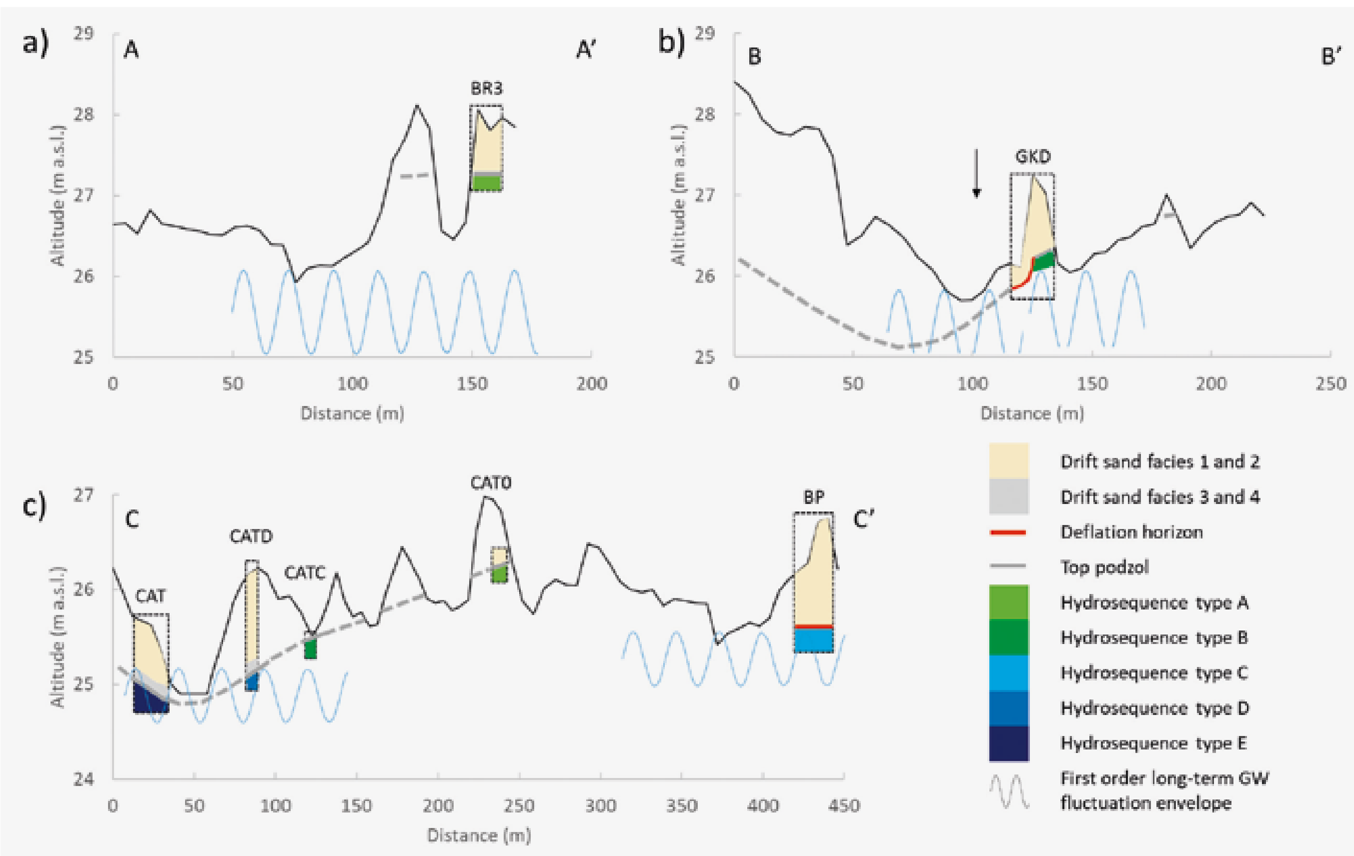


Figure 7. Topographical cross-sections showing the position and interpretation of the studied soil-sediment profiles. (a) Soil-sediment profile BR3. (b) Soil-sediment profile GKD. (c) Soil sediment sequence CAT-CAT0-CATD-CATC-CAT. The sine-wave is meant to illustrate the anticipated variation over longer time periods (decennia, centuries) of the average highest groundwater table around the time of podzolization and drift sand deposition.

area used to be a depression before it partially became overblown by aeolian drift sand. The erosional feature as observed in soil-sediment profile GKD may be related to the existence of a road track which is indicated on the Ferraris map (see arrow in Figure 7b). Possibly, the road track used to run through the center of the depression which became too wet so that the road was shifted laterally towards more drier ground. Note that hoofprints were observed in the basis of the drift sand that overlays the eroded soil (facies 2 in Figure 4b; Beerten et al., 2014). In a previous study, the erosional phase was determined to have taken place around AD 1500-1600 (based on optically stimulated luminescence dating of the drift sands; Beerten et al., 2014), while sand drifting continued until ca. AD 1800. This implies that the inferred groundwater table position for this sequence is valid for at least the period around AD 1500.

The deflation horizon observed in soil-sediment profile BP (Figure 7c) was estimated to have been formed around AD 1500 (Beerten et al., 2012), while drift sands were deposited until ca. AD 1700-1800. The drift sands, belonging to facies 2 and 1, all seem to have been deposited in dry conditions, yet the soil shows some features that may relate to a periodically elevated groundwater table (hydrosequence type C). This leads to a tentative groundwater table reconstruction as illustrated in Figure 7c, which is valid for the period around ca. AD 1500, and a period of unknown duration prior to this age window (since the soil must have been formed prior to deflation and sand drifting).

From profile BP the link can be made to nearby profiles CAT0, CATC, CATD and CAT, which at first sight seem to be toposequences, but in fact can be interpreted as hydrosequences (Figure 7c). Profile CAT0 shows a well-drained Podzol (type A) overlain by drift sand facies 2 and interpreted to have been formed well above the groundwater table. Profile CATC, without drift sand, shows a Podzol which may have been sporadically influenced by groundwater. Profile CATD shows a Podzol hydrosequence type D that was developed while the groundwater table was very close to the surface, yet sufficiently deep to allow for podzolization. From the drift sand characteristics it can be inferred that the groundwater table was still very shallow (and sporadically even outcropping) during deposition of the latter (see indications of standing water in Figure 5d). Finally, the Podzol from profile CAT developed under similar conditions, with a very shallow contemporaneous groundwater table (since the E-horizon is almost completely absent). The drift sands show similar characteristics to the ones from profile CATD and are deposited in very wet conditions and/or standing water.

It is important to note that some soil profiles bear traces which point to polygenetic development. For example, the thin humus bands in profile CAT suggest different drainage conditions than the E-horizon morphology and drift sand facies do. Similarly, drainage conditions for profile GKD would have been different during development of the oximorphic features in the C-horizon than those during development of the deflation horizon. Again, these polygenetic conditions are captured by the fluctuating average highest palaeogroundwater table in Figure 7.

The poorly drained Podzol hydrosequence in profiles CAT and CATD suggests that during its formation the groundwater table was episodically very shallow. It can reasonably be assumed that during some periods groundwater was outcropping. This tentative interpretation is supported by the drift sand characteristics (facies 4). Even though this interpretation might be straightforward, a standing water column can also be the result of extreme precipitation events and/or the presence of an impermeable horizon in the shallow subsoil. In particular, cemented B-horizons may develop into an impermeable barrier capable of supporting a perched water table. In such conditions an iron pan would develop, as is the case for profile GKD (Figure 4b). However, if the B-C horizon transition is saturated, iron cannot precipitate in the form of a pan. The absence of an iron pan in hydrosequences CAT and CATD indeed demonstrates that the groundwater table was very shallow during their development. Alternatively, extreme precipitation may cause the depression to fill up with water for a very short time, even without a hydraulic barrier in the shallow subsoil. In such case, the observed drift sand features of facies 4 reflect frequent heavy precipitation events rather than outcropping groundwater.

In the absence of age control for the drift sands deposited in profiles CAT0, CATD and CAT, it is assumed for now that they were deposited in approximately the same time period as those observed in profiles GKD and BP. As such, the hydrosequence would reflect the average highest groundwater table conditions for the period around AD 1500 and a period of unknown duration prior to this time window (since the soil must have been formed prior to drift sand deposition).

In an earlier study, an attempt was made to reconstruct the groundwater table in the study area using a combination of Digital Terrain Models (DTM's), historical maps and 20th century soil maps (Beerten and Leterme, 2015). In that study, the DTM of the area was carefully inspected and preserved deflation hollows were mapped, assuming that they all belong to the same deflation period (around AD 1500). For the areas depicted in Figure 2 this resulted in an estimated maximum palaeogroundwater table elevation of ca. 25-26 m a.s.l. (TAW). This value seems to be in accordance with the estimated palaeogroundwater table based on drift sand characteristics and Podzol soil morphology outlined above. The present-day average highest groundwater table is ca. 24.5 m a.s.l. (Rogiers et al., 2016) and seems to be slightly lower than the palaeogroundwater table around AD 1500, even if we allow for some uncertainty in the interpretation, as suggested by the sine-wave in Figure 7.

4. Conclusions

In this study the use of drift sand-Podzol hydrosequences was explored in terms of their palaeohydrological significance for an interfluval area in the Mol-Dessel area, NE Belgium. It shows that drift sand characteristics covary with Podzol soil morphology along a topographical gradient. Together they seem to constitute a hydrosequence in the investigated area and as such are a promising palaeohydrological archive. However, at present there are still some issues that need to be resolved. Firstly, a more detailed soil-sediment analysis is needed (geochemistry, granulometry) in order to e.g. quantify the Fe- and C-concentrations of the various horizons, exactly determine the depth of the E-horizon in profile CAT, and verify the genetic interpretation of drift sand facies 4. Additionally, the palaeohydrological interpretation of the sequences would certainly benefit from palaeobotanical analysis (macrobotanical and pollen analysis) since the presence of certain species may be indicative of shallow eutrophic standing water. Finally, more age control for the various horizons and sediment facies would be welcome in order to confirm or refine the existing age model that is currently applied in the region.

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BIOTURBATION AND THE FORMATION OF LATENT STRATIGRAPHIES ON PREHISTORIC SITES

Two case studies from the Belgian-Dutch coversand area

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"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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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

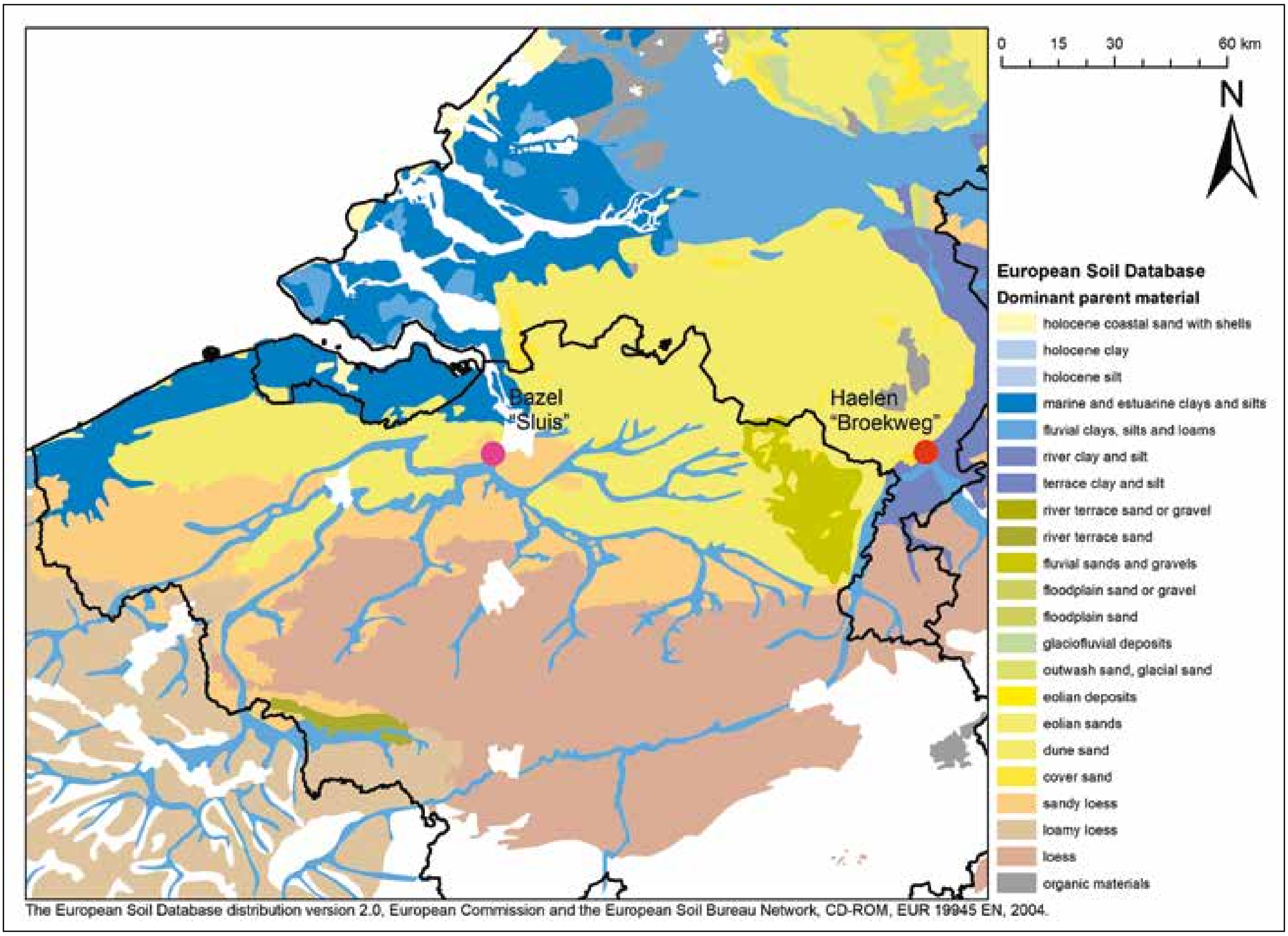

Figure 1. Map of parent materials in Belgium and the southern Netherlands, with the position of the two studied sites.

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 m² (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.

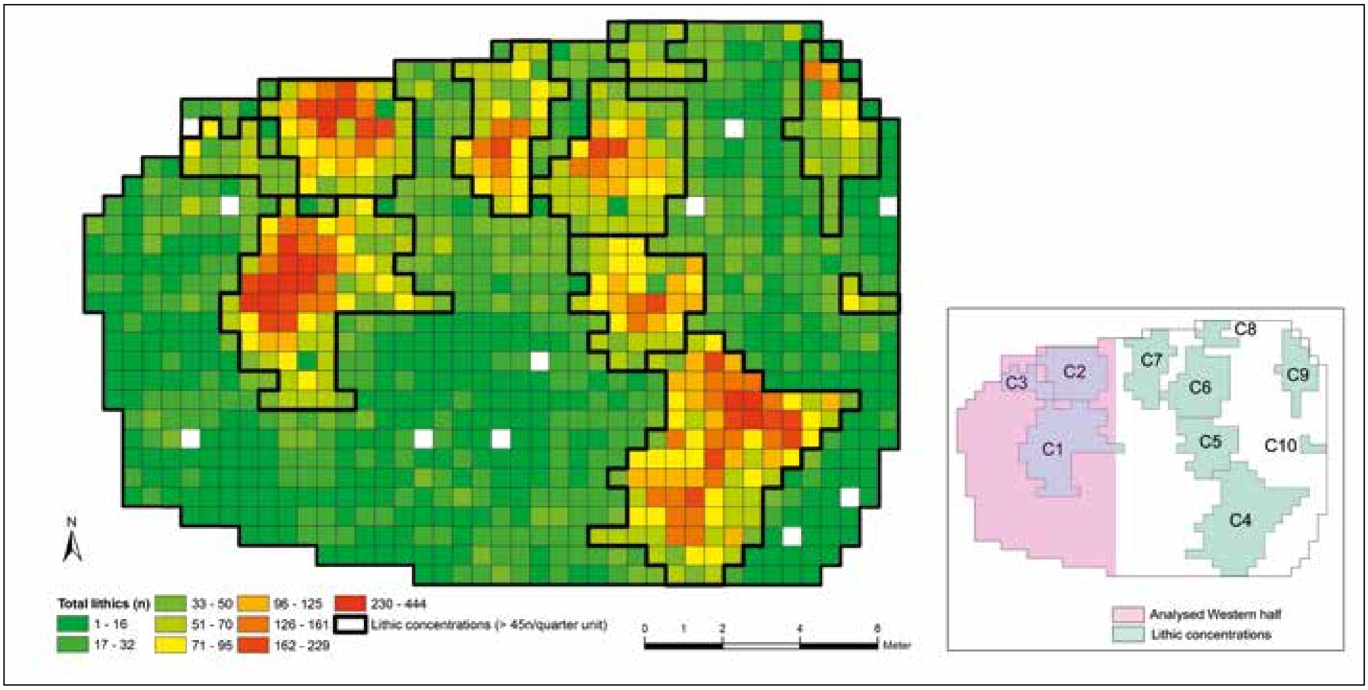

Figure 2. Distribution map of the lithic artefacts within WP1 at Bazel. Small inset map: numbering of the individual artefact clusters.

-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 cm^2) 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 5th 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 timespans 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 5th millennium cal BC, while from -30 cm onwards the chronology shifts to the 8th 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 8th and 5th 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 5th 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 5th millennium cal BC, while in the upper 10 cm they belong to the first half of the 4th 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 (8th millennium cal BC) and those from the Late Mesolithic to the Middle Neolithic (late 6th to mid-4th 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.

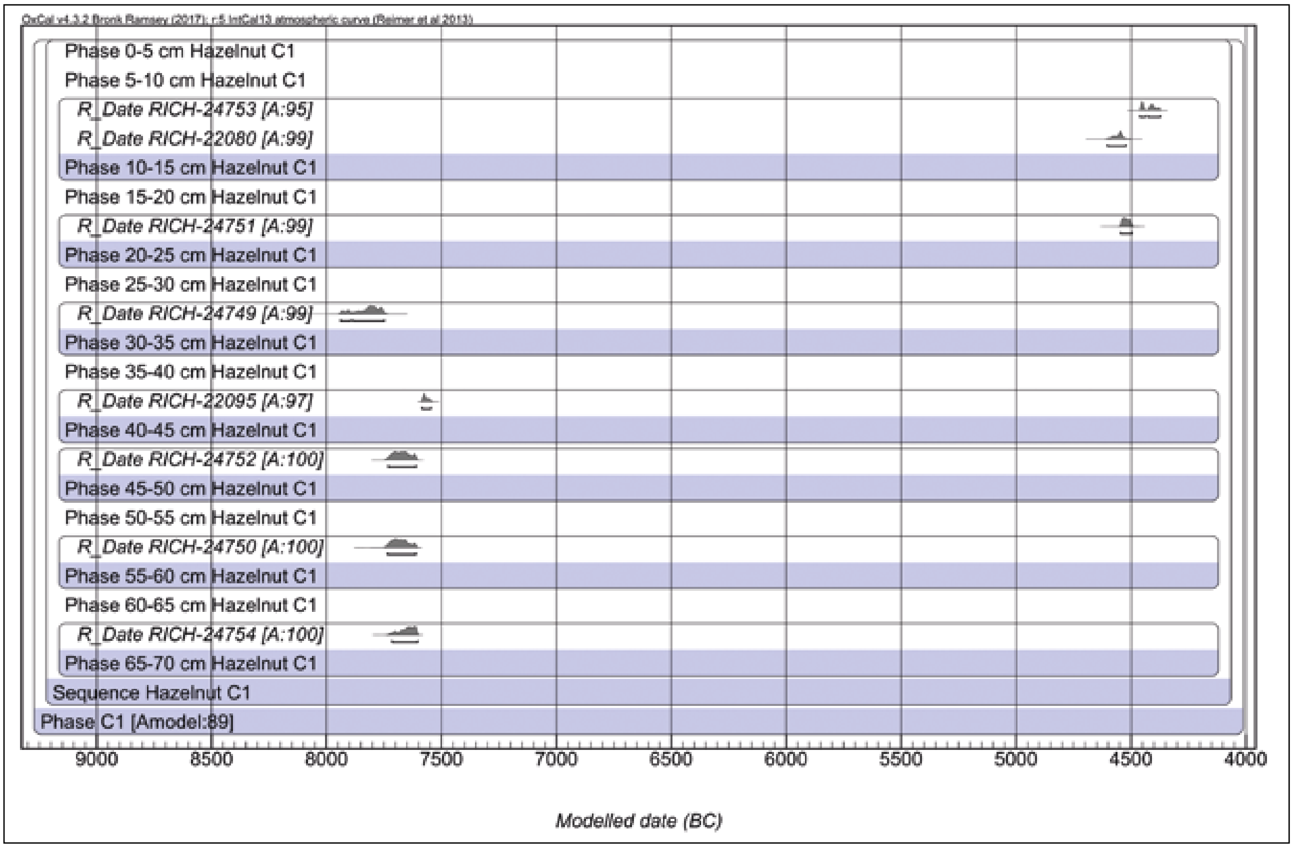

Figure 7. Bayesian model of the dates on charred hazelnut shell from artefact cluster C1.

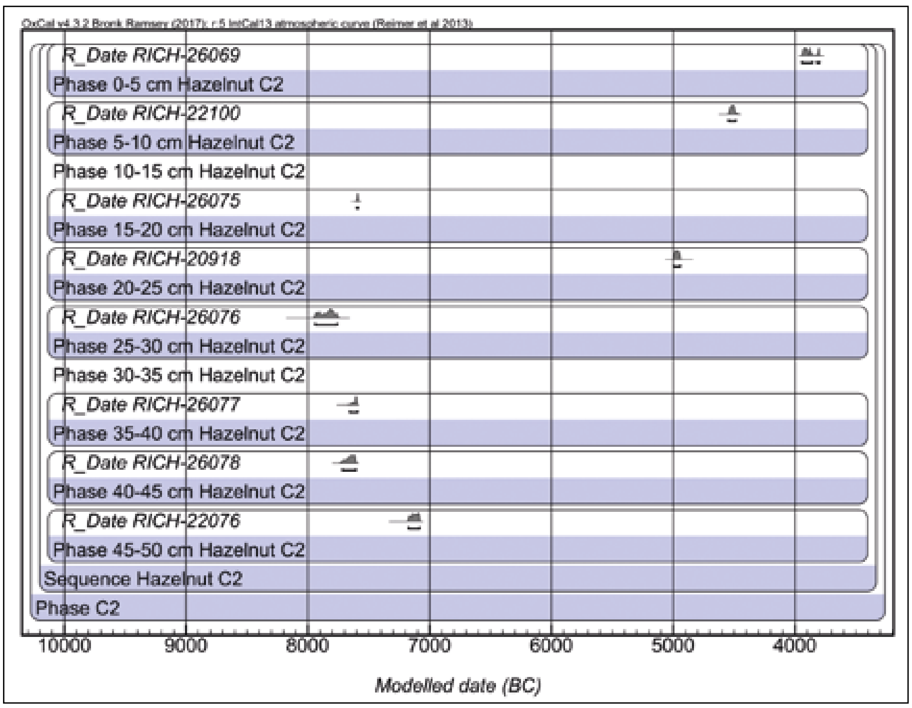

Figure 8. Bayesian model of the dates on charred hazelnut shell from artefact cluster C2.

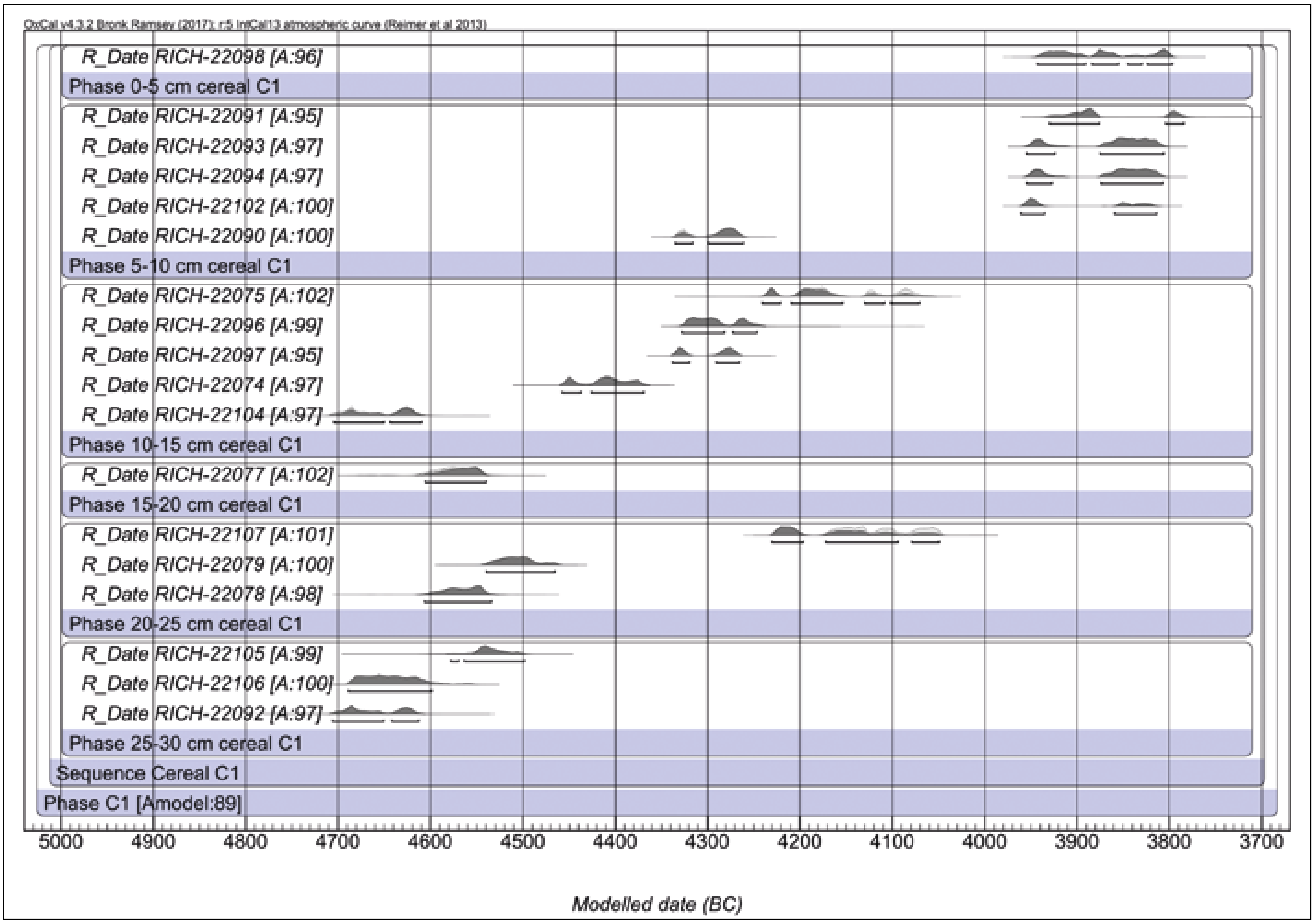

Figure 9. Bayesian model of the dates on carbonized cereal grains from artefact cluster C1.

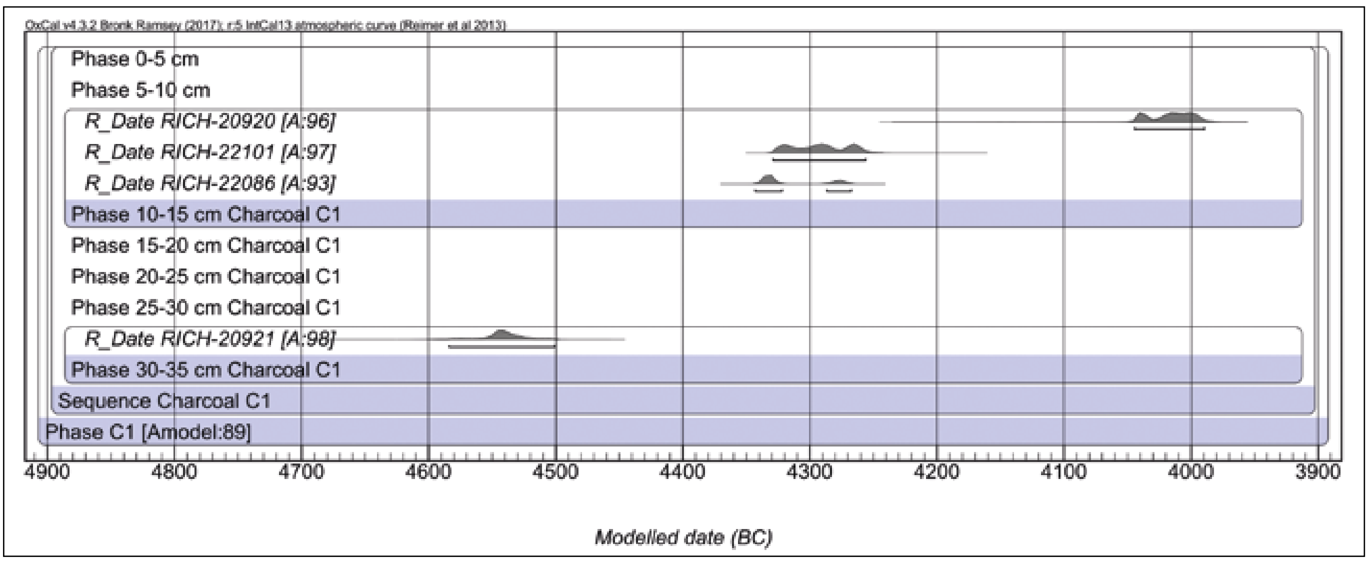

Figure 10. Bayesian model of the dates on charcoal from artefact cluster C1.

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.

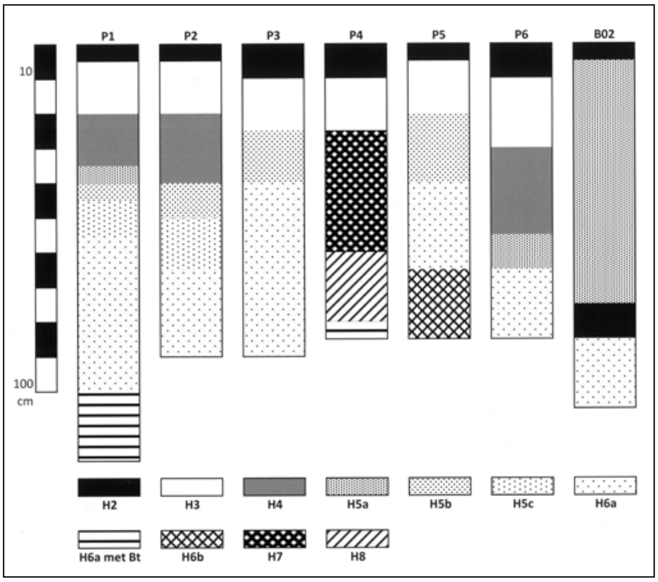

Figure 11. Schematic representation of the soil stratigraphy at Haelen; P1 to P4 profiles are situated within the limits of the archaeological site; P5-P6 and B02 are profiles from the surrounding area (from Bats et al., 2010, fig. 19). H1: topsoil; H2: dark grey-brownish A-horizon; H3: humiferous AE-horizon 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 4^{th} 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).

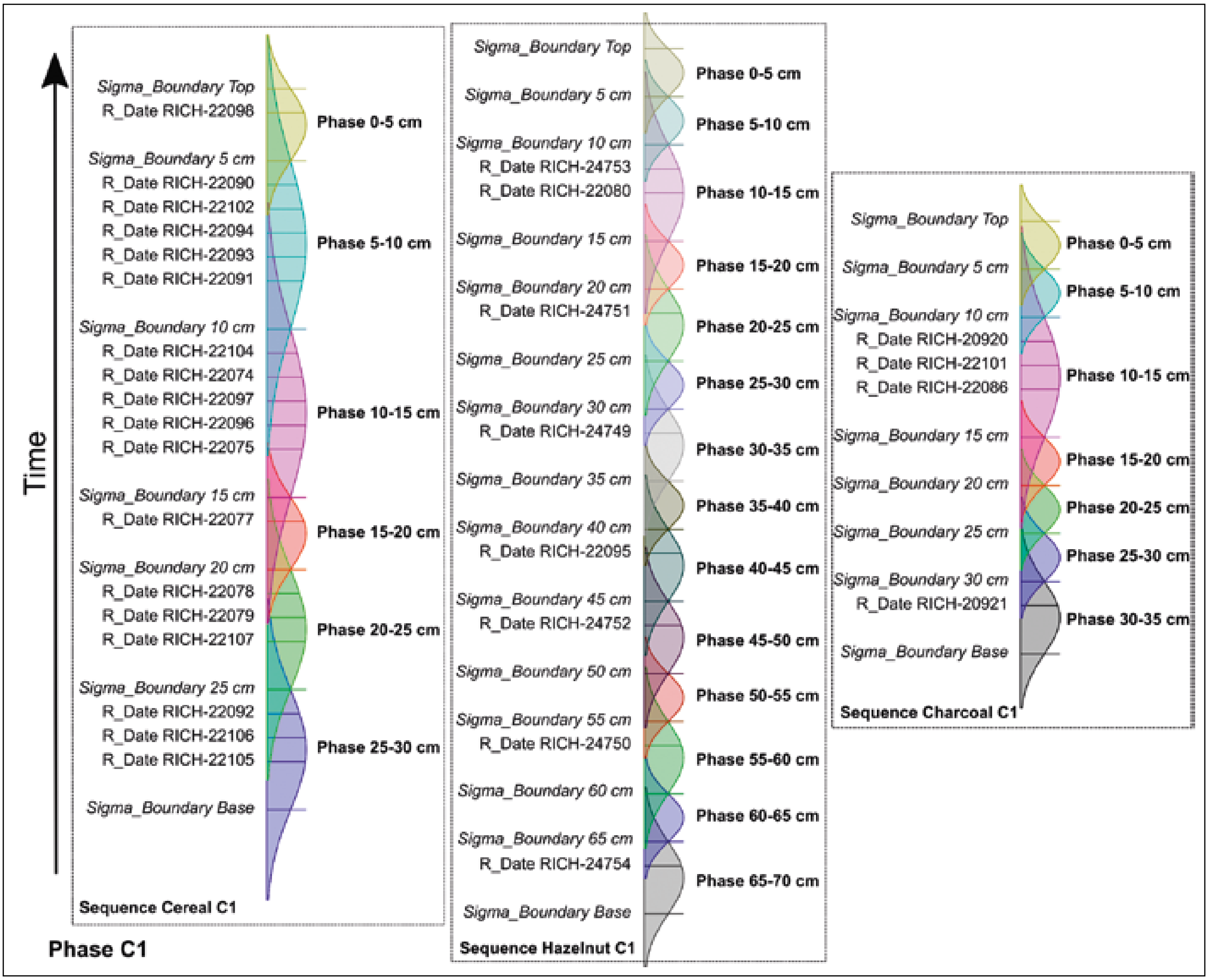
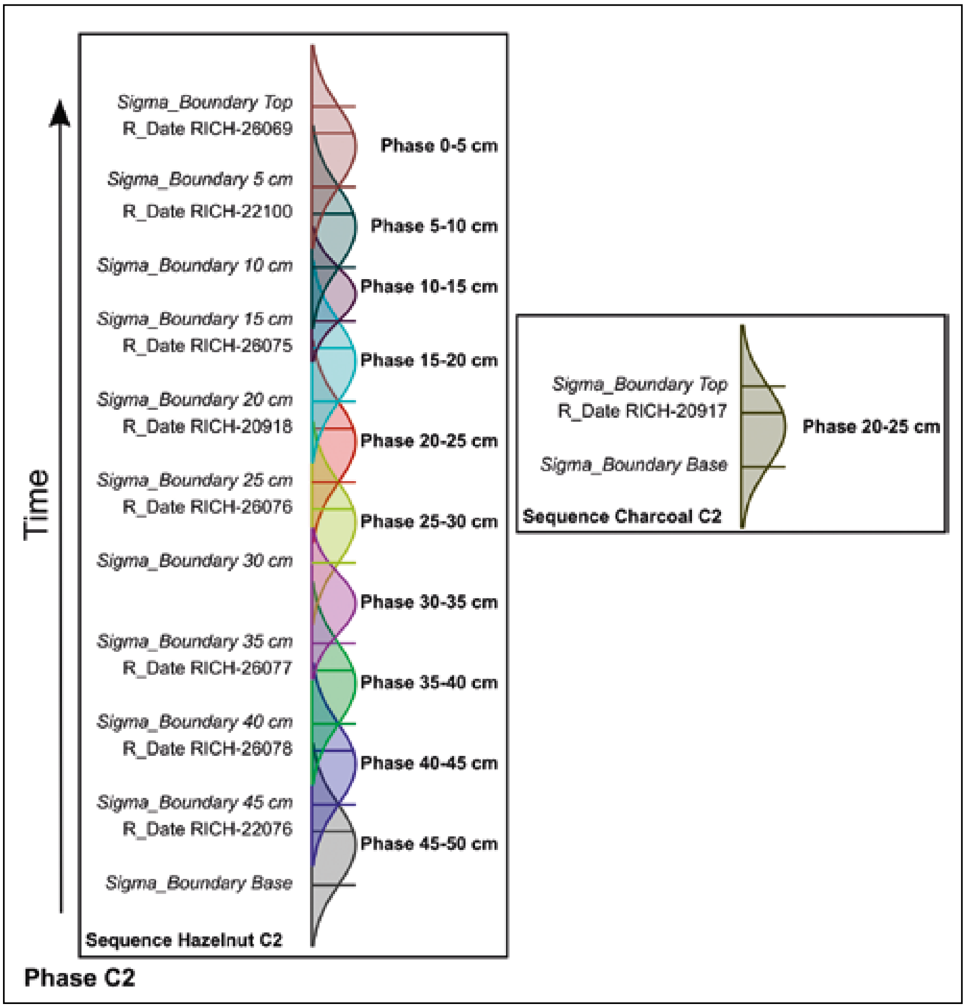


Figure 15. Schematic relationships of prior beliefs and dates from C1 at Bazel.

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



LES FAUX POTEAUX PLANTÉS

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RESUMÉ
Pour un archéologue, une pièce de bois dans le substrat, en positon verticale ou légèrement incliné, est un « poteau », d'autant plus quand le bois est conservé et apparaît régulier et aménagé. Ce véritable dogme archéologique a du mal à être battu en brèche et son identification alternative comme une simple branche enfoncée dans le sol, n'est que rarement envisagé et généralement exclue par maintes archéologues. Vingt ans après il est donc plus que jamais utile, au moins pour les archéologues, de décrire ces structures. Nous discutons également de l'intérêt potentiel de ces branches, qui s'avèrent extrêmement courantes en plaine alluviale, pour d'autres types d'étude.

MOTS-CLÉS
archéologie, dendrochronologie, poteau planté, chêne, branche enfoncée, faux poteau planté, pseudo trou de poteau

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1. Introduction

Roger Langohr n'a pas seulement révélé aux archéologues ce que l'étude des sols pouvait apporter à la compréhension des sites archéologiques dans leur environnement, il a eu aussi un rôle déterminant dans la reconnaissance et l'identification de certains types de structures, considérées, à juste titre ou non, comme anthropiques ou naturelles. L'exemple le plus symptomatique étant celui du (trou de) poteau, étudié depuis plus d'un siècle par des milliers d'archéologues qui ne supportaient pas de contestation dans leur champs d'expertise par excellence puisque pour tout archéologue qui se respecte, reconnaître un poteau est la base du métier… C'est ainsi que le site de Vendresse (Ardennes, France) a été le théâtre d'une révision d'un dogme archéologique en 1998. En effet, on avait profité de la présence de Roger pour lui présenter des poteaux un peu particuliers qui nous intriguaient ; devant l'hilarité générale, Roger les avaient identifiés comme des branches (naturelles) enfoncés dans le sol.

2. Vendresse

Ce site est situé dans la vallée de la Bar, un affluent de la Meuse, à une vingtaine de km au sud-est de Charleville-Mézières. Par la conservation exceptionnelle des bois de construction (Laurelut et al., 2000, 2002 et 2018, pour une bibliographie plus complète) le site est une référence européenne pour la fin de l'âge du fer mais recèle aussi d'importants vestiges (organiques) du Néolithique récent, du Bronze final, du Premier âge du fer et du début de l'Epoque romaine.

Les empreintes des poteaux de Vendresse ne se distinguent que difficilement lors du premier décapage, effectué un peu au-dessous du sol de l'époque. Autant que la lecture des traces était difficile à ce niveau, autant que l'identification des bois conservés devenait évidente à un niveau plus bas, dans une argile très plastique et saturée d'eau. Parmi ces milliers de bois de chêne, toutes époques confondues, il y avait une grande variété, à la fois dans leur forme, taille et position. Certains étaient coupés à

Figure 1. Vendresse (Ardennes). Branche enfoncée.
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Figure 2. Vendresse (Ardennes). Branche enfoncée d'un hêtre.
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Figure 3. Vendresse (Ardennes). Détail d'une branche enfoncée.
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leur base et placés dans de grandes (ou parfois petites) fosses de creusement, d'autres, plus rares, étaient appointés (et enfoncés?). En général, ils étaient en position verticale mais il y en avait aussi dans une position inclinée, d'un angle de l'ordre de 15 à 25°. L'analyse des plans d'ensemble de ces poteaux et leur datation dendrochronologique a permis d'identifier sans ambiguïté des constructions et de proposer des types architecturales, y compris pour les poteaux inclinés (Laurelut et al., 2007).

Pour ce qui est des bois concernés ici (Fig. 1-3), tous en chêne, sauf un hêtre, sur le terrain, en première approche, ils ne se distinguaient par des autres bois de construction; des caractéristiques assez anodines avaient certes été remarquées mais sans qu'on fasse toutefois le lien entre elles à ce stade. Ces bois ont une section ronde d'une bonne dizaine de cm (comme presque tous les autres trouvés depuis) et étaient légèrement courbés, en position subverticale ou carrément incliné, avec la « pointe » vers le bas et brisée. Les mieux conservés étaient à plus d'un mètre de profondeur par rapport au décapage archéologique et à environs 1,5 m par rapport à la surface d'origine. Au premier abord, c'est la courbure et la différence de couleur avec les bois (de construction) qui avaient été remarquée : un brun très foncé, avec une teinte un peu rougeâtre face à un noir homogène, caractéristique, toutes époques confondues, de tous les bois de construction sur ce site.

3. L'identification des faux poteaux plantés

Des différences supplémentaires ont été découvertes pendant les études. Ces « poteaux » ne s'intégraient pas dans des plans de bâtiments, comme la plupart des bois de construction. Les datations dendrochronologiques ne s'avéra pas évidente (cf. ci-dessous), malgré un nombre de cernes conséquent, et il apparaissait aussi qu'il s'agissait de bois de tension caractéristique pour des branches : une croissance excentrée (la moelle n'étant pas au centre) avec des petits vaisseaux pour le bois du printemps et aussi une croissance tordue. Des datations radiocarbones ont finalement permis de les attribuer à une même époque, correspondant *grosso modo* à la fin de l'époque romaine, période non représentée sur le site (à l'exception de quelques monnaies).

La teinte différente provient des propriétés physiques et de la composition différentes entre les branches et le tronc ; puis, la « pointe » brisée orientée vers le bas, ainsi que le diamètre, s'expliquent par la chute (violente) et par la grosse pression effectuée, éventuellement sur une longue durée, sur la branche, par le tronc d'arbre. De plus celui-ci est souvent en équilibre instable après sa chute et les coups de vent provoquent de petits mouvements qui peuvent durer des années jusqu'à ce que les branches se détachent du tronc par pourrissement. Il s'est avéré aussi qu'un des rares hêtres du site était aussi une branche enfoncée (Fig. 2, 3).

Tous ces éléments ne laissaient plus de doute sur l'interprétation.

4. Une idée mal acceptée par les archéologues

Depuis maintenant plus de vingt ans, nous faisons amende honorable en diffusant largement cette connaissance, notamment en présentant régulièrement des images dans les colloques, mais souvent face à la même hilarité. Il y a toutefois un début d'acceptation ces dernières années dès lors qu'on arrive d'abord à présenter les arbres actuels avec leurs branches en cours d'enfoncement (cf. aussi Langohr, 2010), puis les bois conservés comme ici à Marcilly-sur-Seine (Fig. 4 a-d) (Cartron, 2018).

En revanche pour ce qui est des traces laissées par ces branches non conservés dans le sol, le discours a toujours du mal à être accepté. Par ailleurs, la description des poteaux plantés est de plus en plus considérés comme superflue (comme l'identification est considérée comme définitivement acquise). Le cas de Vouziers (Galland et al., 2014) a ainsi été très significative : de multiples traces, sans mobilier et avec des datations incohérentes ont été interprétées à tout prix comme des constructions sans jamais produire un seul poteau ou construction réellement prouvé.

Il reste donc nécessaire de décrire ces structures et de souligner leur fréquence, comme nous le faisons dans cet article.

5. Des branches omniprésentes en vallée alluviale : quel intérêt ?

Ces branches, dont le bois est souvent conservé dans des plaines alluviales ou dans des sites humides sur le plateau, s'avèrent en définitive une source rare, avec un potentiel pour de nombreuses recherches. En effet, les bois utilisés jusqu'à ce jour pour des recherches diverses proviennent essentiellement de chenaux qui contiennent certes de nombreux arbres mais sont assez rares à certaines époques puisque dépendant de l'activité fluviale qui est très variable.

C'est ainsi que dans le programme de recherche sur les bois subfossiles tardiglaciaires et holocènes dans le Nord-est de la France, que nous menons avec Willy Tegel depuis bientôt 30 ans, des centaines de troncs provenant

Figure 4. Branches enfoncées à Marcilly-sur-Seine (Aube).
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de chenaux ont pu être intégrés. Initialement conçu pour la constitution de référentiels dendrologiques (Tegel, 2011, 2013, 2018) ceux-ci sont devenus depuis une quinzaine d'années source de multiples autres recherches et applications : dynamique fluviale, relation homme-vallée, paléoclimat et toute une série d'applications inattendues qui ne cessent de se développer, comme par exemple le cycle du hanneton ou encore l'origine et diffusion des différentes (sous-)espèces à travers les études génétiques particulièrement prometteuses sur le bois subfossile.

Dans la pratique, nous récupérons chaque année des dizaines d'échantillons de chêne et de pin, notamment dans les gravières (Fig. 5), pour établir progressivement ces référentiels (Tegel et al., 2013, 2016, Tegel and Vanmoerkerke, 2018). La première étape consiste à les mesurer et à constituer si possible des petites séquences flottantes pour lesquelles une hypothèse de datation dendrochronologique peut éventuellement être proposée. Dans la deuxième étape, des datations radiocarbones sont effectuées pour confirmer, ou informer l'hypothèse ou pour avoir une première idée de la datation de la séquence dans une fourchette potentiellement très longue, de 10 000 ans pour le chêne et de 13000 ans pour le pin. La troisième étape consiste à raccorder petit à petit ces séquences flottantes, en y intégrant bien évidemment les séries « archéologiques » parfois très riches pour certaines phases, mais parfois inexistantes (encore) pour d'autres phases.

Ces référentiels sont aujourd'hui statistiquement (couverture annuelle < 100) établies jusqu'à 400 avant notre ère et des séquences longues mais discontinues (ou non assurées) existent jusqu'au 6e millénaire. De multiples autres échantillons de pin couvrent la fin du tardiglaciaire

Figure 5. Périgny-la-Rose. Troncs subfossiles, gravière. © Jan Vanmoerkerke, SRA.

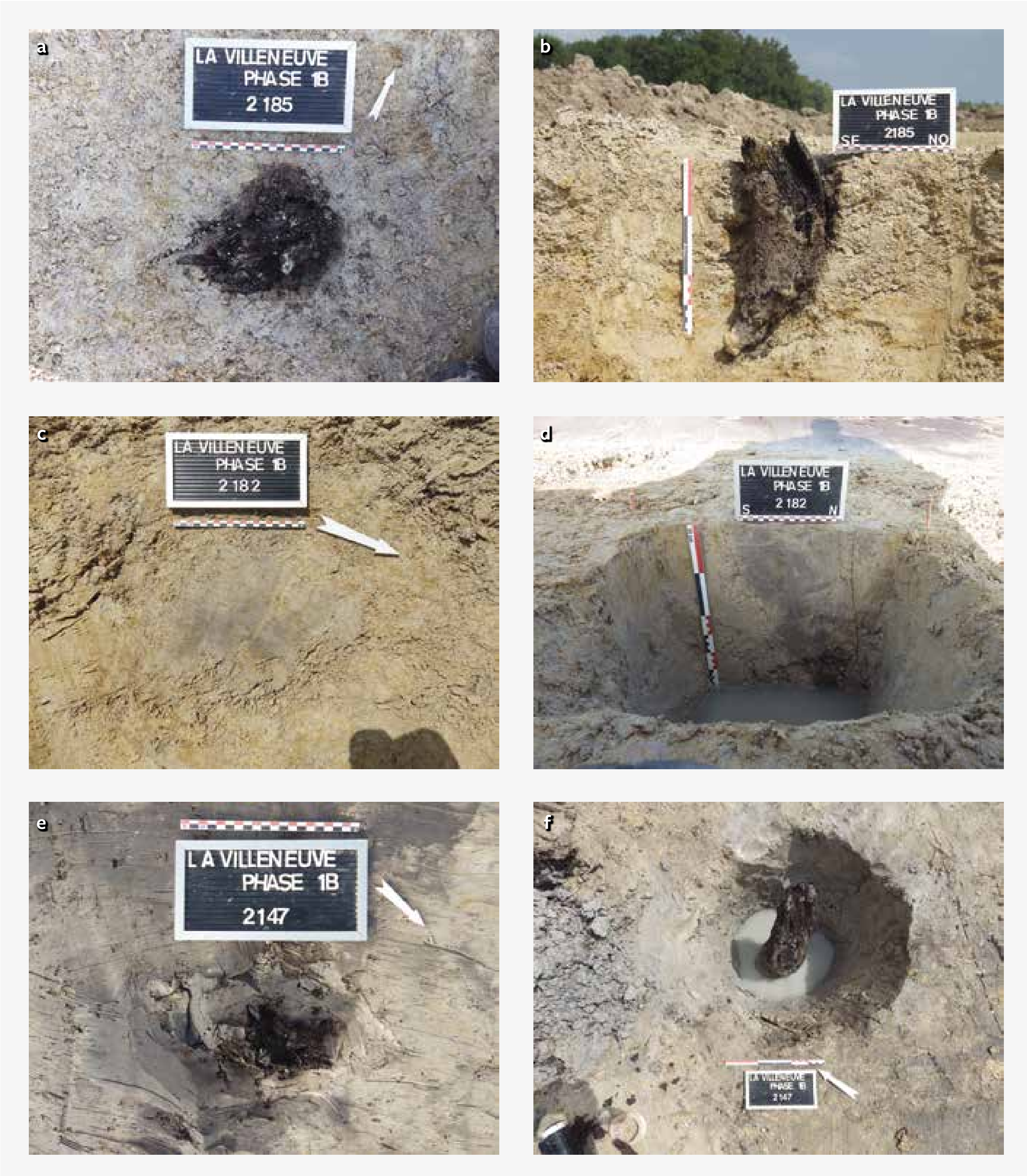

Figure 6. Branches enfoncées à La-Villeneuve-au-Châtelot (Aube) (Ferrier and Ravry, 2017). A gauche, après décapage, à droite, dégagée. © Antoine Ferrier, Evéha.

et le début du holocène et des échantillons de chêne le boréal et le début de l'Atlantique, mais sont encore trop peu nombreux pour constituer un véritable référentiel. Lors de ce travail, les troncs récupérés, généralement hors contexte (Fig. 5) sont, en grande partie, le reflet de l'activité fluviale et documente ainsi souvent les mêmes phases.

Ce n'est pas le cas pour les branches enfoncées (Fig. 6 a-f) qui se retrouvent seul ou en petit groupe et dont on ne connaît pas encore la dynamique de « dépôt ». En tout cas, ce sont les rares bois disponibles pour les époques non ou peu documentés par les troncs subfossiles ; de plus, contrairement aux bois subfossiles, ils permettent de localiser précisément les lieux de croissance.

6. Conclusions

Les faux poteaux plantés sont un bel exemple d'une approche interdisciplinaire, la seule à même de contester, puis expliquer, de fausses certitudes établies par des chercheurs certes de haut niveau mais cherchant trop systématiquement des explications dans leur propre domaine. Ils démontrent aussi l'intérêt d'une autre recherche, sans but initial précis et tout aussi interdisciplinaire où ses branches se révèlent être, à certaines époques, les rares témoins, avec bois conservé.

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FEUX AGRICOLES, DES TECHNIQUES MÉCONNUES DES ARCHÉOLOGUES

L'apport de l'étude archéopédologique des résidus de combustion de Transinne (Belgique)

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RESUMÉ
Les feux de végétation naturels ou anthropiques produisent des écofacts qui peuvent perdurer à l'échelle plurimillénaire dans les sols et les sédiments. Les charbons de bois micro- et macroscopiques sont ainsi employés comme marqueur paléoécologique (pédoanthracologie) ou dans l'étude de l'histoire des feux (charbons sédimentaires). La question de la détermination de l'origine, naturelle (climatique) ou anthropique (agropastorale, accidentelle), reste toutefois délicate à l'échelle de chacun des événements des paléo-feux. Parallèlement, la découverte de résidus de combustion, dans des horizons de sols anciens ou le comblement de dépressions naturelles (chablis) est souvent expliquée par les archéologues comme le fait de brûlis anthropiques du couvert forestier ou de feux affectant les souches des arbres. Toutefois, les hypothèses favorisées dans les interprétations archéologiques, concordent peu avec les pratiques de feux agricoles présentes dans la documentation historique des agronomes. De plus, certaines techniques qui possédaient une relative importance à l'époque Moderne ne sont quasiment jamais mentionnées. C'est notamment le cas de l'écobuage, qui au sens classique, fait référence à une technique de préparation du champ, qui procède par une extraction de la couche superficielle du sol, dont les mottes servent à la réalisation de fourneaux de combustion. Des résidus de combustion potentiellement liés à des feux anthropiques, signalés dans un horizon de sol par Roger Langohr et échantillonné avec lui par Kai Fechner, dans le contexte de la carrière de Transinne (Belgique), font l'objet d'une analyse micromorphologique, anthracologique, et de cuissons expérimentales contrôlées. Ces résultats sont interprétés en fonction des connaissances des processus de combustion des feux naturels et agricoles.

MOTS-CLÉS
écobuage, essartage, agriculture, incendie, rubéfaction, pédoanthracologie, spectrocolorimétrie

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1. Introduction

L'hypothèse que les premières agricultures pratiquées en Europe tempérée reposent sur l'usage du feu est relativement ancienne (Childe, 1929 ; Iversen, 1956) et encore souvent reprise dans la littérature archéologique (Mazoyer et Roudart, 1997 ; Guilaine, 2015). La persistance de ce modèle peut s'expliquer par plusieurs considérations relatives aux écosystèmes passés (potentiel agronomique des sols, milieu forestier contraignant) et aux moyens techniques des sociétés anciennes pour leur exploitation (par ex. nature et type d'outillage aratoire). Mais également par l'existence d'un comparatisme ethnographique plus ou moins implicite (Hodder, 1980), qui associe les agricultures dites itinérantes sur brûlis des régions forestières tropicales humides à des pratiques rudimentaires, en dépit des nombreux travaux des ethnologues et géographes sur la question (Barrau, 1971 ; Dounias et al., 2000 ; Demaze et Manusset, 2008 ; Bahuchet et Betsch, 2012).

Les données matérielles sur lesquelles repose cette hypothèse sont toutefois largement discutables. D'une part, les marqueurs paléo-environnementaux employés en ce sens sont largement ubiquistes et il est particulièrement difficile de distinguer leur origine naturelle ou anthropique (Robin et al., 2015; Canti, 2017). C'est le cas des études portant sur les restes carbonisés en milieux sédimentaires stratifiés, qui constituent actuellement la principale source de données pour discuter des régimes (fréquence et intensité) des paléo-feux (Power et al., 2008). C'est également le cas des travaux portant sur les charbons de bois en contextes pédo-sédimentaires (pédo- et géo-anthracologie), qui impliquent une grande prudence dans l'interprétation de l'origine de ces écofacts (Robin et al., 2015). D'autre part, les données archéologiques utilisées dans ce débat sont limitées car elles ne représentent pas des indices directs de l'activité agricole, et les modèles proposés sont trop réducteur vis-à-vis des réalités anthropologiques (Jacomet et al., 2016 ; Pétrequin et al., 2016). Par exemple, la mobilité résidentielle est souvent confondue avec l'itinérance agricole, et il est tout à fait probable que différents systèmes agricoles aient coexistés à une échelle régionale voire à l'intérieur d'un même groupe humain. Aujourd'hui, les arguments soutenant ou non ce modèle, entre autres les expérimentations d'abattis-brûlis et les données carpologiques intra-site, sont l'objet d'un vif débat (Bogaard, 2002 ; Schier et al., 2013 ; Jacomet et al., 2016 ; Rösch et al., 2017 ; Halstead, 2018).

Le feu, par les modifications physico-chimiques qu'il provoque, permet la fabrication de marqueurs archéo-environnementaux qui peuvent perdurer longtemps. Son emploi dans le cadre d'itinéraires agricoles est donc susceptible de présenter une visibilité archéologique non négligeable. Mais, si des mentions de structures assimilées à des vestiges de feux agricoles sont fréquentes dans la littérature géoarchéologique (Guilaine, 1991), ces découvertes font rarement l'objet d'une attention particulière (Guiblais-Starck et al., en préparation). La question des indices microscopiques potentiellement liés à de tels feux est quant à elle déjà discutée depuis plusieurs dizaines d'années par les micromorphologues (Macphail et al., 1990). Toutefois, le modèle d'interprétation le plus courant, celui de feux liés à des souches d'arbres (Goldberg et Macphail, 2006), n'apparait pas dans la littérature technique et agronomique moderne (Barrau, 1972 ; Portères, 1972). De plus, le sens accordé aux différents termes renvoyant aux feux agricoles n'est pas toujours précisé ou présente souvent des incohérences envers les définitions techniques (Sigaut, 1975). Aussi, l'écobuage au sens classique, qui possédait une relative importance à l'époque moderne, est totalement absent des hypothèses envisagées. Cet état de fait semble pour partie lié aux confusions qui peuvent apparaitre à travers certaines archives historiques (Burri, 2017) et à des glissements sémantiques plus ou moins récents (par ex. écobuage employé au sens de brûlis pastoral ; Ribet, 2009). Pourtant, ces problèmes terminologiques ont été soulignés a de multiples reprises depuis bientôt 50 ans (Barrau, 1971 ; Portères, 1972 ; Sigaut, 1975 ; Grenand, 1996 ; Ribet, 2009 ; Dumez, 2010). Afin de pouvoir identifier les indices archéologiques potentiels de ces feux, il est donc nécessaire de les étudier en terme de techniques (Sigaut, 2012) : soit de connaitre quelles sont les modalités de ces feux (structure et fonctionnement), et à quels problèmes leur emploi répond (fonction) ?

L'objectif de cet article, est d'attirer l'attention sur la nécessité de considérer les feux agricoles d'un point de vue technique et systémique. Après un bref état des lieux des interprétations de structures associées à de tels feux dans la recherche géoarchéologique, nous présenterons une synthèse des principales techniques de feux agricoles décrites dans les archives agronomiques et ethnographiques modernes. Les modalités de combustion de ces techniques et des feux naturels nous servent ensuite à proposer un modèle général de leurs produits. Enfin, un cas d'étude de résidus de combustion est développé et discuté vis-à-vis de cette documentation.

2. Interprétations géoarchéologiques des traces de feux agricoles

2.1. STRUCTURES ET RÉSIDUS DE COMBUSTION MACROSCOPIQUES

Bien que les résidus carbonisés (toutes archives confondues) constituent les marqueurs de feu les plus étudiés, ils ne sont pas les seuls produits de la combustion qui permettent leur caractérisation. Les transferts thermiques induits par la chauffe, peuvent entrainer des modifications physico-chimiques importantes des sols et des sédiments : mélanisation, rubéfaction, cimentation, désagrégation ou vitrification (Fechner et al., 2002 ; Mentzer, 2014 ; Mallol et Dietl, 2017). La nature et les modalités de manifestation des transformations minéralogiques dépendent de facteurs complexes, impliquant tant le contexte édaphique (texture, matière organique, quantités et formes du fer, etc.) que les spécificités des feux (type et état du combustible, etc.). La caractérisation de ces modifications via différentes méthodes (propriétés magnétiques, analyses chimiques) peut donc permettre de comprendre les évènements à leur origine. De plus, les résidus chauffés ont l'avantage de posséder une résistance mécanique et chimique supérieure à d'autres produits de la combustion (phytolithes, végétaux non-ligneux carbonisés), ce qui en fait des marqueurs pertinents à documenter (Canti, 2003 ; Villagran et al., 2017). Par exemple, la persistance des modifications minéralogiques a déjà été employée pour mettre en évidence des zones de « brûlis », via des méthodes de prospection magnétique (Marmet et al., 2002).

Le développement de l'archéologie préventive et la systématisation des opérations de diagnostic a permis la mise au jour dans différents contextes, de vestiges du feu qui ne peuvent être associés à des activités domestiques ou artisanales, soit du fait de l'absence d'indices spécifiques de telles activités (structures, mobiliers, scories, etc.), soit par l'absence même de contexte archéologique dans les niveaux concernés (espaces hors-sites). Ainsi, on trouve dans les rapports de fouille, et plus rarement dans des publications, des faits enregistrés sous ces divers termes : foyer d'essartage, foyer de déforestation ou chablis brûlé (par. ex. Bell, 1983 ; Marmet et al., 2002 ; Le Jeune et al., 2005 ; Cremaschi et Nicosia, 2012 ; Cubizolle et al., 2014). Ils sont généralement interprétés comme les vestiges d'élimination du couvert ligneux par le feu, voire d'incendies naturels affectant les systèmes racinaires des arbres. Malheureusement, ces faits archéologiques ou naturels font rarement l'objet de caractérisations approfondies qui permettraient de comprendre leur formation. Ce constat est problématique car les structures renseignées sous ces termes, regroupent en réalité des structures très différentes : à la fois des traces dont la morphologie atteste avec certitude de chablis dont le remplissage contient des résidus de combustion (Fechner et al., 2008) et, des concentrations non structurées de résidus de combustion, parfois essentiellement formées de terre rubéfiée (Blouet et Faye, 1986 ; Marembert et Prodéo, 2007). Il parait donc raisonnable de s'interroger sur l'interprétation analogue qui peut être proposée pour des faits si différents.

2.2. INDICES MICROSCOPIQUES

Si ces structures ont relativement peu suscité l'intérêt des archéologues, la question des indices microscopiques permettant d'attester de feux agricoles constitue un sujet important dans les recherches micromorphologiques (Deák et al., 2017). Cette approche est en effet particulièrement pertinente dans l'étude des produits de combustion, leur composition, leur morphologie et des processus liés à leur fonctionnement ou leur taphonomie (Huisman et al., 2012 ; Mallol et al., 2017). Ainsi, plusieurs chercheurs attestent de feux anthropiques, en s'appuyant sur la présence de résidus de combustion présents dans des paléosols (Gebhardt, 1993).

Les découvertes récurrentes de marqueurs de feu (charbon, phytolithe, cendre, sol brûlé) associés à des traces de déforestations (chablis ou traits pédologiques de perturbation assimilés) ont été employés par Goldberg et Macphail (2006) pour proposer un modèle général de technique de déforestation (Macphail et al., 1990 ; Macphail et Goldberg, 1990). Celui-ci comprend l'annélation des arbres (écorçage en anneau) pour provoquer leur mort et faciliter leur dessouchage par renversement, puis leur combustion directement sur place. Les auteurs précisent que la mise à feu de chablis naturels a également pu être entreprise de manière opportuniste, et qu'il est difficile d'attester avec certitude de l'origine anthropique de ces faits. D'autre part, Deák et al. (2017) indiquent que des traces de foyers matérialisés par des sols rubéfiés peuvent être indirectement associés à des défrichements par le feu, puisque lors de certaines expérimentations d'essartage, des foyers sont parfois nécessaires à la production de braises (Rösch et al., 2004).

3. Feux agricoles : définitions et mise en évidence archéologique

3.1. LES FEUX NATURELS

Les incendies naturels sont provoqués par la rencontre d'une source de forte chaleur (par ex. la foudre) avec un combustible, et en présence d'oxygène (Scott et al., 2014). Leur déclenchement et leur diffusion dépendent de plusieurs paramètres : le combustible (type, état, humidité, volume, répartition, etc.), les conditions météorologiques (température, précipitation, vent, etc.) et le contexte géomorphologique (topographie, hydrographie, végétation potentielle, etc.). L'interaction de ces variables est à l'origine d'une inflammabilité de la végétation et donc de régimes de feu très variables à l'échelle du globe (Power et al., 2008). Théoriquement, trois types de feu sont distingués selon la source de combustible : feu de surface (végétation de surface, litière), feu de cime (végétation aérienne), feu de (sous-)sol (horizon organique, tourbe ; Davis, 1959).

La combustion de la biomasse végétale entraine la formation de nombreux produits : charbons, cendres, suies (black carbon), aérosols et divers composés volatiles, dont une partie est incorporée et exportée dans le panache de fumée de l'incendie (Scott et al., 2000, 2014 ; Simoneit, 2002 ; Bodí et al., 2014). D'autre part, les incendies de surface peuvent entrainer des modifications physico-chimiques du sol : décomposition de la matière organique, accroissement de l'hydrophobicité, désagrégation, changements de couleur (Certini, 2005 ; Parsons et al., 2010 ; Mataix-Solera et al., 2011). Celles-ci sont en lien avec l'intensité des feux (flux d'énergie émise) et leur sévérité (impact sur l'écosystème ; Keeley, 2009), et sont, de plus, très variables d'un incendie à l'autre, mais également à l'échelle d'un même évènement, où les sol brûlés présentent l'aspect de mosaïques chaotiques (Kushla et Ripple, 1997 ; Parsons et al., 2010 ; Scott et al., 2014). En particulier, la présence de concentrations de végétaux ou de troncs et branches au sol peut entrainer une combustion à forte température mais surtout prolongée en un même point, avec des surfaces de combustion rubéfiées superficielles (Goforth et al., 2005 ; Mataix-Solera et al., 2011). Aussi, et plus rarement, ils peuvent mener à la cuisson d´éléments du sol minéral en fragments de type brique, si ceux-ci sont déjà en surface lors du feu (Mataix-Solera et al., 2011 ; Scott et al., 2014). Toutefois, à une échelle globale, ce type de modification est relativement ponctuel, car les sols possèdent une mauvaise conductivité thermique, entrainant une décroissance rapide de la température dès les premiers centimètres sous la surface (Scott et al., 2014).

3.2. L'ESSARTAGE

L'essartage (slash-and-burn, swidden/shifting cultivation) correspond à un système agraire forestier itinérant reposant sur l'emploi du feu (Fig. 1 ; Barrau, 1972). Il consiste à « abattre une parcelle de forêt, brûler le bois, ensemencer le terrain une ou quelques années avant de l'abandonner de nouveau à la forêt » (Sigaut, 1975, 18). L'essartage était courant dans plusieurs régions d'Europe jusqu'au début du XXème s. Aujourd'hui, il est essentiellement présent dans les régions tropicales, avec quelques variantes, où il correspond aux systèmes dits de culture sur brûlis, ou abattis-brûlis, pratiqués par plusieurs centaines de millions d'individus (Dounias et al., 2000). Si on relève plusieurs variantes d'exécution selon le type de milieu forestier concerné (primaire ou secondaire), l'essartage procède généralement par les mêmes grandes étapes : (1) abattage du bois, parfois concomitant à l'exploitation des écorces ; (2) séchage durant au moins une année ; (3) débitage et préparation du bois au sol, disposé en andains ou diversement ; (4) mise à feu en plusieurs points et suivi de la combustion par tirage du bois et aération, généralement contre le vent ; (5) nettoyage de la parcelle, voir rebrûlage des bois restants en tas (cherbottage) ; (6) semis dans la foulée et enfouissement au râteau ou à la herse, voire avec un araire spécifique. La mise en culture peut parfois durer quelques années, guère plus de trois ans, du fait qu'elle est tributaire de l'enrichissement apporté par l'important volume de cendres. Le travail du sol est réduit à son minimum, et bien que l'essartage s'apparente à un déboisement, il exclue strictement l'enlèvement des souches, qui seules permettront la reconstitution rapide du couvert végétal ligneux (Mazoyer et Roudart, 1997). La durée de l'abandon du terrain s'étale généralement entre une quinzaine et plus d'une cinquantaine d'années, et, est supérieure à la durée d'usage du terrain, d'où sa qualification d'itinérant. Après culture, le terrain peut également servir pour le pâturage.

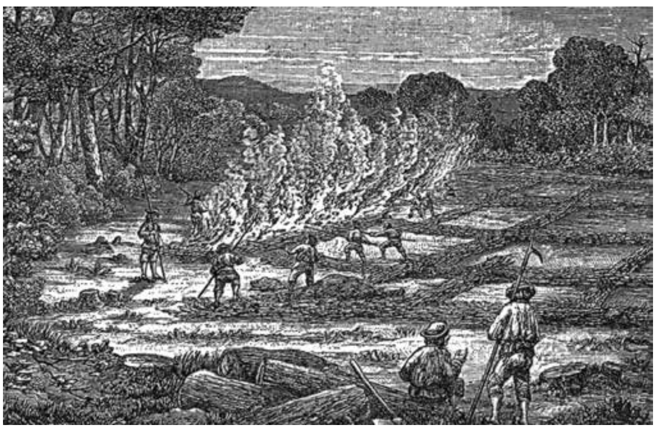

Figure 1. Détail d'une représentation d'un essartage (Dessin d'E. Rousseau, gravure sur bois, F. Depelchin, 1886, Les forêts de la France). Noter la disposition du combustible et la réserve de fûts.

Si les pratiques d'abattis-brûlis ont été abondamment documentées par les ethnologues, elles ont également suscité l'intérêt des archéologues et écologues, lesquels ont mis en place des expérimentations depuis plus de 50 ans (Iversen, 1956 ; Reynolds, 1977 ; Ehrmann et al., 2014 ; Kelm, 2014). Ces recherches visaient principalement à montrer la pertinence de l'essartage dans les régions non tropicales. Elles se sont surtout intéressées à des questions de productivité, de coût et de succession végétale. Finalement, relativement peu de travaux publiés sont disponibles concernant leurs effets physiques et produits (Ponomarenko et al., 2019), ceci certainement aussi du fait qu'ils sont assez limités comparés à ceux d'incendies sévères. En effet, le brûlage contrôlé et progressif permet d'obtenir une combustion relativement homogène, bien que les surfaces traitées puissent présenter des irrégularités, encroûtements, ré- ou désagrégations (Eckmeier, Gerlach, et al., 2007 ; Herrmann et al., 2007 ; Schulz et al., 2014 ; Thomaz, 2017). La stabilité structurale des sols peut ainsi être réduite ou améliorée, comme pour les feux naturels.

La texture de l'horizon de surface est un paramètre primordial où seuls les contextes dominés par des textures fines sont avantagés par le feu (Mataix-Solera et al., 2011 ; Thomaz, 2017). Toutefois, l'importance de la chauffe sur la cimentation des agrégats de sol n'est pas clairement établie dans la littérature (Thomaz, 2017), et la présence ou non d'agrégats de sol brûlés superficiellement pourrait s'expliquer par des modalités de combustion du feu, qui ne sont pas toujours analogues avec les procédés « traditionnels » (diamètre et disposition du bois, roulage des bûches ; par ex. Ketterings et al., 2000). Seule la réalisation de foyers adjacents aux champs essartés présente des modifications thermiques importantes (Schulz et al., 2014), que l'on devrait pouvoir comparer à celles observées par exemple sous les feux d'amas de bois (*pile-burning* ; Pastor et al., 2010 ; Smith et al., 2016). Toutefois, il n'est pas fait mention de tels foyers dans la documentation agronomique (Sigaut, 1975). Enfin, après les cendres, les charbons de bois constituent le produit le plus important de cette pratique, bien que leur quantité peut paraître relativement limitée en comparaison du volume de bois brûlé, du fait que la combustion se déroule principalement sans déficit d'oxygène (Eckmeier, Rösch, et al., 2007). Leur enfouissement partiel via l'activité biologique, en fait un marqueur indissociable de cette pratique, bien que leur variabilité quantitative et spatiale nécessite de plus amples recherches (Eckmeier, Gerlach, et al., 2007 ; Reynolds, 1977). Finalement, il nous semble que ces expérimentations d'essartage offrent des possibilités de référentiels de marqueurs environnementaux encore sous exploités pour l'étude de cas archéologiques et paléo-environnementaux (Ponomarenko et al., 2019).

3.3. L'ÉCOBUAGE

L'écobuage au sens classique se rapporte à plusieurs systèmes agricoles, dont la préparation du champ repose sur une méthode de combustion complexe du sol superficiel, par la réalisation de fourneaux (Fig. 2 ; Sigaut, 1975). Diverses variantes existent dans de nombreuses régions du globe, et des écosystèmes variés : landes, prairies denses, pâtures, zones tourbeuses ou inondées, etc. (Bouteyre, 1958 ; Guillot, 1973 ; Dzaba, 1987 ; Nzila, 1992 ; Jobbé-Duval et al., 2007). L'écobuage est attesté en France au XVIII et XIXème s. par de nombreux auteurs (Sigaut, 1975), et malgré un rapide déclin coïncidant au développement de la mécanisation agricole et des engrais chimiques, il persista très ponctuellement jusque dans les années 1950 (Portères, 1972 ; Métailié, 1999). Contrairement à l'essartage, la cyclicité culturale est plus réduite. De manière théorique, on observe (1) des systèmes de culture temporaire, où la période de friche est largement supérieure à celle de la durée d'usage de la terre, cultures et pâturages confondus, et (2) des systèmes de culture permanente ou les terres restent en usage (herbage, pâturage).

Cette pratique culturale se déroule généralement selon les opérations suivantes : (1) écroûtage, pelage de la terre ou dégazonnement ; (2) séchage de la terre et des herbes maintenues ; (3) construction des fourneaux de combustion ; (4) mise à feu ; (5) épandage des résidus, possible labour ; (6) semis, parfois directement sur les buttes de combustion non épandues. L'extraction de la couche superficielle du sol rapproche l'écobuage de l'étrépage, excepté que dans ce cas, le sol est exporté, impliquant un transfert de fertilité à l'échelle du terroir, là où l'écobuage vise à une amélioration in situ de la fertilité. Par ailleurs, en Europe de l'ouest jusqu'au XVIIIème s., le terme écobuage ne s'appliquait qu'à l'action de peler la terre (Portères, 1972). Cet écroutement peut se faire de manière très superficielle jusqu'à quelques dizaines de centimètres selon les caractéristiques des sols travaillés (matière organique, texture, réseau racinaire, etc. ; Moreau et al., 1998 ; Jobbé-Duval et al., 2007). La structure du sol prélevé (par ex. plaques de gazon ou mottes) va conditionner les structures de combustion, dont la complexité et les dimensions sont très variables (1 à 3 m de diamètre extérieur), allant de simples tas de mottes retournées à celles de véritables fourneaux où les plaques de sols font office de maçonnerie, avec porte frontale et ajout de combustible pour l'armature (Fig. 2).

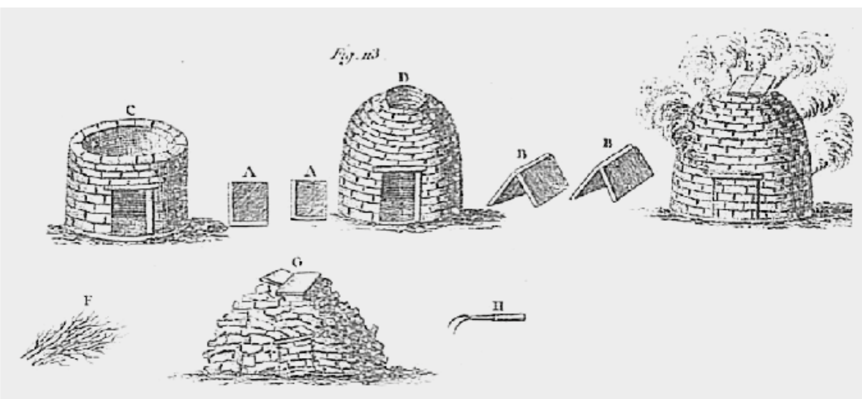

Figure 2. Extrait d'une illustration de l'écobuage vu par Duhamel Du Monceau en 1760 (Des semis et plantations des arbres, et de leur culture ; Source gallica.bnf.fr / BnF). A et B sont les plaques de gazons servant à la maçonnerie des fourneaux. Le fourneau en haut à droite (E) est en cours de combustion, et celui en bas (G) est entièrement consumé. Noter l'aménagement d'une porte et d'une ouverture au sommet du fourneau.

L'écobuage, par sa combustion lente et à couvert va entrainer une cuisson notable des mottes de sols employées pour ses structures (Fig. 3). Si leur fraction minérale et en particulier celle argileuse est suffisamment importante, ces mottes peuvent être changées en « brique » (Nicolaï, 1961 ; Jobbé-Duval et al., 2007). D'ailleurs, quelques auteurs mentionnent que dans certaines régions l'écobuage été pratiqué avant tout dans l'objectif de cuire l'argile (Portères, 1972). Vraisemblablement, selon les cas, les éléments du sol peuvent être exposés à une cuisson plus ou moins oxydante, rubéfiante ou noircissante, engendrant une plus ou moins grande hétérogénéité des buttes écobuées (Nzila, 1992 ; Jobbé-Duval et al., 2007). Par contre, les surfaces sous les structures ne semblent que peu affectées par la chauffe, de manière comparable au cas des plateformes de charbonnage (Gebhardt, 2007 ; Powell et al., 2012). Bien qu'il puisse être uniquement composé d'éléments non ligneux (Sigaut, 1975), la disposition du combustible au bas des structures en condition de basse température de chauffe (maximum de 420 °C selon Moreau et al., 1998), implique une pyrolyse limitée et une importante carbonisation de celui-ci (Chabal et al., 1999). Enfin, il faut évidemment tenir compte du fait que ces résidus peuvent être volontairement remaniés par épandage et labour, mais ici, le manque de documentation ne permet pas d'aller plus loin.

3.4. L'ESSARTAGE À COUVERT

Malgré les spécificités évidentes des deux systèmes précédents, quelques descriptions historiques documentent une pratique mixte : l'essartage à feu couvert. Il consiste en la réalisation de fourneaux, qui contrairement à l'écobuage, incluent cette fois des quantités importantes de bois, notamment des fûts, recouverts de mottes de sols (Blache, 1923). Cette technique est appliquée à des boisements fortement engazonnés, mais il est aussi possible que les deux composantes, bois et sols, proviennent de zones attenantes à la parcelle traitée (par ex. apports de rejets de coupes forestières sur des terrains gazonnés ; Blache, 1931 ; Sigaut, 1975). Ce cas possède l'intérêt d'illustrer la complexité des techniques du feu, et que de manière empirique « toutes les transitions sont possibles entre l'essartage proprement dit (à feu courant) et l'écobuage » (Sigaut, 1975). Bien que l'on ne dispose pas de documentation précise sur ces produits, on peut supposer que les mottes de terres des structures subiront des transformations au moins aussi importantes que pour l'écobuage classique. En effet, la présence de fûts et de branches va vraisemblablement entrainer une combustion à relativement plus haute température, tel qu'on l'observe pour les charbonnières (Paradis-Grenouillet, 2012 ; Powell et al., 2012 ; Dupin et al., 2017). Le combustible ligneux devrait être au moins partiellement carbonisé, selon que la cuisson des fourneaux soit réalisée intégralement à couvert, ou qu'elle implique des arrangements particuliers, comme la réalisation de creusements sous les structures pour la circulation d'oxygène (Sigaut, 1975).

Figure 3. Buttes d'écobuage après leur combustion sur les pelouses denses en cordillère de Cochabamba, Bolivie (Illustration de Jobbé-Duval et al., 2007).

3.5. AUTRES FEUX AGRO-SYLVO-PASTORAUX

Un des emplois assez commun du feu dans les itinéraires agricoles est celui du brûlage à feu courant, notamment pour le déchaumage, afin de détruire les mauvaises herbes en surface et certains parasites encore présents dans les chaumes laissés sur le terrain fauché (feu de post-récolte). Sigaut (1975) décrit également un procédé appelé brûlot qui consiste à mettre le feu à diverses plantes récoltées, séchées et mises en tas dans les champs. Par ailleurs, dans le cas des contextes tourbeux, du fait de leur richesse en matière organique, l'écobuage procède sans réalisation de fourneau, les mottes de tourbes extraites et séchées étant alors brûlées à feu courant (Sigaut, 1975). Ces exemples illustrent les formes de transition possibles entre feux courants et écobuage classique. Le feu courant occupe également une place importante dans le cadre des pratiques pastorales, dans l'objectif de l'entretien et de la régénération des pâtures : renouvellement de l'herbe, augmentation de l'appétence, lutte contre les parasites, suppression de la végétation ligneuse (Métailié, 1996 ; Dumez, 2010).

Ce sont ces feux pastoraux qui sont souvent improprement mentionnés comme écobuage (Dumez, 2010 ; Ribet, 2011). Aujourd'hui, en France, ces feux sont pratiqués dans les espaces ouverts d'altitude, herbacés à buissonnants, avec des fréquences de un à dix ans (Métailié, 1996 ; Ribet, 2011). Toujours en lien avec les techniques pastorales, il est intéressant de mentionner que d'après quelques rares auteurs, l'essartage pouvait être employé directement pour l'établissement d'une prairie temporaire (Montelius, 1953 ; Sigaut, 1975). Enfin, ajoutons que le brûlage courant et extensif n'est pas proprement une technique culturale ou pastorale, puisqu'il est utilisé dans le cadre d'activités cynégétiques, pour la favorisation ou la fructification de certaines espèces végétales (artisanat ou cueillette), ou encore pour faciliter la récolte de cultures bien précises (Bruzon, 1990 ; Dumez, 2010).

3.6. PROPOSITION D'UN MODÈLE THÉORIQUE DES PRODUITS POTENTIELS DES FEUX

Si la documentation nous manque pour certaines pratiques bien particulières, la compréhension des modalités de mise à feu permet de supposer les résidus qu'elles peuvent produire ou non. Par exemple, les feux courants de milieux herbacés, naturels ou anthropiques, sont peu susceptibles d'être identifiés dans les archives pédo-sédimentaires car ils concernent principalement une végétation non ligneuse et ils n'affectent que de manière indirecte le sol sous-jacent (apport de cendre). Toutefois, ils sont susceptibles d'être mis en évidence de manière indirecte, par le transport aérien de particules dans des réceptacles sédimentaires humides (Jensen et al., 2007 ; Courtney Mustaphi et Pisaric, 2014). La Figure 4 est une proposition de modèle général des produits potentiels de différents types de feux selon leurs modalités.

Evidemment, cette approche synthétique possède certaines limites, comme le manque de référentiels pour certaines pratiques, la non prise en compte d'autres marqueurs du feu, ou, la non considération d'évènements extrêmes ou liés à des contexte géo-climatiques précis (Fitzpatrick et al., 2014 ; Roperch et al., 2017). Elle est complémentaire à une grille de lecture plus détaillée (Guiblais-Starck et al., en préparation) et se veut comme une première proposition pour discuter des interprétations des indices micro- et macroscopiques des feux agricoles.

4. Cas d'étude : les résidus de combustion de Transinne (Ardennes)

4.1. CONTEXTE ET PROBLÉMATIQUE

L'observation de traces de combustion dans un profil au cours d'une prospection pédologique menée par R. Langohr et K. Fechner, a suscité l'intérêt de leur échantillonnage en vue d'une caractérisation. En effet, leur mise au jour dans une région ou des pratiques agricoles comme l'essartage sont relativement bien documentées dans les archives historiques, pouvait supposer un lien avec ces vestiges. Découvertes dans une carrière de kaolin en cours d'exploitation, servant régulièrement de champ d'étude pédologique (Bock et al., 2010), un prélèvement en bloc de ce sol a été réalisé. Le site est localisé à environ 2 km au nord du centre de Transinne (Fig. 5 ; Libin, 6890, Belgique), sur un sommet de plateau à environ 440 m d'altitude.

La carrière est enclavée au sein d'un important massif forestier comprenant différents peuplements, hêtraies et chênaies acidophiles, taillis de bouleaux, stades pionniers herbacés de type lande, auxquels s'ajoutent des plantations d'épicéas et de pins sylvestres d'âges variés. Sur les cartes de Ferraris (1770-1778), la localité se situe à l'interface entre une zone boisée au nord (haute futaie) et une zone ouverte (bruyère) au sud (Fig. 5a). C'est également le cas sur les cartes établies par Vandermaelen (1846-1854) et celle du dépôt de la guerre (1865-1880 ; Fig. 5b), dont la précision topographique est plus grande (http://geoportail.wallonie.be). Nous avons privilégié la caractérisation des résidus de combustion via des méthodes qui nécessiteront des analyses complémentaires, mais qui fournissent de premières informations pertinentes sur les processus de formation de ces éléments. Ce travail ne vise donc certainement pas à établir une méthodologie de référence pour l'étude de tels vestiges, mais plutôt à montrer qu'ils possèdent un intérêt notable pour les géoarchéologues.

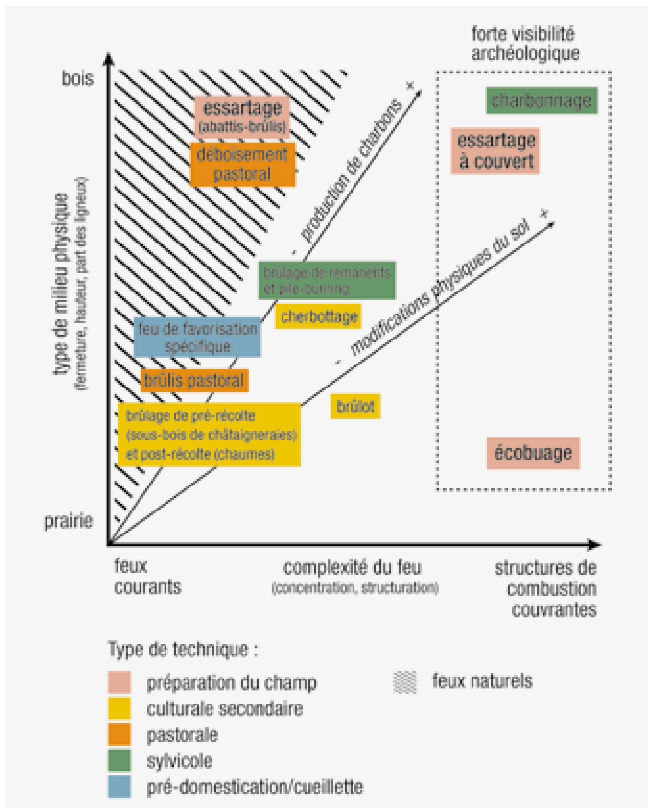

Figure 4. Synthèse théorique des modifications édaphiques induites par différents types de feu en fonction de leur milieu d'application (copyright C. Menbrivès).

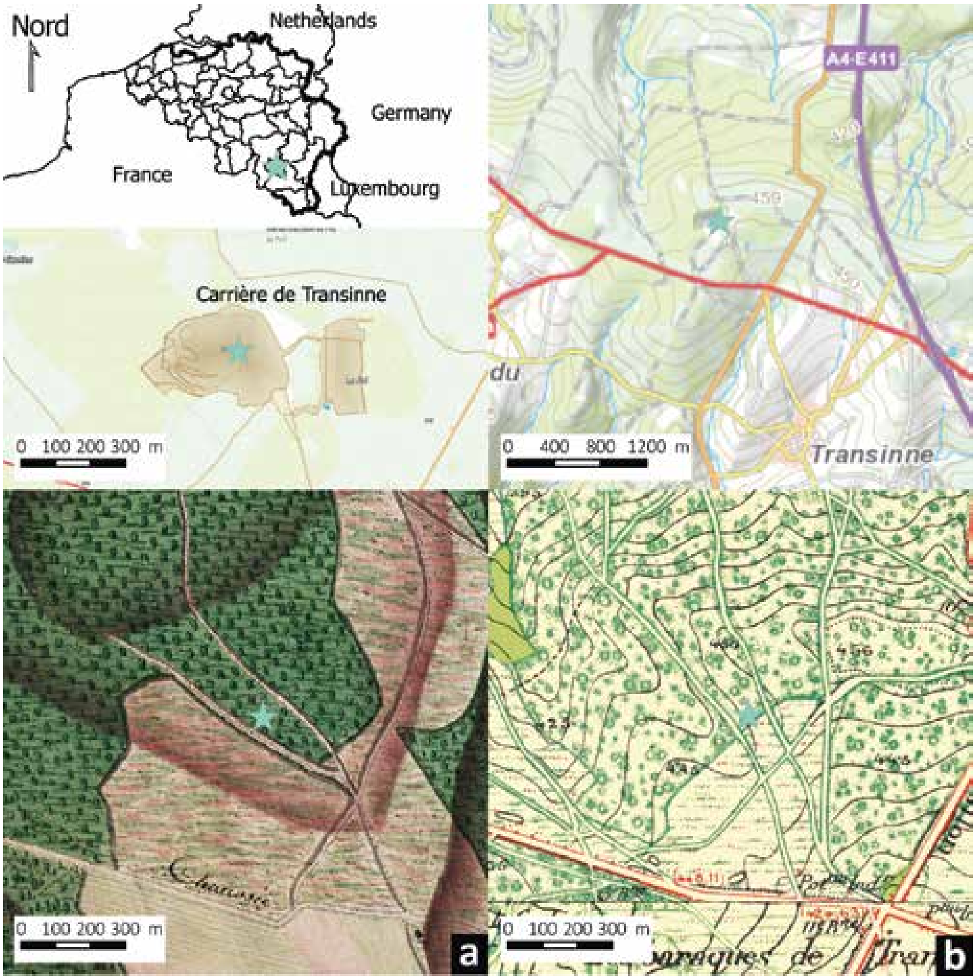

Figure 5. Carte de localisation du site d'étude (fond cartographique TOPO IGN, sources des données : SPW, http://geoportail.wallonie.be) et position approximative sur les archives cartographiques anciennes (sources des données : SPW, http://geoportail.wallonie.be) : (a) Cartes de Ferraris (1770-1778) et (b) carte du dépôt de la guerre (1865-1880).

4.2. MATÉRIELS ET MÉTHODES

Un sous-prélèvement en bloc orienté centré sur les résidus de combustion a été réalisé pour la préparation d'une lame-mince (90 x 120 mm ; Laboratory of Mineralogy & Petrology, Ghent University). L'analyse micromorphologique a été faite sur microscope polarisant (Plateforme ArchéoScopie, MA&E René-Ginouvès, Nanterre), en s'appuyant sur les référentiels géoarchéologiques des traits microscopiques (Nicosia et Stoops, 2017 ; Stoops et al., 2018). Une partie du bloc a été fouillée manuellement, selon quatre prélèvements continus partant du sommet du profil, avec tamisages successifs à 4, 2 et 1 mm. Les charbons de bois isolés ont fait l'objet d'une analyse anthracologique au microscope optique à réflexion (Laboratoire d'Archéobotanique, MA&E René-Ginouvès, Nanterre), en se basant sur les descriptions anatomiques des bois européens (Schweingruber, 1990). Des échantillons homogénéisés de terre fine (< 2 mm) ont été préparés pour la réalisation de cuissons contrôlées en laboratoire dans un four à moufle (Thermolyne). Des échantillons homogénéisés d'environ 5 g placés dans un creuset en porcelaine ont été cuits une fois durant une heure à des températures échelonnées de 50 °C entre 200 et 1000 °C. Une fois refroidis à température ambiante, deux paramètres ont été mesurés. La susceptibilité magnétique (S.M.), paramètre physique qui traduit la capacité d'un matériau à acquérir une aimantation sous l'effet d'un champ magnétique (Brodard, 2013), a été mesurée à l'aide d'un susceptibilimètre portable MS3 équipé d'un capteur MS2E (Bartington). La couleur des échantillons a été mesurée avec un spectrophotomètre (Techkon SpectroDens), avec une source d'éclairage D65. Les résultats sont exprimés dans le système colorimétrique CIE-L*a*b*, où L* représente la luminance du noir (0) au blanc (100), et les paramètres a* et b* expriment les variables chromatiques respectivement selon les axes vert-rouge et bleu-jaune

(Viscarra Rossel et al., 2006). Les réflectances du spectre du domaine visible (longueurs d'onde de 400 à 700 nm) ont également été mesurées par paliers de 10 nm. La difficulté d'isoler les éléments de terre brulée, qui présentent une faible cohérence, n'a pas permis de les quantifier (voir partie 4.3.2 et Fig. 7). Les refus de tamis ont donc été triés sous loupe binoculaire, afin d'obtenir suffisamment de résidus pour mesurer leur coloration et les comparer aux résultats des cuissons.

La coloration et les variables magnétique sont des paramètres fortement influencés par la chauffe, en particulier du fait qu'elle modifie les quantités de matière organique et la minéralogie des oxydes de fer présents. C'est pourquoi ces variables ont déjà été employées pour la caractérisation de températures de chauffe de céramique ou de sol (Mirti et Davit, 2004 ; Terefe Wondafrash et al., 2005 ; Lugassi et al., 2010 ; Rasmussen et al., 2012). L'approche testée dans cette étude est largement expérimentale d'une part du fait que nous n'avons testé qu'une partie des variables liées à la cuisson et au refroidissement du sol (Pernot et Frerebeau, 2018), et d'autre part que ces éléments de terre brûlée peuvent résulter d'une formation complexe (chauffe multiple, variabilité spatiale) et de processus taphonomiques difficiles à quantifier.

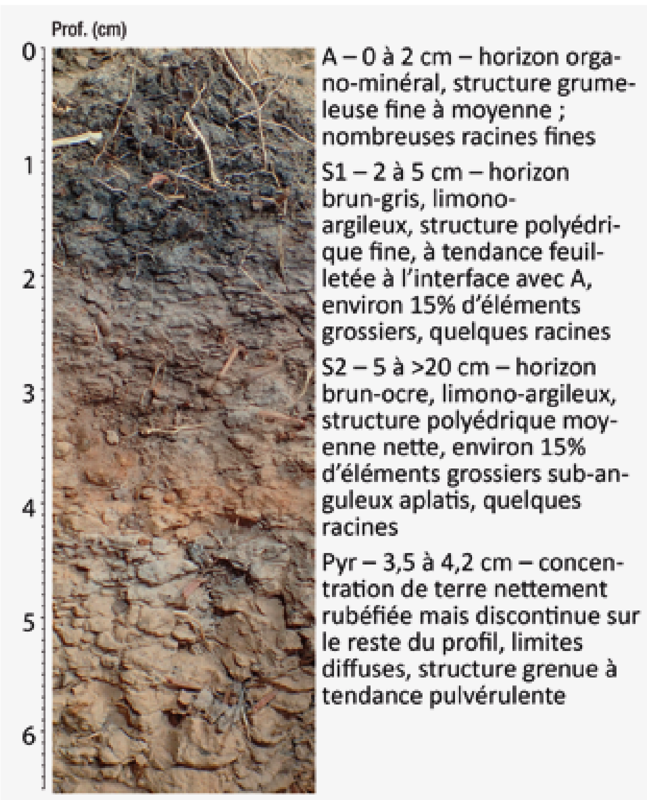

Figure 6. Photographie du sommet du profil pédologique du prélèvement présentant les traces de combustion et description des horizons observés sur l'ensemble du bloc.

4.3. RÉSULTATS

4.3.1. Observations générales

Le sol prélevé est développé à partir d'un matériau lœssique et de produits d'altération de divers conglomérats, notamment de schistes, grès quartzitiques et siltites (Bock et al., 2010 ; Dumoulin et Blockmans, 2013). Il est très peu carbonaté et présente une texture limoneuse faiblement argileuse et peu caillouteuse (charge en gravier de 10 à 20 %), impliquant une assez faible portion de sables. Sa coloration générale est brun-ocre, mais plus grise dans les premiers centimètres sous l'horizon organo-minéral (Fig. 6), qui pourrait correspondre à un lessivage encore assez faiblement exprimé. Toutefois, nous n'avons pas noté de différenciation texturale marquée, de ce fait, ce sol peut être rattaché au groupe des sols bruns acides, ou Brunisols (Baize et Girard, 2009). Ajoutons que l'étude d'un profil pédologique proche de celui étudié, a révélé dans les 30 premiers centimètres la présence de bandes subhorizontales d'argiles qui pourraient être liées au labour voire à l'ouverture du sol par des arbres incomplètement arrachés (Bock et al., 2010). A la même profondeur, de nombreux petits fragments de charbons ainsi que quelques rares fragments de terre cuite ont aussi été relevés. Le Tableau 1 présente les données générales des prélèvements du bloc étudié. La répétition des mesures de S.M. sur la terre fine homogénéisée des différents prélèvements (n=60) montre que les valeurs les plus fortes se manifestent vers 10 cm de profondeur et sont plus homogènes que celles des échantillons supérieurs et inférieurs. Toutefois les mesures directes sur le bloc montrent une grande hétérogénéité spatiale avec des valeurs ponctuelles dans les premiers centimètres de l'horizon minéral qui dépassent 1000 x 10^{-5} uSI.

Tableau 1 Données édaphiques des prélèvements de sol de l'étude anthracologique

Prélèvement	Tra5	Tra10	Tra15	Tra20
Profondeur (cm)	2-7	7-12	12-17	17-22
Masse totale (g)	211	232	330	344
Masse graviers (g)	36	20	39	31
Eau résiduelle (%)	2,20	1,90	1,61	1,52
M.O. (%)	9,25	6,17	4,90	4,16
$CaCO_3$ (%)	1,56	1,57	1,55	1,63
Fragments charbons (nbre)	90	107	22	23
Masse charbons (mg)	16,57	13,00	5,38	9,16
Anthracomasse (mg/kg ^{1})	1491	1391	118	211
S.M. moyenne (x10^{-5} uSI)	54,67	88,73	53,20	26,80
S.M. écart-type	18,04	12,45	19,05	11,12

4.3.2. Etude micromorphologique

L'observation microscopique montre la présence de résidus liés à une combustion sur la totalité de la lame-mince. Aucun agencement général n'apparait dans leur organisation si ce n'est des concentrations plus ou moins denses et étendues, surtout réparties à l'interface de l'horizon organo-minéral et les premiers centimètres inférieurs. La matrice présente des indices d'altération thermique plus ou moins marqués, dont la morphologie s'échelonne depuis des traces brunifiées diffuses, a des micro-agrégats arrondis nettement rubéfiés et bien distinct du fond matriciel (Fig. 7). Les zones brunifiées ou faiblement rubéfiées s'observent de l'échelle supra-centimétrique à millimétrique, supposant une désagrégation d´éléments chauffés relativement gros. La juxtaposition d'éléments plus ou moins fortement indurés et rougis au sein de certaines concentrations suppose des chauffes d'intensités hétérogènes, bien que toujours nettement en conditions oxydantes, ou des remaniements post-combustion. Les éléments rubéfiés ne présentent pas de différences texturales marquées avec le fond matriciel, mais certaines masses ont des microfissurations plus visibles, que l'on peut attribuer à la chauffe. A certains endroits, on remarque que ces agrégats sont associés aux bordures des fissures inter-agrégats du sol, donnant l'impression d'un important remaniement physique de ces résidus (aspect pulvérisé). Nous n'avons observé que quelques rares agrégats pédologiques infra-millimétriques carbonisés et plutôt arrondis, indiquant une chauffe en conditions réductrices. La présence assez sporadique de plages millimétriques aux limites diffuses, plus jaunes et de texture fine (avec des proportions plus faibles en quartz ; Fig. 8b) supporte l'hypothèse d'un mélange biomécanique d'agrégats de différents horizons, potentiellement liés à des labours.

Plusieurs fantômes de végétaux englobés dans des masses rubéfiées sont visibles, dont certains correspondent vraisemblablement à des organes fructifères (Fig. 8a). De plus, des charbons de bois millimétriques et de nombreuses particules opaques carbonisées infra-millimétriques, difficilement identifiables et bien intégrées dans le fond matriciel apparaissent sur toute la surface de la lame. Ces particules ne montrent pas d'orientation particulière, par contre, quelques charbons dans la partie sommitale de l'horizon minéral présentent une position subhorizontale avec des fracturations liées à une compression verticale. On observe également, associés ou non aux zones chauffés, plusieurs jeunes tiges aériennes de dicotylédones carbonisées, de taille infra-millimétrique. Enfin, de nombreux sclérotes de champignon de morphologies variées sont

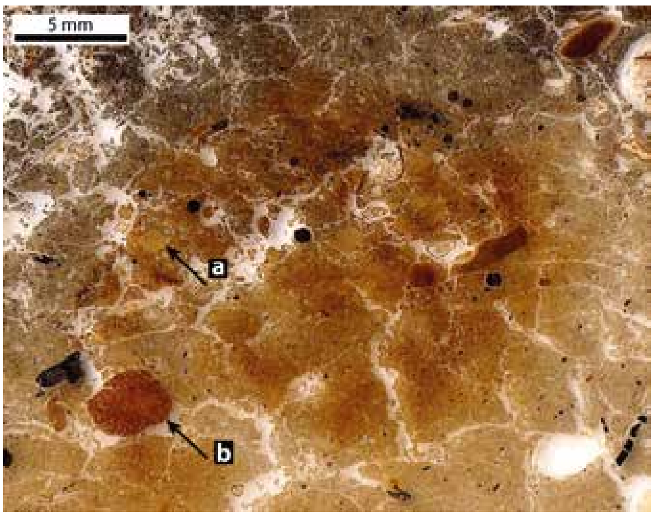

Figure 7. Vue en lame mince (scan) d'une trace circulaire rubéfiée diffuse correspondant à un agrégat centimétrique brûlé en cours de désagrégation, tels que ceux observés lors de la fouille du bloc et difficilement individualisables. L'hétérogénéité des colorations au sein de cette masse et la présence d'agrégats millimétriques de coloration nettement différenciée (a) suggère l'existence de remaniements mécaniques de différents horizons lors de sa formation. (b) Agrégat pédologique millimétrique nettement rubéfié et distinct du fond matriciel.

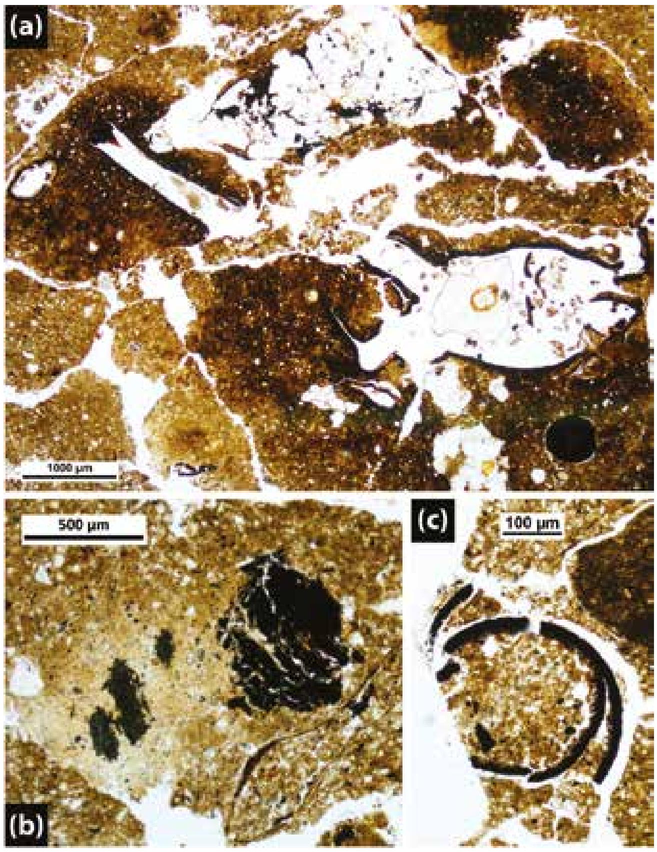

Figure 8. Photographies de quelques traits microscopiques observés en lame mince (PPL). (a) Reste végétal pris dans une masse de terre fortement rubéfiée en désagrégation, en bas à droite sclérote de champignon carbonisé. (b) Matière organique carbonisée amorphe dans une micro-plage de texture fine intégrée dans le fond matriciel. (c) Paroi externe d'un sclérote carbonisé.

présents. Plusieurs sont carbonisés et présentent encore une structure interne, mais d'autres éléments correspondent certainement à des parois externes de sclérote plus ou moins désintégrés (Fig. 8c), ce qui pourrait indiquer des températures de combustion de l'ordre de 550 °C mais aussi plus basses (Scott et al., 2010).

4.3.3. Etude anthracologique

Les charbons de bois, peu visibles en coupe, se révèlent relativement abondant au tamisage. Les deux prélèvements supérieurs montrent des anthracomasses comparables et nettement plus élevées que ceux réalisés plus bas (Tableau 1). L'analyse a porté sur 242 charbons, presque tous inférieurs à 2 mm de diamètre, rendant l'identification assez difficile. Les résultats sont présentés dans le Tableau 2. Seuls 152 fragments ont pu être déterminés au niveau du genre, mais au moins 10 espèces sont distinguées, ce qui peut sembler relativement élevé au vu du faible volume de sol traité. Nous n'avons pas pu identifier avec certitude d'éléments racinaires, par contre, au moins une dizaine de fragments présentent une moelle de tige aérienne, et sept autres des cernes de croissance très fortement courbés. De plus, 23 charbons montrent une nette vitrification, voire une fusion partielle des éléments anatomiques. Le chêne (*Quercus* sp.) n'a pas toujours pu être distingué du châtaignier (*Castanea sativa* Mill.), mais ce dernier n'est pas présent dans la région (Lambinon et Verloove, 2012). L'anatomie des Maloideae suppose que les deux fragments trouvés proviennent d'espèces différentes (fréquence des épaississements spiralés et largeurs de rayons), mais l'identification au genre est difficile. Enfin, aucune gymnosperme n'a été trouvée et les taxons reconnus peuvent tous correspondre à des espèces locales. Le classement des taxons selon leurs groupes fonctionnels (Rameau, 1999) montre que les espèces des phases pionnières sont très bien représentées, ainsi que celles de phases forestières transitoires. *Fagus sylvatica*, espèce de fin de succession forestière, est présent en faible quantité.

4.3.4. Susceptibilité magnétique

La Figure 9 présente les résultats de l'analyse de la susceptibilité magnétique (S.M.) des chauffes expérimentales. Les courbes montrent une évolution relativement similaire mais avec des amplitudes très différentes selon la profondeur correspondante de l'échantillon. Pour celui de surface, la S.M. croît nettement à partir de 450 °C jusqu'à 600 °C. Après une chauffe à 650 °C cette valeur a drastiquement baissé. Puis, elle ré-augmente nettement à 700 °C avant de diminuer progressivement jusqu'à 850 °C. Ces changements sont beaucoup moins marqués pour les échantillons profonds, et sont globalement corrélés à l'importance de la matière organique des échantillons. Ces variations s'expliquent par les transformations minéralogiques des oxydes de fer présents initialement dans le sol, entre des formes dont le comportement magnétique spontané est faible (goethite, hématite), à d'autres dont celui-ci est fort (magnétite, maghémite), et inversement, à différentes températures (Cornell et Schwertmann, 2003 ; Brodard, 2013). Les très fortes valeurs de la S.M. indiquent vraisemblablement la formation de magnétite et/ou

Tableau 2 Résultats anthracologiques présentant le nombre et la masse de charbons par taxons et prélèvements

Echantillon (profondeur)			Nombre 5	Nombre 10	Nombre 15	Nombre 20	Masse (mg) 5	Masse (mg) 10	Masse (mg) 15	Masse (mg) 20	Nbre tot.	Masse tot. (mg)
Fagaceae	***Fagus sylvatica* L.**	Hêtre	3	3 (5)		1 (1)	6	8 (8)		3 (2)	**13**	**27**
	Quercus sp.	Chênes	4	5			28	37			**9**	**65**
	Castanea/Quercus	Châtaignier/Chêne	13 (1)	16 (4)	1 (2)	3	54 (1)	59 (10)	1 (2)	3	**40**	**130**
Betulaceae	***Alnus sp.***	Aulnes		6		1		26		1	**7**	**27**
	Betula sp.	Bouleaux	8 (4)	4	4	2	35 (5)	6	10	10	**22**	**66**
	Alnus/Betula			5	3			11	7		**8**	**18**
	***Carpinus betulus* L.**	Charme	(1)	2			(6)	3			**3**	**9**
	***Corylus avellana* L.**	Noisetier	4 (4)	23 (4)	1		7 (35)	51 (6)	1		**36**	**100**
	Carpinus/Corylus		3				10				**3**	**10**
	Betulaceae inid.		9	2	1		13	4	1		**12**	**18**
Salicaceae	***Salix sp.***	Saules			2	1			1	3	**3**	**4**
	Populus/Salix	Peupliers/Saules	1	3		1	7	5		3	**5**	**15**
Aceraceae	***Acer campestre* L.**	Érable champêtre		(1)	1			(1)	2		**2**	**3**
Caprifoliaceae	***Viburnum opulus* L.**	Viorne Obier		1				2			**1**	**2**
Rosaceae	**Maloideae**			2				5			**2**	**5**
	Angiosperme dicotylédone		28	10	3	4	37	12	4	3	**45**	**56**
	inidentifiable		7	11	4	9	11	34	5	23	**31**	**73**

Les valeurs entre parenthèses correspondent aux fragments incertains (cf.). Le dégradé de gris indique du plus clair au plus foncé les taxons pionniers, post-pionniers/nomades, et dryades maghémite. Les faibles valeurs mesurées à 650 °C pourraient alors s'expliquer par la transformation de ces oxydes en hématite, dont le point de Curie est proche (≈683 °C). Toutefois, la réapparition de valeurs élevées entre 700 et 800 °C suppose la réapparition de formes ferrimagnétiques qui ne sont pas encore transformées en hématite, par exemple de la maghémite issue de formes passant par des transformations intermédiaires (ferrihydrite ou lépidocrocite ; Cornell et Schwertmann, 2003). Bien que des analyses supplémentaires soient nécessaires pour préciser ces variations, deux résultats encore préliminaires peuvent être avancés : la matière organique joue un rôle important sur les changements minéralogiques et l'acquisition d'un comportement magnétique, et, selon les paramètres de cuisson testés, les agrégats rubéfiés correspondraient à une chauffe comprise entre 500 et 800 °C.

4.3.5. Coloration

La Figure 10 présente les résultats des mesures colorimétriques des échantillons chauffés. Puisque les paramètres chromatiques a* et b* présentent une bonne corrélation (coeff. Pearson = 0.959), ils sont additionnés. L'évolution de la coloration au cours de la chauffe est assez similaire pour les trois échantillons les plus profonds, mais les variations sont beaucoup plus marquées et n'interviennent pas aux mêmes seuils de température pour l'échantillon supérieur. Globalement, on remarque d'abord un assombrissement, puis la teinte des échantillons devient progressivement plus jaune-rouge et s'éclaircit, avant de montrer des variations plus ou moins désordonnées aux plus fortes températures testées. Ces variations peuvent s'expliquer par la carbonisation et l'oxydation progressive de la matière organique jusque vers 550 °C (Ulery et Graham, 1993), et selon les échantillons, à partir de 200-300 °C par la formation d'oxydes de teinte rouge, comme l'hématite rouge-sang et la maghémite rouge-brun (Cornell et Schwertmann, 2003). Les valeurs chromatiques (a* et b*) des échantillons non chauffés sont proches de celles mesurées pour des goethites synthétiques (Cornell et Schwertmann, 2003, p. 132), ce qui semble confirmer l'importance de cet oxyhydroxyde dans la composition minéralogique initiale (coloration jaune). De plus, l'observation individuelle des courbes de la première dérivée des mesures de réflectance (données non présentées) confirme l'importance de l'hématite par l'augmentation progressive des valeurs entre 540 et 570 nm avec la chauffe (Deaton et Balsam, 1991 ; Zhou et al., 2010).

La projection de la coloration « moyenne » des agrégats rubéfiés sur le graphique se superpose aux colorations mesurées pour les échantillons à 10 et 15 cm de profondeur à 500 °C. L'échantillon situé à 20 cm de profondeur à la même température est assez proche, par contre, celui de 5 cm le plus proche correspond à une température qui s'élève à 650 °C. L'observation individuelle des spectres de réflectance confirme que l'échantillon situé à 15 cm et chauffé à 500 °C possède des colorations statistiquement très proches des agrégats rubéfiés. Enfin, sur l'axe chromatique bleu-jaune (b*) observé individuellement, l'échantillon à 5 cm de profondeur n'atteint une valeur comparable à celle des agrégats rubéfiés seulement à partir de 800 °C, contre 550 °C pour les autres.

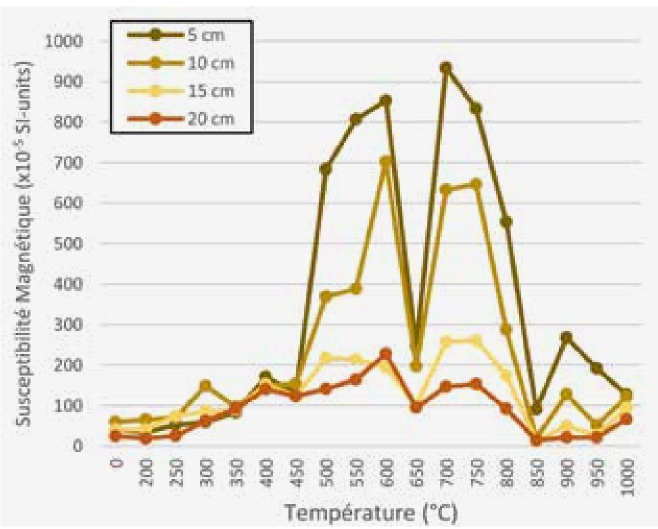

Figure 9. Evolution de la susceptibilité magnétique en fonction des températures de chauffe des échantillons de terre fine de différentes profondeurs.

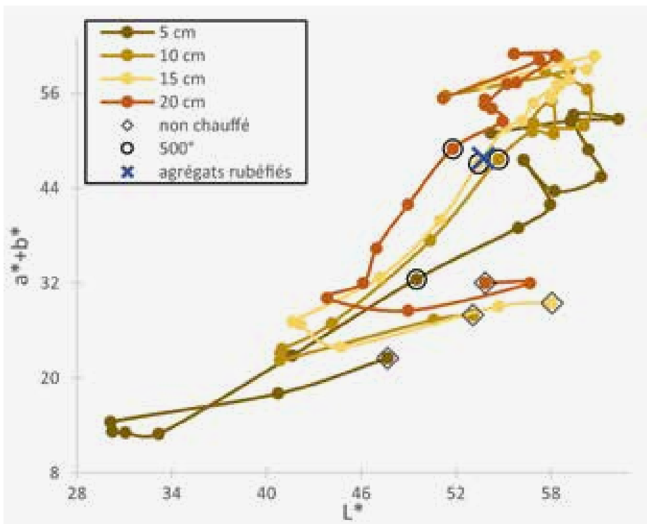

Figure 10. Evolution de la coloration des échantillons aux différentes températures de chauffe selon leur clarté (L*) et leur chromaticité totale (a*+b*) correspondant à un axe théorique bleu-vert (en bas) à jaune-rouge (en haut). Les losanges correspondent aux échantillons de sol non chauffés (séchés à température ambiante) et les cercles aux échantillons chauffés à 500 °C.

5. Discussion

5.1. INTERPRÉTATION DES RÉSIDUS DE COMBUSTION DE TRANSINNE

Les approches employées suggèrent une relative complexité des processus de combustion réels liés aux résidus identifiés et soulignent la nécessité de diversifier les méthodes de caractérisation. Le Tableau 3 présente de manière synthétique les résultats de cette étude et leurs principales limites. En effet, en l'absence actuelle de datations absolues, il est difficile de préciser si ces indices proviennent d'un ou plusieurs évènements cumulés, et de discuter de l'importance des phénomènes taphonomiques au cours du temps. De plus, la restriction spatiale des observations ne permet pas de discuter de leur extension. Malgré cela, il nous semble pertinent de discuter les processus de formation de ces résidus vis-à-vis des connaissances sur les feux naturels et agricoles présentés plus haut. En effet, l'absence d'indices archéologiques associés aux résidus permet de s'orienter vers l'hypothèse de tels évènements.

Si l'on suppose fortement la concomitance de la formation des éléments rubéfiés et d'au moins une partie des végétaux carbonisés, de par leur agencement ponctuel, la présence récurrente de tiges végétales aériennes microscopiques carbonisées peut paraitre étonnante dans le cadre d'une combustion en conditions oxydantes, qui devrait entrainer une comburation (production de cendres) facilitée des petits éléments végétaux. Par contre, cette observation serait cohérente dans le cas d'une combustion couverte. Si la nette coloration rouge de certains agrégats permet de supposer une chauffe de forte intensité, différents travaux montrent que le degré de rubéfaction doit être considéré avec précaution, car ce paramètre est très variable selon la composition du matériel considéré (Canti et Linford, 2000). Suivant ce constat, il est pertinent de réaliser des cuissons contrôlées afin d'obtenir un référentiel colorimétrique spécifique. D'une part, les températures estimées des agrégats rubéfiés isolés (a priori les plus résistants ?) ne sont pas très élevées, et d'autre part, les couleurs correspondent plus certainement à des agrégats provenant de l'horizon minéral à 10-15 cm de profondeur. Ce résultat est relativement incohérent avec les données de températures mesurées lors d'incendies naturels, qui, bien qu'elles peuvent indiquer des valeurs supérieures à 500 °C en surface du sol, montrent une rapide décroissance dès les premiers centimètres inférieurs (Neary et al., 1999 ; Scott et al., 2014 ; Jordanova et al., 2018). Les agrégats rubéfiés indiquent donc une combustion affectant un horizon minéral mis à nu, soit par des perturbations naturelles, soit par une action anthropique volontaire.

Les traits micromorphologiques de perturbation ou de remaniement identifiés ne permettent pas de trancher

Tableau 3 Synthèse de l'analyse des résidus de combustion du bloc de Transinne

Méthodes	Résultats	Interprétations ou hypothèses	Limites et biais
Micromorphologie	charbons de bois, tiges carbonisées de dicotylédones	végétation ligneuse évoluée et jeune	observations ponctuelles sur une surface réduite, morphologie de certains résidus de combustion parfois limitée
	altérations thermiques : traces brunes diffuses à des agrégats nettement rubéfiés et individualisés ; quelques agrégats carbonisés infra-millimétriques	chauffe principalement en condition oxydante, mais d'intensité variable	
	végétaux englobés dans des masses brûlées	préparation du sol ou remaniements mécaniques avant combustion	
	nombreuses particules carbonisées microscopiques intégrées dans le fond matriciel	forte production de résidus carbonisés ou importants remaniements biomécaniques post-dépositionnels ?	
	fragmentation verticale de charbons subhorizontaux	tassement ou compaction post-dépositionnels	
	concentrations texturales fines jaunâtres	remaniements biomécaniques, possible labour ou apports latéraux lors du dépôt ?	
Anthracologie	végétation pionnière bien représentée mais également espèces de fin de succession forestière ; richesse taxonomique élevée sur un volume réduit ; absence de résineux	feux cumulés ou combustible volontairement concentré (structure de combustion) ?	validité spatiale de l'information anthracologique non connue, datations absolues manquantes
		feux antérieurs aux plantations forestières (contemporaines ?)	
		feux succédant à une perturbation du milieu (milieu ouvert) ou végétation boisée anthropisée	
Cuissons expérimentales	courbes d'évolution de la S.M. en fonction de la température ; forte S.M. des agrégats rubéfiés ; corrélation à l'importance de la M.O.	chauffe entre environ 450 et 800°C pour l'obtention de valeurs de S.M. du même ordre	spécificités de la combustion réelle non reproduites en laboratoire ; modalités de durée de cuisson et de refroidissement testées uniques
		agrégats provenant de l'horizon de surface ?	
	courbes d'évolution de la coloration selon la température ; coloration "moyenne" des agrégats rubéfiés ; spectres de réflectance	agrégats provenant de l'horizon minéral à 10-15 cm de profondeur, chauffés vers 500°C	

vers l'une ou l'autre hypothèse, et, nous n'avons pas d'indices incontestables qui permettent d'appuyer l'existence d'un chablis (Langohr, 1993 ; Bobrovsky et Loyko, 2016). De plus les résultats anthracologiques sont clairement opposés aux arguments généralement considérés pour l'identification d'un chablis brûlé en place : charbons majoritairement mono-spécifique et racinaires (Goldberg et Macphail, 2006). Par contre, nos différents résultats ne montrent aucune contradiction apparente dans l'hypothèse de structures de combustion impliquant une concentration de combustible dans des fourneaux. D'un point de vue théorique, il s'agit même de l'explication la plus cohérente avec les spécificités de la combustion supposées : agrégats de sub-surface chauffés en atmosphère oxydante, carbonisation de tiges microscopiques, indices de pédoturbation au sens large. En l'état actuel de nos investigations, l'hypothèse de résidus de structures de combustion à couvert reste donc la plus probable.

5.2. FEU ET AGRICULTURE DANS LES ARDENNES

Le massif des Ardennes est un territoire géographique pour lequel on dispose d'une documentation historique relativement abondante concernant les pratiques agricoles du feu (Boutry, 1920 ; Noirfalise et Thill, 1959 ; Froment, 1968 ; Dupré, 2004). L'emploi récurrent de l'essartage a notamment joué un rôle relativement important dans l'évolution de la couverture boisée de certaines localités, en favorisant des essences héliophiles, qui rejettent facilement de souche (Bouleaux, Aulnes, Noisetier ; Berghen, 1970 ; Rameau et al., 1993). Le Chêne était en particulier intéressant pour l'essartage puisqu'il permettait une exploitation conjointe de son écorce pour la tannerie. D'ailleurs, il semble que cette industrie ait joué un rôle important dans le maintien de l'essartage à une époque récente (début du XXème s.), où des taillis pouvaient être essartés très régulièrement pour maximiser la récolte d'écorces (une quinzaine d'années au plus court ; Sigaut, 1975). Après l'ouverture du terrain pour l'agriculture, des taillis herbeux se reconstituent et peuvent servir pour le pâturage. Les techniques agricoles avec combustion à couvert sont également connues dans les Ardennes, essartage à couvert et écobuage, bien que ce dernier était localement désigné sous le même terme que l'essartage (Boutry, 1920 ; Froment, 1968). Les archives, les descriptions techniques, et même les témoignages oraux démontrent donc leur importance localement, au moins durant les derniers siècles. Ce constat, bien qu'il ne constitue pas en soi un argument à notre interprétation, questionne d'une part la visibilité archéologique générale de ces pratiques, et d'autre part le relativement faible nombre de travaux menés sur la question (Herbauts et al., 1990). Il apparaitrait donc pertinent de mettre en place des projets d'étude de plus grande envergure dans ce secteur, afin de pouvoir ensuite discuter de la mise en évidence d'agricultures du feu dans des régions moins documentées, ou pour des périodes plus anciennes.

6. Conclusions

L'étude conduite à Transinne illustre la pertinence de caractériser plus précisément des traces de combustion a priori peu diagnostics. Le choix de méthodes d'analyse adaptées aux questionnements géo-archéologiques posés par les structures découvertes, s'il n'autorise pas forcément une interprétation définitive, devrait au moins permettre de préciser leur formation et leur fonctionnement : combustible, paramètres de la chauffe, etc. S'il est par ailleurs évident que ces faits archéologiques nécessitent une plus grande attention, et ce, dès leur mise au jour, il est aussi indispensable que les structures macroscopiques a priori mieux préservées, fassent également l'objet d'investigations (Guiblais-Starck et al., en préparation). Les traces pédo-sédimentaires découvertes en contexte préventif devraient ainsi permettre de mieux interpréter les résidus uniquement perceptibles à l'échelle microscopique.

Nous n'avons que peu développé la question des processus taphonomiques des résidus découverts à Transinne, ainsi que la validité méthodologique des estimations de température de chauffe. La question de l'importance de la diagenèse sur les agrégats chauffés mérite d'être détaillée plus amplement, car c'est une problématique centrale dans l'étude des structures de chauffe anciennes ainsi que sur la question de la préservation de l'ensemble des résidus pyrolytiques au sens large (Courty, 2012). Toutefois, il nous semble que ces questions ne sauront être résolues sans considérer la complexité des feux anthropiques, même hors des sites archéologiques *stricto sensu*. Au final, plutôt que de proposer des modèles d'interprétation théorique seulement fondés sur la base de données géoarchéologiques (Macphail et Goldberg, 1990), il nous semble primordial d'accorder une plus grande attention aux aspects techniques (structure, fonctionnement, fonction) des emplois du feu, dont la dénomination et la définition en constitue un des fondements incontournable (Sigaut, 1975, 1991).

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MICROMORPHOLOGIE DES CONSTRUCTIONS EN TERRE ET CONVERGENCE DE FACIÈS

Le cas du site des Genêts à Ablis (Yvelines, France)

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RESUMÉ
La fouille préventive d'un site ayant initialement livré des restes de constructions en terre néolithiques, dans l'extrémité nord de la Beauce, nous a fourni l'occasion d'étudier plus précisément son contexte stratigraphique (micromorphologie, granulométrie, datation OSL). Les résultats montrent que ces restes ont en réalité été confondus avec des organisations naturelles. L'évolution du sol et la bioturbation sont en effet à l'origine de nombreux faciès qui, aux échelles microscopiques, peuvent imiter ceux produits par un travail de la terre. Cette convergence entre faciès naturels et faciès anthropiques constitue un terrain d'étude encore peu exploré dans la reconnaissance des témoins architecturaux en terre crue. L'élaboration plus systématique d'un référentiel de traits naturels (à partir de lames issues du substrat des sites) et anthropiques (à partir d'éléments façonnés avérés) apparaît nécessaire afin de limiter les biais d'interprétation.

MOTS-CLÉS
constructions en terre, Néolithique, Bassin parisien, micromorphologie, équifinalité

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1. Introduction

Les résultats d'un diagnostic archéologique réalisé en août 2015, préalablement à la construction d'une zone pavillonnaire au lieu-dit les Genêts à Ablis, à environ 50 km au sud-ouest de Paris, ont conclu notamment à la présence de restes de bâtiments en terre crue du Néolithique identifiables par la présence d'éléments modulaires façonnés (Brutus et al., 2015). Face à cette découverte jugée exceptionnelle, une fouille-test a été prescrite par le Service Régional d'Archéologie d'Île-de-France. Réalisée en août 2016, elle avait pour principal objectif de questionner l'existence d'éléments en terre crue.

La reconnaissance d'éléments en terre est liée à plusieurs critères, des plus évidents comme les briques aux moins lisibles comme la bauge, demandant à être confirmés par un protocole de fouille et des analyses adaptés (De Chazelles, 2016). Si l'existence de constructions en terre, et uniquement en terre, sans autres éléments porteurs comme les poteaux en bois, est une évidence en région circumméditerranéenne, y compris dans le sud de la France (e.g. De Chazelles et Roux 2010 ; Gutherz et al., 2011 ; Sénépart et al., 2015), leur identification et leur existence même ont été et continuent de nous interroger pour la moitié nord du pays (Riche et al., 2016). En effet, dès le Néolithique ancien, la plupart des constructions pérennes sont réalisées sur poteaux porteurs avec des parois en clayonnage et torchis, le tout étant couvert par une toiture végétale (Masuch et Ziessow, 1985). Ces bâtiments sont généralement matérialisés par les trous d'implantation des poteaux et par des restes de torchis cuits, plus exceptionnellement par des fragments de parois à enduit intérieur (Hauzeur, 2006). En cas de forte érosion ou de construction plus légère, seuls ces éléments de terre cuite, conjugués à d'autres indices comme les fosses à rejets domestiques et le mobilier, permettent d'assurer la présence de bâtiments et plus largement celle d'un habitat pérenne.

Ces dernières décennies ont vu s'étendre la reconnaissance de bâtiments en terre crue dans les régions tempérées du nord de l'Europe, avec toutes les difficultés d'identification que cela implique. Pour en assurer la conservation dans ces régions, il faut généralement des conditions géomorphologiques exceptionnelles provoquant un ensevelissement rapide et suffisant des vestiges, ou bien des conditions archéologiques singulières comme des bâtiments partiellement enterrés ou incendiés. Pour certains chercheurs, les éléments en terre sont parfois bien présents, car, même s'ils ne sont pas visibles et identifiables à l'œil nu, ils sont reconnaissables par le biais d'analyses micromorphologiques (Friesem et al., 2017 ; Cammas, 2018). L'étude de lames minces s'avère en effet un complément utile aux observations de terrain malgré les biais possibles, liés par exemple à un échantillonnage non-représentatif ou à des convergences de faciès (lorsque plusieurs processus aboutissent à une même organisation sédimentaire).

À Ablis, suite au diagnostic, tous les éléments favorables à l'existence d'un site bien conservé semblaient réunis : une nappe de vestiges contenant du mobilier domestique, des éléments façonnés (« pains de terre ») et des restes d'élévation décelés sur le terrain, de même que des sols construits et des restes d'aménagement en bauge perçus en lame mince (Brutus et al., 2015). Ce site, devenu référence (Wattez et al., 2018), s'ajoutait ainsi à la série des sites beaucerons à éléments en terre crue prétendus conservés comme ceux de la Fosse Blanche à Prasville (Bailleux et al., 2015), des Friches de Flotville à Sours (Hamon et al., 2014) ou encore des Grands Noyers à Gas (Noël et al., 2015). Or, malgré une méthodologie adaptée et des conditions édaphiques favorables lors de la fouille (semblables à celles du diagnostic), aucun de ces vestiges n'a été mis en évidence. Cet article propose une explication à ce contraste de résultats d'après les principales données stratigraphiques et micromorphologiques obtenues lors de la fouille (Hauzeur et Rué, 2018).

2. Contexte géomorphologique

L'emprise est localisée dans le bassin versant de la Voise, affluent de la rive droite de l'Eure avant sa confluence avec la Seine. Cette région marque l'extrémité nord de la Beauce. D'après la carte géologique à 1/50000 de Dourdan (Bricon et Ménillet, 1971), le secteur d'étude se situe sur la formation des « limons des plateaux » qui forme une couverture presque continue d'apports lœssiques pléistocènes, d'épaisseur généralement métrique. Les formations sous-jacentes correspondent aux Sables de Lozère (argile jaune sableuse à éléments de calcaire altéré) et aux Argiles à meulières de Montmorency, d'âge cénozoïque.

D'après la carte pédologique à 1/100000 de Chartres (Crahet et al., 1981), l'emprise est située sur un sol brun lessivé, à la limite entre deux unités pédologiques distinguées par leur degré d'hydromorphie. Les profils décrits dans les environs du site se rattachent aux Luvisols (Baize et Girard, 2009). Ces sols se sont progressivement différenciés en plusieurs horizons au cours de l'Holocène par la migration d'éléments minéraux (lessivage). Ils présentent ainsi un horizon supérieur appauvri (horizon éluvié, E) et un horizon inférieur d'accumulation (horizon argilique, BT). L'exploitation agricole de ces sols provoque souvent la transformation ou la disparition de l'horizon E.

D'après les vues aériennes anciennes, on constate sans surprise une simplification progressive du parcellaire à partir des années 1950. Sur les vues des années 2000,

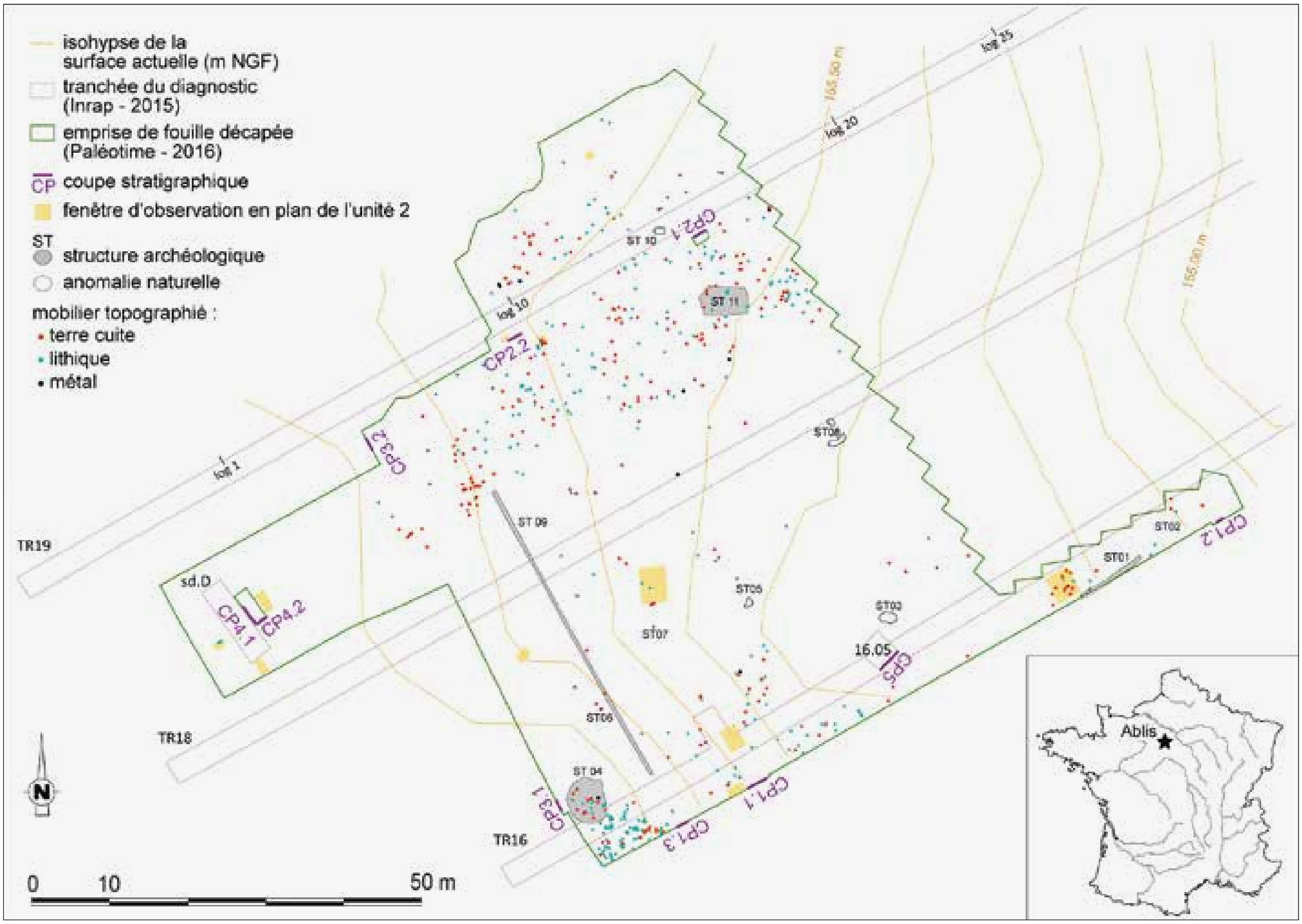


Figure 1. Plan des investigations géoarchéologiques et des découvertes archéologiques (M. Rué, A. Hauzeur, J.-B. Caverne).

lorsque les conditions édaphiques le permettent, l'ancien parcellaire ressort particulièrement bien. Les cellules décamétriques visibles à 1,5 km au sud-ouest de l'emprise, signalées par Bertran et al., (2013), indiquent par ailleurs que la couverture limoneuse a enregistré une phase périglaciaire à pergélisol. Sa mise en place a donc débuté avant la période du Dernier maximum glaciaire.

La surface actuelle du terrain étudié est globalement inclinée vers l'est selon une pente moyenne faible, généralement inférieure à 1 %. Le site est localisé à proximité immédiate d'un point haut du relief, à une altitude de 158 m.

3. Méthodologie

3.1. TERRAIN

Les observations stratigraphiques se sont focalisées sur dix coupes (CP) nettoyées sur une largeur minimale d'un mètre et réparties sur l'emprise. Deux de ces coupes (CP4.1 et CP5) sont situées au même emplacement que celles du diagnostic où des vestiges en terre crue ont été identifiés (respectivement au droit des sondages D et 16.05, Fig. 1). Les profils dégagés ont été examinés sous différentes conditions d'observation (ombre/lumière, avant/après séchage) et soumis à différents observateurs. Ils ont fait l'objet d'une rectification fine à la truelle, mais également d'une exploration au couteau afin d'observer la manière dont se désagrège naturellement le sol (structure). Les dépôts ont été séquencés en unités pédosédimentaires (UPS) d'après leur texture, couleur, structure et principaux traits pédologiques. La description des UPS et l'identification de la couleur Munsell ont été effectuées sur sédiment frais (sauf pour l'UPS1, plus sèche). En complément des coupes, onze fenêtres d'étude des faciès en plan ont été implantées à différents endroits de l'emprise. Elles ont en commun d'être toutes situées dans l'UPS2, là où s'insère la nappe de vestiges et où la plupart des éléments de terre crue ont été initialement signalés.

Les principaux prélèvements ont été réalisés à l'endroit précis où des éléments architecturaux ont été reconnus au diagnostic, dans le sondage D, sur la coupe CP4.1. Cette dernière a été étudiée en deux temps : une première portion a été nettoyée et enregistrée (au nord) puis une seconde partie a été reculée (au sud) afin de sortir de la zone d'influence possible du remblai du sondage D. C'est cette portion qui a été échantillonnée. La coupe CP4.1 a été complétée par une section perpendiculaire (CP4.2) afin de mieux appréhender l'évolution spatiale des UPS. Des mesures *in situ* de la susceptibilité magnétique volumique ont été réalisées à l'aide d'un appareil Bartington muni d'un capteur MS2K. Ce paramètre permet d'estimer la quantité de particules magnétiques qui ont tendance à augmenter dans les horizons de surface ou les niveaux anthropisés (Pétronille, 2009). Le taux de réponse du capteur est de 50 % à 3 mm de profondeur et de 10 % à 8 mm (Dearing, 1999).

3.2. LABORATOIRE

Les trois blocs de sédiment prélevés sur la coupe CP4.1 (PR4 à 6, Fig. 2) ont été litholamellés au laboratoire EPOC à l'Université de Bordeaux 1 (UMR 5805) après séchage à l'air. Chaque bloc a fait l'objet de deux lames minces de grand format séparées d'environ 5 mm afin de mieux apprécier l'organisation spatiale des matériaux aux échelles microscopiques. Les observations ont été réalisées au moyen d'un microscope polarisant Leica DM750 à des grossissements de 25, 40 et 100x, selon l'approche préconisée par Stoops 2003.

Treize échantillons espacés verticalement de 10 cm ont fait à la fois l'objet d'analyses microgranulométriques et de dosages géochimiques (PR7 à 19). Seuls les résultats des analyses granulométriques sont présentés ici. L'appareil utilisé est un granulomètre par diffraction laser Malvern Mastersizer 2000, capable de détecter des particules entre 0,2 µm et 2 mm de diamètre. Quelques agrégats sont placés dans 700 mL d'eau courante, sans adjonction de dispersant. La solution est alors soumise à des ultrasons pendant une minute afin de dissocier les particules. Les résultats correspondent à la moyenne de trois mesures. La variation de la distribution granulométrique entre ces trois mesures est insignifiante. Le calcul de cette distribution utilise le principe de Fraunhofer qui assimile les particules à des disques plats et opaques à la lumière. La limite entre les argiles, limons et sables a été fixée respectivement à 6,6 et 60,3 µm d'après Makó et al., 2017 pour permettre la comparaison avec d'autres méthodes. Trois prélèvements plus volumineux (2 kg) issus des horizons supérieurs (PR20 à 22) ont été séchés à l'air libre, pesés puis tamisés à l'eau, sans prétraitement, à l'aide de tamis normés à 0,5 et 2 mm afin, entre autres, d'estimer la quantité d'éléments anthropiques lithiques et céramiques potentiellement présents.

Un prélèvement pour datation par luminescence stimulée optiquement (OSL) a été réalisé à la base de la séquence limoneuse (PR3). Ce prélèvement n'a pas fait l'objet d'une mesure de la radioactivité *in situ*. Il provient cependant d'un environnement sédimentaire relativement homogène, éloigné des terriers et des cailloux. Les analyses ont été menées par le centre GADAM de l'Institut de Physique à Gliwice en Pologne. Elles portent sur les particules quartzeuses de taille comprise entre 90 et 125 µm, selon le protocole *Single Aliquot Regeneration* (Murray et Wintle, 2000). La date proposée a été calculée en utilisant le *Central Age Model* (Galbraith et al., 1999) à partir des résultats obtenus sur 12 aliquotes.

4. Résultats

4.1. SÉQUENCE STRATIGRAPHIQUE ET INSERTION DES VESTIGES

Six principales unités ont été reconnues sur le terrain, sur une épaisseur explorée d'environ 2,5 m. On trouve ainsi, de haut en bas (Tab. 1, Fig. 2, Fig. 3a à c) :

- UPS1 : l'horizon cultivé actuel, d'épaisseur régulière (environ 30 cm), à mobilier archéologique rare ;
- UPS2 : un horizon limono-argileux brun renfermant du mobilier en épandage diffus, d'épaisseur variable (environ 30 cm), affecté par plusieurs générations de bioturbation (Fig. 3c) provoquant en plan l'apparition de taches blanchâtres (descente de l'UPS1 dans l'UPS2) ;
- UPS3 : un horizon limono-argileux brun-jaune, exempt de mobilier, épais d'environ 40 cm, subdivisé en deux sous-unités sur CP4.1 : 3a au sommet (faciès commun), 3b à la base (faciès à petites concrétions noires arrondies, à contour net, millimétriques, <5 %) ;
- UPS4 et 5 : un complexe argileux brun, sans mobilier, d'épaisseur variable, marqué à son sommet par un pavage caillouteux et, localement à la base, par des volumes graveleux festonnés (fig. 3b) suggérant des déformations par cryoturbation ou argiliturbation ;
- UPS6 : des argiles bariolées à quelques cailloux et blocs siliceux (formation oligocène des Argiles à meulière de Montmorency).

Conformément aux données des cartes géologique et pédologique, le profil formé par les UPS1 à 3 est constitué par un même matériau, d'origine principalement lœssique, décarbonaté, qui s'est progressivement différencié en horizons par les processus pédogénétiques. Les observations de terrain permettent de reconnaitre le profil d'un Luvisol typique (Baize et Girard 2009), tronqué par les labours :

- UPS1 : horizon cultivé sur l'ancien horizon éluvié (LE) ;
- UPS2 et 3 : horizon argilique (BT1), plus intensément bioturbé à son sommet (UPS2).

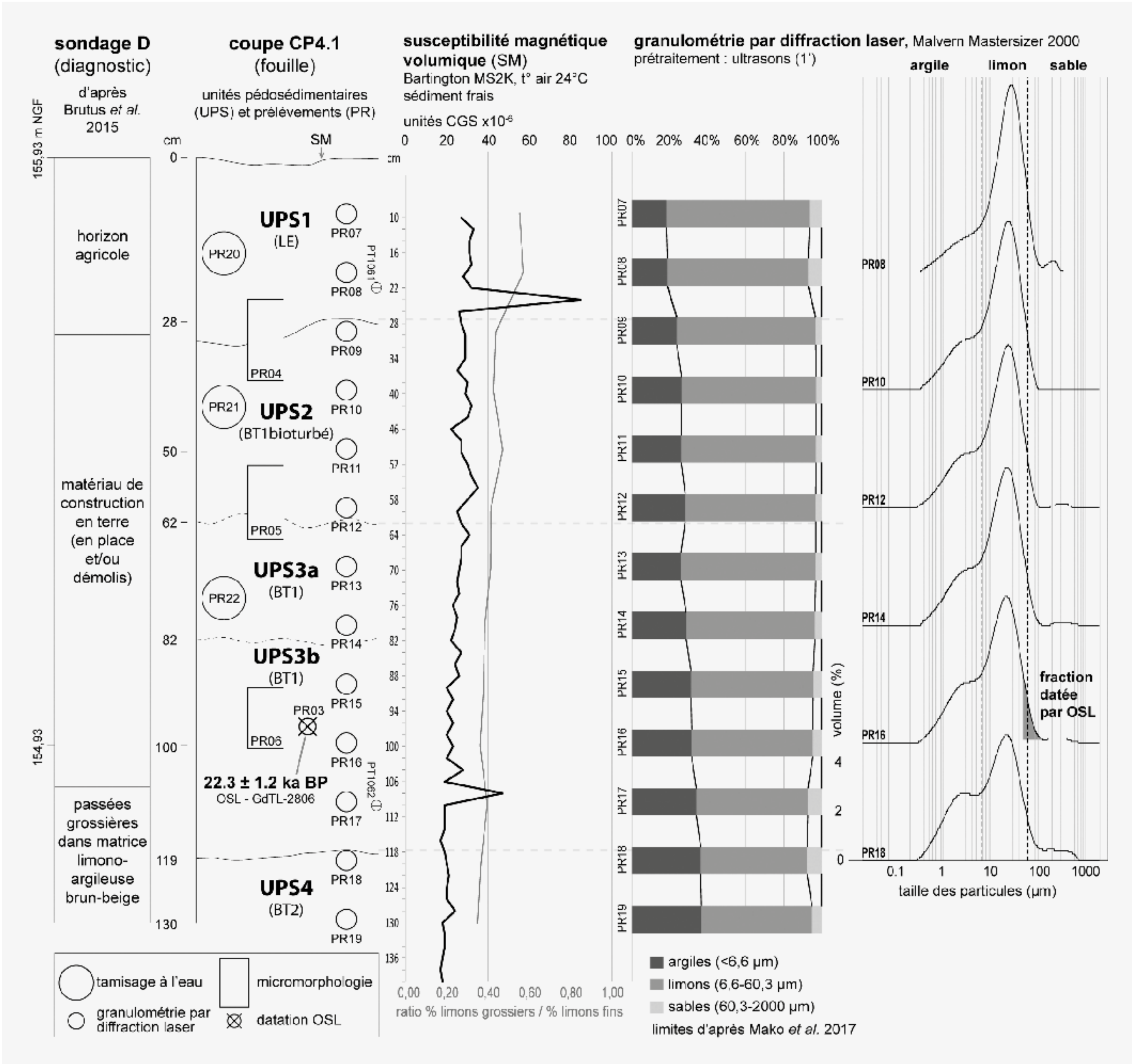


Figure 2. Séquençage stratigraphique, évolution verticale de la susceptibilité magnétique et des fractions granulométriques le long de la coupe CP4.1 (M. Rué). A gauche, l'interprétation donnée à l'issue du diagnostic archéologique (Brutus et al. 2015).

- Les UPS4 et 5 constituent probablement un second et troisième horizon argilique (BT2 et BT3).

Cette organisation stratigraphique générale est semblable en tout point de l'emprise de fouille. Les travaux de viabilisation du terrain situé à l'ouest ont permis de montrer qu'elle s'étend bien au-delà. D'après le diagnostic, les éléments architecturaux en terre seraient localisés dans les UPS2 et 3 (Fig. 2), voire jusque dans l'UPS4 si l'on en croit l'interprétation réalisée *a posteriori* sur des photographies du sondage D. Les deux lames minces étudiées lors du diagnostic proviennent de l'UPS2, dans un secteur où cette unité a été identifiée sans ambiguïté (à proximité de CP1.1, Fig. 1).

Les résultats analytiques obtenus sur les UPS1 à 4 permettent d'avancer les points suivants (Fig. 2) :

1) Aucune discontinuité texturale importante n'apparaît dans le profil. On constate au contraire une augmentation progressive de la teneur en argile vers le bas du profil, comme le montrent par ailleurs les

analyses précédemment réalisées sur ce type de sol (Crahet et al., 1981). Ce résultat est l'expression de l'argilluviation, en accord avec le contexte pédosédimentaire décrit plus haut.

2) Les dépôts sont tous caractérisés par la forte présence de limons (entre 59 et 73 % dans l'horizon BT1), dont la distribution granulométrique traduit une origine éolienne, avec un mode qui dérive progressivement de 28 à 22 µm vers le bas du profil. La fraction >2 mm est très faible dans l'horizon BT1 (<0,05 %) alors qu'elle est légèrement plus élevée dans l'horizon cultivé (0,6 %). Elle est principalement constituée par des graviers siliceux et des concrétions millimétriques noires. La quantité d'éléments anthropiques >2 mm recueillie dans les prélèvements tamisés est très faible (quelques éléments de terre cuite de la taille des graviers dans les UPS1 et 2, une esquille de silex dans l'UPS1).

3) Le signal de la susceptibilité magnétique diminue également vers la base et reste relativement constant dans les UPS1 et 2. Les valeurs restent basses dans ces deux unités, ce qui suggère, comme pour les résultats granulométriques sur la fraction >2 mm, une faible anthropisation du sol du point de vue de ce paramètre. Les résultats obtenus sur des surfaces occupées néolithiques ou protohistoriques montrent en effet des signaux nettement plus contrastés et élevés (Hulin et al., 2011). La diminution des valeurs de la susceptibilité dans la partie inférieure du sol peut être imputable à l'hydromorphie, en accord avec ce qui a été observé sur le terrain.

Le mobilier recueilli au décapage (lithique, terre cuite, métal), atteste de plusieurs périodes s'étalant du Néolithique (moyen ?) aux périodes médiévales et modernes. Il a été principalement récolté dans l'UPS2 et ne montre aucune organisation spatiale en faveur d'un habitat. En plan, sa répartition traduit une conservation différenciée selon les anciennes parcelles. La densité est faible, avec une moyenne de 0,1 pièce/m² (531 pièces sur 5340 m², tout type d'artefact confondu). Même dans le cas des concentrations les plus importantes, comme dans le sud-ouest de l'emprise (Fig. 1), la densité reste peu élevée, avec 1,8 objet par mètre carré. Verticalement, l'épandage apparaît dilaté et homogène (mélange de témoins de différentes périodes). Seules trois structures archéologiques avérées ont été découvertes : une possible fosse d'extraction antique, deux tracés linéaires (fossés de parcellaire ?) et un empierrement d'âge indéterminé (Hauzeur et Rué, 2018).

4.2. OBSERVATIONS MICROMORPHOLOGIQUES

L'examen des six lames minces (Fig. 4) a permis de déceler les principales micro-organisations suivantes :

UPS1 (LE)

La base de l'UPS1, observable sur les lames PR4a et b, est constituée par un assemblage dense de particules silto-quartzeuses selon une microstructure cavitaire. La teinte claire de l'UPS1 témoigne du caractère lessivé de l'unité. On observe une association de traits symptomatiques du labour : (i) des intercalations brunes teintées

Table 1 Principales caractéristiques des unités pédosédimentaires (UPS) (M. Rué)

Unité	UPS1	UPS2	UPS3	UPS4	UPS5	UPS6
Horizon	LE	BT1 bioturbé	BT1	BT2?	BT3?	C
Texture	limoneuse, rares graviers	limono-argileuse, rares graviers	limono-argileuse, rares graviers	limono-argileuse, quelques graviers et cailloux	argileuse	argileuse
Macrostructure	polyédrique à grumeleuse	polyédrique à tendance prismatique	polyédrique à tendance prismatique	polyédrique	polyédrique	polyédrique
Couleur Munsell	brun-olive clair (2,5Y 5/3)	brun-jaune sombre (10YR 4/4)	brun-jaune (10YR 5/8)	brun-jaune (10YR 5/6)	brun vif (7.5YR 4/6)	bariolée (brun à gris)
Figures sédimentaires	croutes de battance (en place ou remaniées)	croutes de battance piégées dans certains terriers	-	pavage caillouteux discontinu au sommet	-	-
Traits pédologiques (macro)	-	conduits biologiques comblés par LE et/ou BT1 ; terriers	conduits biologiques comblés par LE et/ou BT1 ; quelques taches décolorées diffuses	taches décolorées au contour orangé diffus (glosses)	taches décolorées au contour orangé diffus (glosses)	taches décolorées ; concrétions noires diffuses
Mobilier archéologique	rare (terre cuite, lithique, métal), épars	rare (terre cuite, lithique, métal), épars	-	-	-	-
Limite inférieure	nette et rectiligne	diffuse et ondulée	nette et rectiligne	nette, rectiligne à irrégulière	(peu observée)	(non observée)
Lame mince	PR4	PR4, PR5	PR5, PR6	-	-	-
Microstructure	cavitaire ; à chenaux	à chenaux ; cavitaire	à chenaux ; cavitaire	-	-	-
Masse basale	assemblage dense de silts quartzeux ; motif de biréfringence indifférencié	assemblage dense de silts quartzeux ; motif de biréfringence à légère striation entrecroisée	assemblage dense de silts quartzeux ; motif de biréfringence à légère striation entrecroisée	-	-	-
Traits pédologiques (micro)	intercalations brunes ; taches brunes diffuses organo-minérales	intercalations brunes ; revêtements argileux orangés (nombreux) ou poussiéreux (rares)	revêtements argileux orangés, plus épais à la base ; rares revêtements argilo-silteux bruns ; hyporevêtements noirs	-	-	-

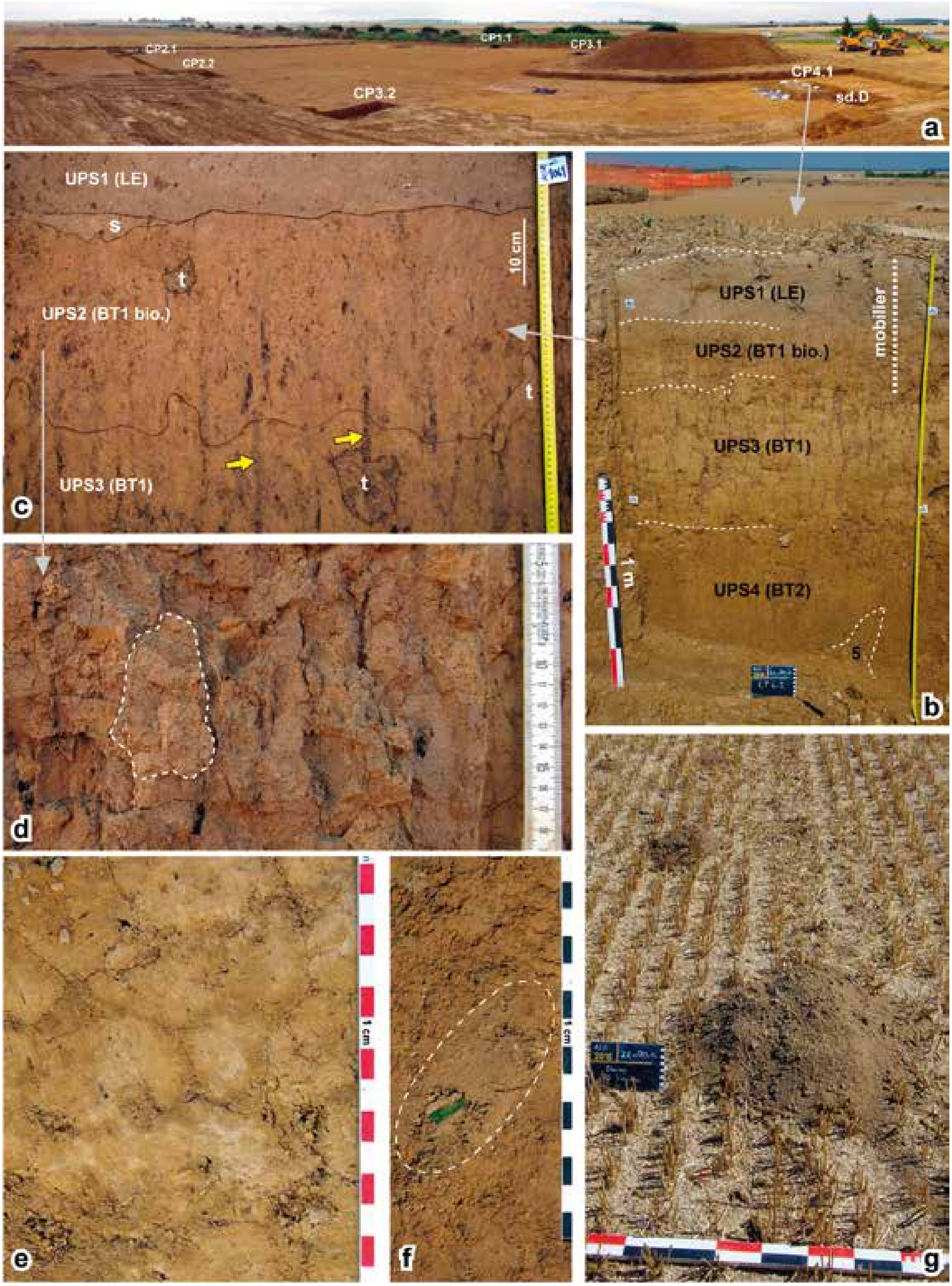


Figure 3. a. Panorama de l'emprise de fouille depuis le nord-ouest et localisation des coupes.

b. Coupe CP4.1 (sondage D du diagnostic) après quelques heures de séchage.

c. Détail du sommet de la coupe CP4.1 (fraîche), s. base de sillon à petites taches claires (limons ruisselés), t : terrier comblé. Les conduits biologiques récents se distinguent aisément (flèches).

d. Détail de la structure de l'horizon BT1 d'où se dégagent des gros agrégats à tendance prismatique.

e. Effet « pain de terre » provoqué par l'humidification et le séchage partiel du BT1 (en plan).

f. Vue en plan d'un terrier dans le BT1 dans lequel est descendu un fragment de céramique glaçurée.

g. Remontée de la terre par la bioturbation en août 2017, au nord du site. Au premier plan, une taupinière atteignant 20 cm de hauteur recouvre une surface d'environ 1/3 de m². Photographies M. Rué et A. Hauzeur.

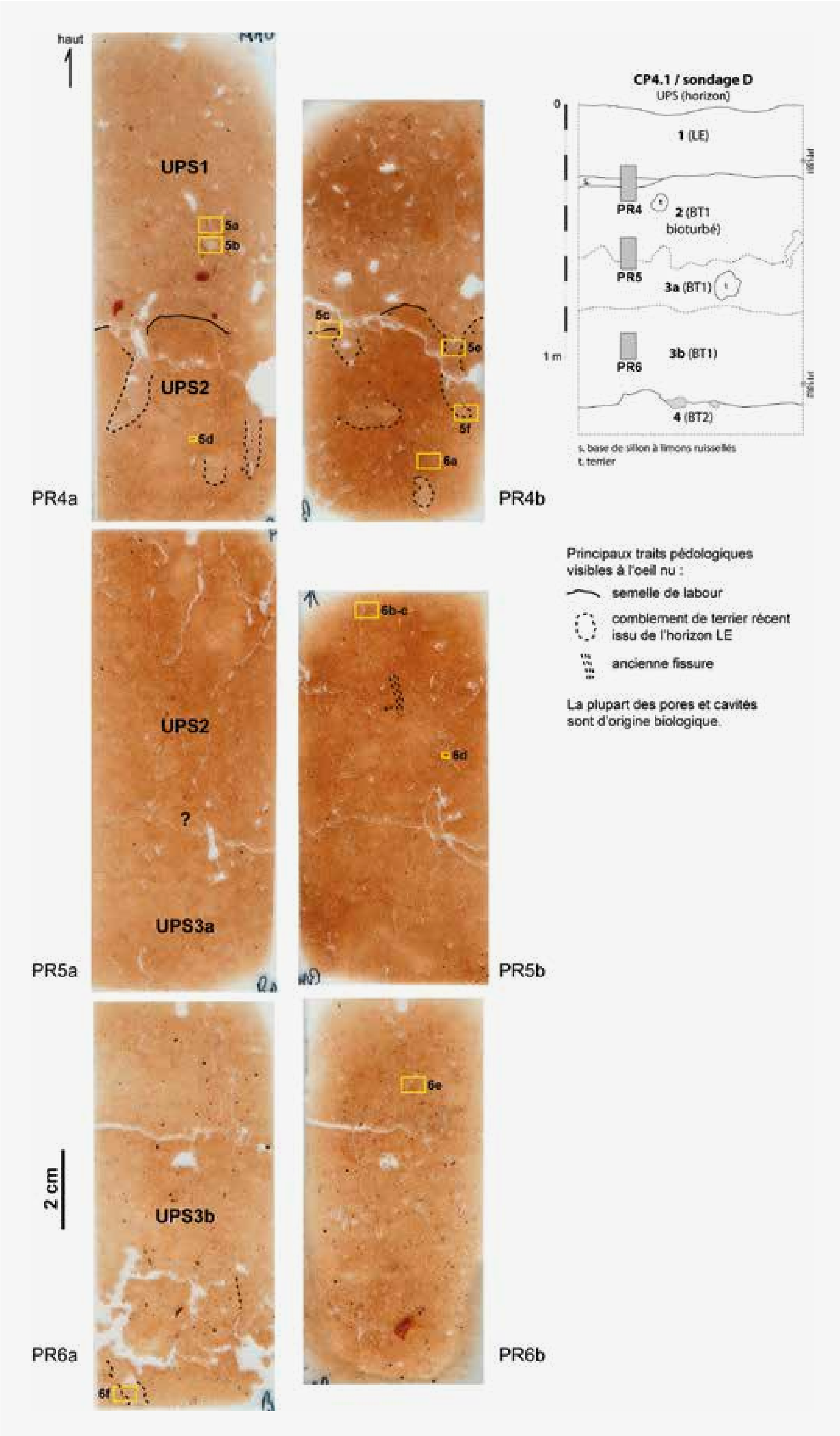


Figure 4. Scans des lames minces et localisation des clichés (M. Rué). Chaque bloc prélevé a fait l'objet de deux lames minces séparées d'environ 5 mm (a et b) afin de mieux appréhender la variabilité spatiale et le volume des traits pédologiques.

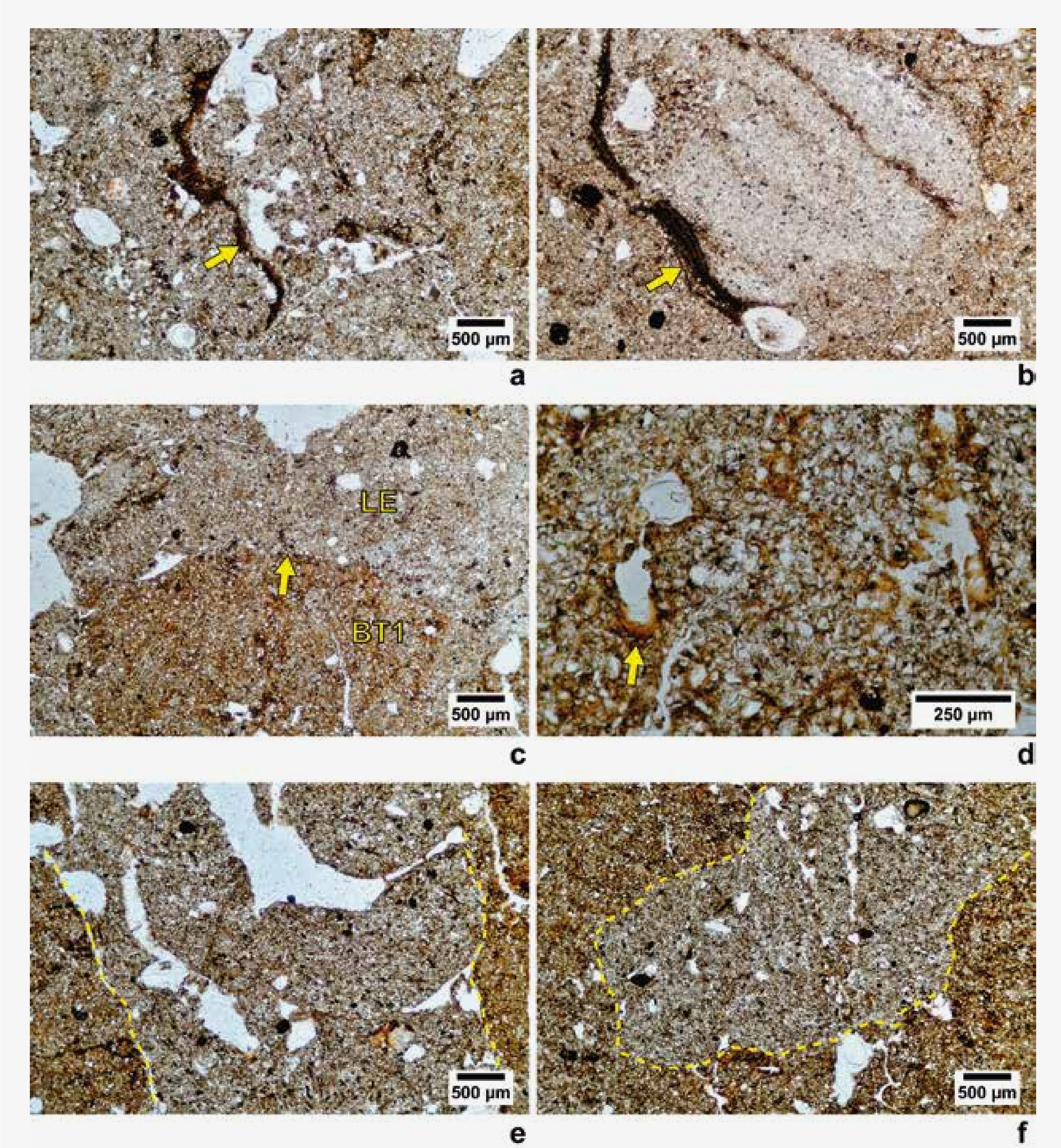


Figure 5. Aperçu des microfaciès (M. Rué). Lumière polarisée non analysée.

UPS1 (LE) :

a. Intercalation brune (flèche) au sein d'une matrice éluviée à porosité biologique.

b. Intercalation microlitée (flèche) en bordure d'un fragment remanié de croûte de battance.

UPS2 (BT1), sommet :

c. Contact irrégulier entre l'horizon éluvié (LE) et l'horizon argilique (BT1) provoqué par l'effet conjugué du labour et de la bioturbation. Il s'agit respectivement des microfaciès A et B du diagnostic interprétés comme d'origine anthropique.

d. Apparition de revêtements illuviaux orangés en position primaire (flèche).

e. et f. Sommet (e) et extrémité apparente (f) d'une galerie de vers comblée par la matrice éluviée de l'horizon cultivé.

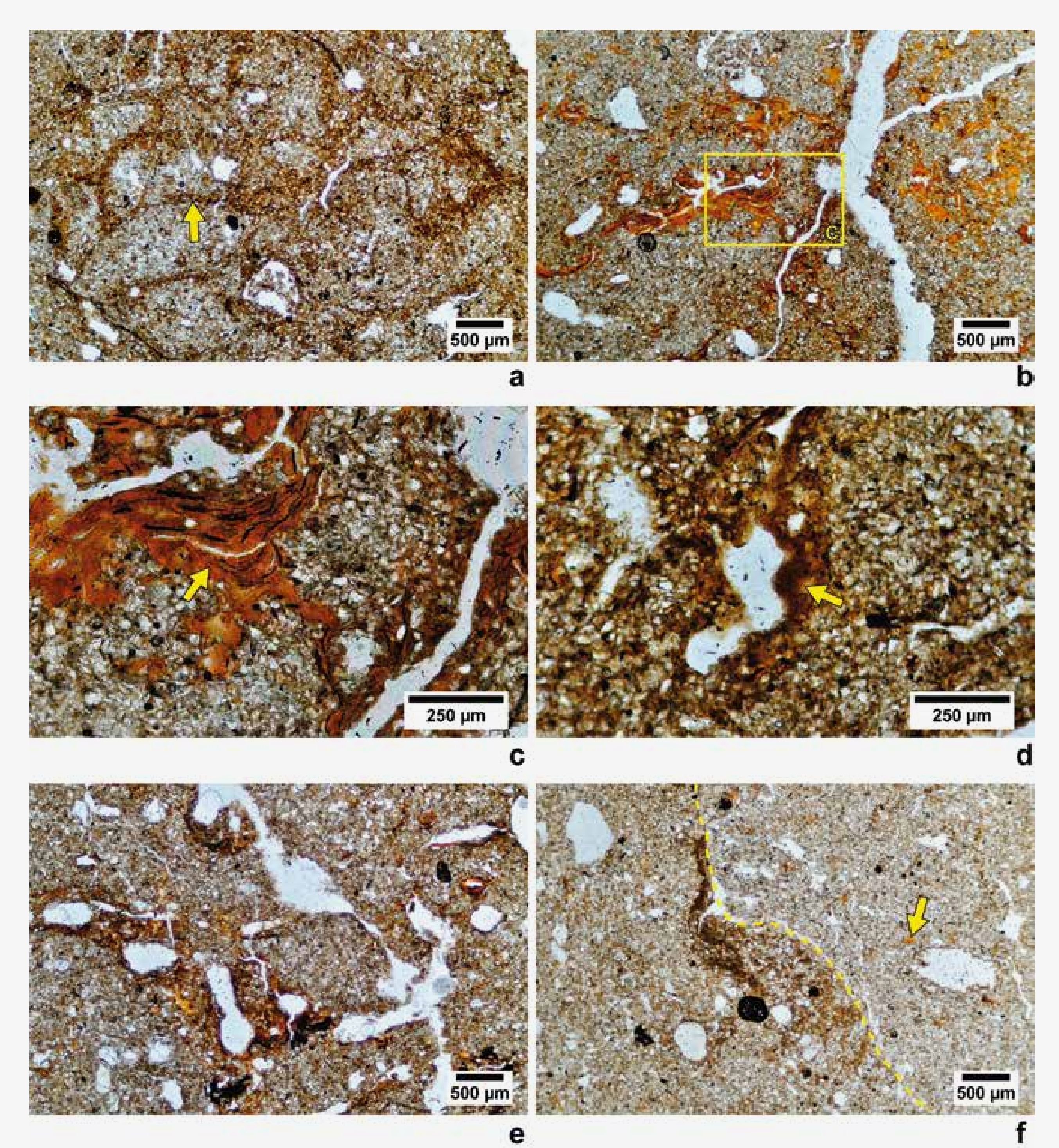


Figure 6. Aperçu des microfaciès (suite) (M. Rué). Lumière polarisée non analysée.

UPS2 (BT1), sommet :

a. Nombreuses intercalations brunes imputables à la bioturbation (flèche).

UPS2 (BT1), base :

b et c. Les revêtements illuviaux microlités orangés sont localement bien développés et en conformité avec la porosité (flèche).

d. Présence de quelques revêtements illuviaux bruns « poussiéreux » non lités, d'origine agricole possible.

UPS3 (BT1), base :

e. Organisation plus complexe et apparition d'hyporevêtements noirs provoqués par l'hydromorphie.

f. Les conduits biologiques sont toujours présents (à droite), comblés par un matériel proche des horizons superficiels et incluant des microfragments de revêtements orangés (flèche).

par de la matière organique, parfois bien développées (Fig. 5a et b), qui traduisent des remaniements par écoulement visqueux, et (ii) des fragments remaniés de croûte de battance (Fig. 5b), témoignant d'épisodes de ruissellement sur sol dénudé. La semelle de labour est marquée par une limite nette et rectiligne bien visible sur les lames lorsqu'elle n'a pas été perturbée par la faune du sol ou les racines (Fig. 4, Fig. 5c).

UPS2 (BT1 bioturbé)

Sur les lames PR4 et 5, qui recoupent respectivement le sommet et la base de l'UPS2, on constate que le matériau est, comme pour l'horizon labouré, constitué par un assemblage dense de limons quartzeux bien triés affecté par de nombreuses cavités et des vides planaires. Il se caractérise par l'apparition de revêtements illuviaux argileux orangés (Fig. 5d). Aucune figure syn-sédimentaire n'est visible, ni indice de labour ancien. On sait toutefois que la bioturbation peut rapidement en effacer les traces (Davidson, 2002). Les traits induits par la bioturbation sont très nombreux (cavités remplies de déjections de lombricidés, terriers comblés ou non, intercalations, etc.). Certains conduits recoupés présentent un comblement caractéristique à fabrique en croissant, de type « meniscate backfill » (Seilacher, 2007) ou « bow-like » (Kooistra et Pulleman, 2010), constitué par un empilement concave de matériel limoneux clair semblable à celui de l'UPS1 et généré par les vers de terre (Fig. 5e et f). La présence d'intercalations entrelacées (Fig. 6a), qui occupent parfois des surfaces importantes, résulte de la fusion partielle d'anciennes déjections de vers de terre (Thompson et al., 1990).

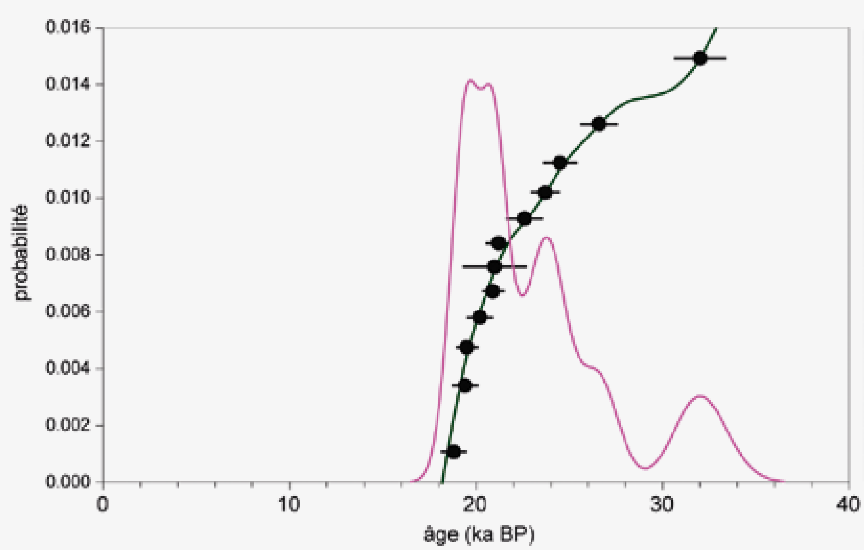
Les revêtements argileux orangés apparaissent en position conforme avec la porosité ou, plus rarement, finement broyés et intégrés dans la matrice du sol par les différentes perturbations. Ceux en place dans la porosité sont de plus en plus épais vers le bas (Fig. 6b et c). Ces revêtements en croissant, à ligne d'extinction large en lumière polarisée analysée, traduisent une longue phase de pédogenèse sous couvert forestier (Fedoroff et Courty, 1987). On distingue également quelques revêtements illuviaux plus sombres et non lités (Fig. 6d), conséquence possible de la mise en culture de la surface actuelle (Lewis, 2012). Aucun faciès imputable à un travail anthropique de la terre à des fins architecturales n'apparaît, travail qui aurait nécessairement impacté l'organisation des revêtements les plus anciens. Enfin, aucun reste anthropique n'a été décelé.

UPS3 (BT1)

La partie inférieure de l'horizon BT1 est principalement documentée par les lames PR6a et b. Le matériau est constitué par un assemblage dense de limons quartzeux affecté par des cavités et vides planaires, semblables à ceux de l'UPS2. On note l'apparition de sables grossiers et graviers siliceux, de revêtements plus complexes, de concrétions noires à contour net et d'hyporevêtements noirs imputables à l'hydromorphie (Fig. 6e). Malgré la profondeur, la porosité biologique est toujours abondante et l'on trouve encore des conduits comblés par l'UPS1 (Fig. 6f). Aucun trait anthropique n'est perceptible.

4.3. DATATION OSL

La datation des quartz de la partie inférieure de l'UPS3 (BT1) a donné un âge central d'enfouissement de 22,3 ± 1,2 ka BP (Fig. 2 et 7), ce qui renvoie à la principale période de sédimentation lœssique du dernier cycle climatique, au cours du stade isotopique 2 (Antoine et al., 2016). Ce



Référence fouille	ALG16-PR3
Référence laboratoire	GdTL-2806
Matériau analysé	quartz 90-125 µm
Unité	UPS3 (BT1)
Altitude (m NGF)	154,97
Profondeur / surface (cm)	95
Date de prélèvement	23/08/2016
Date de réception du résultat	13/06/2017
Nombre d'aliquotes	12
Teneur en eau de l'échantillon (%)	17,1 ± 0,5
Paléodose (Gy)	62,5 ± 2,7
Débit de dose (Gy/ka), alpha	0,0230 ± 0,0061
Débit de dose (Gy/ka), beta	1.481 ± 0,074
Débit de dose (Gy/ka), gamma	1,094 ± 0,035
Débit de dose (Gy/ka), cosmique	0,202 ± 0,02
Débit de dose (Gy/ka), total	2,800 ± 0,084
Age (ka) avant 1950	**22,3 ± 1,2 ka**

Figure 7. Courbe de distribution des âges OSL par aliquote et tableau des résultats (GADAM).

résultat est cohérent avec les traits d'altération pédologique présentés précédemment, en particulier les illuviations argileuses monophasées reconnues dans la porosité des UPS2 et 3 (pédogenèse Holocène). Aucune figure de gel profond n'a pourtant été observée aux échelles macro- et microscopiques dans l'unité datée bien que les dépôts limoneux enregistrent généralement bien ces traits. La pédoturbation holocène explique sans doute la disparition progressive de ces figures. Cet âge confirme le caractère condensé des dépôts, avec un taux de sédimentation moyen de l'ordre de 0,4 mm/an. Les aliquotes ont donné des âges pléistocènes, ce qui exclut des remaniements holocènes pour l'UPS3. L'interprétation de cette unité comme matériau de construction apparaît donc improbable. On sait en effet que le remaniement du sol impacte rapidement la paléodose et donc l'âge des échantillons (Kemp et al., 2014).

5. Discussion

5.1. ORIGINE DES MATÉRIAUX ET PROCESSUS SÉDIMENTAIRES RECONNUS

Comme souvent en contexte à faible taux de sédimentation, les figures syn-sédimentaires responsables de la mise en place des matériaux sont rares ou absentes. A Ablis, la structure massive des matériaux limoneux est cohérente avec des apports colluviaux en contexte de faible aggradation sédimentaire. Les processus de surface, comme la bioturbation, les alternances de gel-dégel ou le *splash*, ont vraisemblablement provoqué l'homogénéisation des matériaux au fur et à mesure de leur accumulation. Mise à part la semelle de labour actuelle et le pavage caillouteux à la base de l'horizon BT1, aucune limite d'érosion ne se distingue en coupe ou en lame mince. En outre, aucune organisation sédimentaire des mobiliers n'a été observée sur le terrain (comme des concentrations d'objets orientées dans l'axe de la plus grande pente du terrain). Cette non-reconnaissance de figure syn-sédimentaire rend donc hypothétique la mise en place du sommet de la séquence et de son contenu archéologique. Dans ce cas, l'étude taphonomique des mobiliers permet généralement de préciser les processus de formation du site (Bertran et al., 2017). Cette approche implique l'application d'outils adaptés (étude de la distribution granulométrique des objets après tamisage, analyse des fabriques, recherche de remontages, étude détaillée des états de surface, etc.). A Ablis, ces outils ne répondaient pas à l'objectif principal de la fouille centré sur l'identification d'aménagements en terre.

L'origine des fractions graveleuses et sableuses est principalement locale, par érosion puis transport des altérites tertiaires ou par remontée par la bioturbation. La fraction limoneuse est en grande partie d'origine éolienne alors que la fraction argileuse qui augmente vers le bas du profil est, au moins en partie, générée par l'altération géochimique et l'argilluviation.

Les figures post-sédimentaires sont en revanche plus nombreuses, surtout celles générées par la bioturbation. La plupart des structures biologiques cataloguées par Piron et al., (2012) sont par exemple reconnaissables dans l'UPS2. Sous nos latitudes, le brassage du sol par les vers de terre est estimé à au moins 100 tonnes par hectare et par an pour une prairie, soit autour de 10 kg de matériau remanié par m² et par an (Bouché, 2014; Jagercikova et al., 2014). L'étude micromorphologique quantitative de trois Luvisols situés sur le plateau des Alluets, à 40 km au nord d'Ablis, dans un contexte pédosédimentaire proche, a montré que la bioturbation impacte environ 65 % du volume total du sol à 40 cm de profondeur et 20 à 30 % de ce volume à 150 cm de profondeur (Sauzet, 2016). Toujours d'après ce travail, en un à deux siècles, « la masse totale de sol bioturbé par l'activité des vers de terre équivaut à la masse de sol contenue dans les 40 premiers cm de sol » (Sauzet, 2016, 106). On imagine mal dans ce cas comment peuvent subsister des micro-organisations anthropiques âgées de plusieurs millénaires.

A Ablis, quatre principales étapes peuvent être avancées pour expliquer la formation des UPS1 à 3:

1) Apports limoneux éoliens au cours du Pléistocène supérieur associés à des remaniements verticaux et latéraux pouvant expliquer la présence de la fraction grossière.
2) Cryoturbations durant les phases à pergélisol.
3) Pédogenèse holocène provoquant la différenciation des horizons E et BT1, l'apparition de traits hydromorphes en profondeur et la disparition partielle des stigmates périglaciaires.
4) Mise en culture affectant l'horizon E et le sommet de l'horizon BT1.

Cette séquence n'a rien de surprenant en contexte lœssique, elle a souvent été documentée (*e.g.* Langohr, 2001; Jamagne, 2011; Gebhardt et al., 2014). Différentes phases de colluvionnement ont probablement rythmé sa formation au cours de l'Holocène, mais elles sont indécelables ici.

5.2. MATÉRIAU ARCHITECTURAL VERSUS PÉDOLOGIQUE

Aucun reste en terre crue n'a été perçu lors de la fouille, ni en plan ni en coupe, malgré la surface décapée et les bonnes conditions d'observation. Les résultats analytiques sont cohérents avec une origine naturelle de la stratigraphie. La date OSL en témoigne très clairement.

Les « pains de terre » identifiés en plan lors du diagnostic résultent en réalité de la structuration polyédrique de l'horizon BT1, une conséquence de l'argilluviation qui caractérise les sols lessivés. Appelée « sur-structure » par Gaucher (1968) et Baize, Jabiol (2011), elle délimite en plan des polygones centimétriques à décimétriques, qui, selon le traitement que l'on opère (balayage, séchage, etc.), ressortent plus ou moins bien (Fig. 3e). A cette structure polyédrique s'ajoute une structure grumeleuse induite par l'activité de la faune du sol, augmentant ainsi la variabilité des faciès. Plus en profondeur, c'est l'hydromorphie qui explique les figures interprétées comme des restes d'éléments architecturaux. Toutes ces organisations sont omniprésentes sur l'emprise de la fouille et même au-delà.

Les microfaciès anthropiques perçus initialement dans les lames minces s'apparentent à des traits communs dans ce type de sol, en grande partie générés par l'activité biologique, en particulier par les vers de terre. Le rôle de ces derniers ne peut être négligé en raison des volumes importants de terre déplacés (Stein, 1983 ; Armour-Chelu et Andrews, 1994 ; Canti 2003). A Ablis, la bioturbation a progressivement mélangé la matrice claire de l'horizon LE à celle orangée de l'horizon BT1, générant ainsi une grande diversité de microfaciès. Ce biomalaxage, pour reprendre une expression introduite par Langohr (2001), explique les nombreuses organisations interprétées comme des aménagements en terre crue aux échelles microscopiques. Au sommet de l'horizon BT1, le biomalaxage se conjugue aux passages répétés de la charrue (Fig. 5c). Les galeries empruntées par les vers peuvent également mimer des organisations anthropiques singulières (selon l'échelle à laquelle on les observe). Le « joint » séparant deux « pains de terre » (Brutus et al., 2015, p. 70) correspond par exemple à l'une de ces galeries, au comblement à fabrique en croissant symptomatique du passage d'un ver. Nos résultats soulèvent donc, en partie, un problème de convergence de faciès, un biais d'interprétation pourtant connu en micromorphologie des sols (Brewer, 1972 ; Valentine et Dalrymple, 1976 ; Kemp, 1998).

Ces constats pourraient être élargis aux sites où des restes en terre ont été localisés dans un contexte pédosédimentaire similaire à celui d'Ablis, c'est-à-dire sous l'horizon cultivé, dans les unités plus fortement impactées par la bioturbation. La question se pose également pour les successions de sols d'occupation décelées en lame mince, comme en région Centre-Val de Loire sur les sites des Carreaux à Prunay-le-Gillon, des Friches de Frotville à Sours ou encore des Grands Noyers à Gas (Wattez et Onfray, 2014 ; Onfray et Wattez, 2015 ; Onfray, 2019) où les faciès anthropiques apparaissent étonnamment bien conservés. Dans la plupart des études, le substrat des sites est par ailleurs rarement documenté en lame mince, alors que son examen détaillé devrait constituer la base des études. L'élaboration plus systématique d'un référentiel de traits naturels (à partir de lames minces issues du substrat) et de traits anthropiques (à partir d'éléments façonnés avérés) semble en effet indispensable afin de limiter le biais d'équifinalité, de même que l'intégration de ce référentiel dans les rapports et publications. La réalisation de datations OSL pourrait également s'avérer utile dans certains cas.

5.3. HYPOTHÈSES SUR LA PROVENANCE DES OBJETS EN ÉPANDAGE DANS L'HORIZON BT1

La présence de vestiges épars de différentes époques dans le sol, sans concentration notable et selon des densités faibles, est souvent difficile à expliquer. A Ablis, plusieurs hypothèses peuvent être avancées pour expliquer cette configuration.

5.3.1. Occupations résidualisées

Une première hypothèse consiste à considérer que les occupations se sont déroulées directement sur place (ou à proximité immédiate), sur une surface proche de celle actuelle, et que le ou les niveaux occupés se sont secondairement résidualisés par évacuation de leur fraction fine, fragmentation et altération d'une partie des vestiges (en particulier par les labours). La rareté des structures et le très faible taux d'anthropisation des UPS n'argumentent pas dans ce sens. Nous ne pouvons toutefois pas exclure complètement cette hypothèse dans le cas d'occupations à faible impact sur le sol.

5.3.2. Apports par les amendements

Une partie du mobilier en épandage rencontré pourrait également s'expliquer par la pratique de la fumure, un phénomène sous-estimé dans la formation des épandages archéologiques (Poirier et Nuninger, 2012). Il reste cependant difficile à quantifier. A Ablis, la répartition du mobilier apparaît localement contrainte par l'ancien parcellaire, ce qui peut plaider en faveur de cette hypothèse.

5.3.3. Apports par colluvionnement

L'origine colluviale des dépôts ou des vestiges est souvent proposée par habitude ou confort intellectuel. A Ablis, l'hypothèse d'une provenance des mobiliers par l'érosion d'occupations situées plus en amont se heurte toutefois à la présence des revêtements illuviaux argileux orangés dans l'horizon BT1 et dont la formation implique une longue phase de pédogenèse sous couvert forestier. Ceux observés en position primaire dans l'UPS2 semblent en effet incompatibles avec une mise en place synchrone de cette unité et de son contenu archéologique par colluvionnement (ni même avec un remaniement par le labour qui, à terme, provoque la destruction de ces illuviations anciennes). En outre, l'horizon E, qui s'est formé au cours de la pédogenèse luvisolique holocène, est toujours présent dans la séquence étudiée puisqu'il constitue le support de l'horizon labouré. Il est également présent plus en amont du site. Cette configuration indique que, si des processus érosifs ont eu lieu, ils ont été superficiels. Enfin, aucune limite pouvant correspondre à une troncature érosive n'a été observée en coupe ou décelée par les analyses. Ainsi, l'hypothèse colluviale ne peut être mise en avant pour expliquer à elle seule la présence de mobilier dans l'UPS2.

5.3.4. Rôle de la bioturbation

Les nombreux stigmates provoqués par la bioturbation nous amènent à proposer un autre mécanisme impliqué dans la formation du site : l'enfouissement progressif des vestiges par la bioturbation. Ce processus permet d'expliquer la présence d'objets épars et d'âge variable dans la partie supérieure de l'horizon BT1. Il est également compatible avec la préservation des traits illuviaux anciens. L'intégration des vestiges dans le sol s'opère à la fois par la descente des objets le long des conduits biologiques (Fig. 3f) et par la remontée progressive de la terre en surface par les organismes (Fig. 3g). L'estimation des taux d'enfouissement varie assez fortement d'une étude à l'autre. Si l'on retient la fourchette comprise entre 0,25 et 0,4 mm/an (Richards Humphreys, 2010), la profondeur atteinte en un millénaire avoisine environ 25 à 40 cm. Juste après l'abandon des objets en surface du sol, les taux d'enfouissement apparaissent toutefois encore plus élevés (Butt et al., 2016). L'enfouissement des vestiges par la faune du sol est rarement pris en compte par la communauté archéologique dans l'étude taphonomique des sites (Schwartz, Gebhardt 2011). Ce mécanisme est pourtant bien documenté (Balek, 2002 ; Johnson, 2002 ; Feller et al., 2003 ; Morin, 2006 ; Walkington, 2010).

Seule une étude taphonomique précise des mobiliers permettrait de préciser ou nuancer la contribution relative de ces différents processus. Une origine mixte des vestiges est pour le moment vraisemblable, limitant de fait la lecture archéologique des plans de leur répartition.

6. Conclusions

La fouille du site des Genêts à Ablis n'a pas confirmé la présence d'aménagements en terre crue décelés initialement, ce que la plupart des résultats analytiques ont également confirmé. Notre étude montre que les organisations architecturales perçues durant l'évaluation ont été confondues avec des traits pédologiques naturels, démontrant ainsi que les faciès diagnostics d'un travail de la terre aux échelles microscopiques ne sont sans doute pas aussi nombreux que ne le suggèrent les publications. Ces organisations sont provoquées à la fois 1) par l'évolution structurale et géochimique d'un dépôt lœssique à partir du Dernier maximum glaciaire et 2) par la bioturbation, à l'origine de nombreux microfaciès qui, dans certains cas, imite une action humaine. Cette convergence entre faciès naturels et faciès anthropiques est fréquente dans les disciplines archéologiques. Elle constitue cependant un terrain d'étude encore peu exploré dans la reconnaissance des témoins architecturaux en terre crue. Enfin, la formation de la nappe d'objets située dans la partie supérieure du Luvisol résulte d'une histoire taphonomique complexe faisant intervenir plusieurs processus naturels (colluvionnement, résidualisation, bioturbation, etc.), limitant ainsi son exploitation archéologique.

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FACING COMPLEXITY

An interdisciplinary study of an early medieval Dark Earth witnessing pasture and crop cultivation from the centre of Aalst (Belgium)

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ABSTRACT
The ubiquitous urban Dark Earths compose a main challenge for urban archaeologists. Due to their homogeneous character they cannot be readily understood based on field data alone. Geoarchaeology (field study and micromorphology) has shown to be particularly well suited to tackle these layers, and to reveal their complex formation histories and the human activities and natural events involved. During the excavations of the site of Sint-Jozefs-college in the centre of Aalst (Belgium) a thick dark earth was discovered underneath the remains of the rampart of the 11th century town wall. An interdisciplinary study, involving archaeology, geoarchaeology and phytolith analysis has been performed. It demonstrates that the Dark Earth layer has a long formation history involving pasture and crop growing, intimately mixed with soil processes such as bioturbation and colluviation. The identified activities confirm the rather rural character of the area until the 11th century AD.

KEYWORDS
urban geoarchaeology, soil micromorphology, phytoliths

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1. Introduction

The understanding of the formation and build-up of urban deposits is an important issue in urban archaeology. Beyond being the container for artefacts and ecofacts, soils and sediments can provide detailed information on the context in which human activities took place locally, and on the wider environment. Although many layers can readily be identified during fieldwork, part of the urban stratigraphy remains difficult to understand based on field data alone (see for instance Devos et al., in press). This is especially true for the urban Dark Earths. These are thick, dark coloured, humic, homogeneous units covering large surfaces that are often rich in anthropogenic remains (charcoal, ceramic, brick, bone, mortar, coprolites, slag, etc.) (Nicosia et al., 2017; Devos, 2019). Geoarchaeological studies, and especially micromorphology, have shown to be particularly well adapted to study these layers and reveal their secrets (see for instance Macphail, 1994; Cammas et al., 1995; Devos et al., 2011; Nicosia et al., 2013; Nicosia and Devos, 2014; Borderie et al., 2015; Wouters et al., 2017; Nicosia, 2018; Devos, 2019). The numerous studies performed in European towns demonstrated the often complex and unique formation histories of the urban Dark Earth. This implies that each Dark Earth should be investigated on an individual basis. It is only by doing so that the site stratigraphy can be understood and the succession of human activities and natural events can successfully be deciphered.

During the excavation on the site of Sint-Jozefscollege in Aalst, a Dark Earth composed of two thick, dark, humic and macroscopically stratigraphically undifferentiated units, whose origin, formation and archaeological significance were unclear, were identified and sampled.

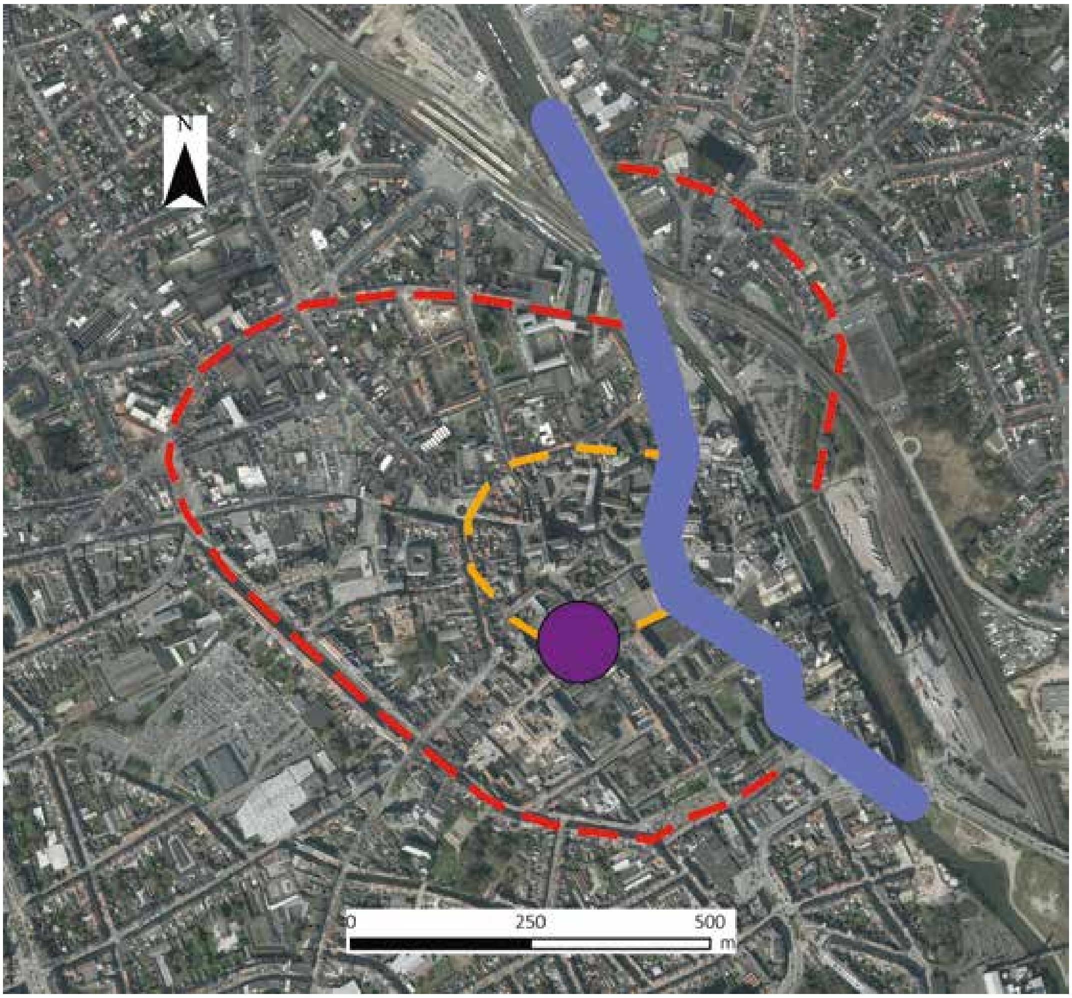


Figure 1. Map showing the location of the site of Sint-Jozefscollege and the two stone town ramparts (orange: first town wall; red: second town wall; blue: the medieval course of the Dender river; purple dot: site of Sint-Jozefscollege). Digitale versie van de Orthofoto's, middenschalig, kleur (Informatie Vlaanderen, 2017).

The aim of the present study is to verify field hypotheses and to evaluate the potential of integrated archaeological, geoarchaeological and phytolith studies to understand these Dark Earth units.

Figure 2. View from the east on the excavation trench.

2. The archaeological site and its historical meaning

The site of Sint-Jozefscollege is situated at the edge of the historic centre of Aalst, on the left bank of the Dender river (Fig. 1). On the Belgian soil map the area is located at the margins of the loess deposits. The site is marked as 'built area' (OB) (Louis, 1961), which implies that no detailed information on local soil development is available. The elevation of the site is ca. 13m above sea level. The excavations of 2009 (Fig. 2) revealed among others the presence of the remains of the ditch and earthen rampart of the first town wall (De Groote and Moens 1995; De Groote et al. 2010a; De Groote et al. 2010b) (Fig. 3). Underneath this earthen defence wall, which remnants functioned as a protective bell, a thick Dark Earth was observed (Fig.s 3, 4). As the Dark Earth covered some Merovingian remains (*infra*), this 30 to 40 cm thick layer can be generally dated between the 6th and the middle of the 11th century. It is divided into an older, about 10 cm thick, light coloured homogenic unit (Fig. 4a: unit 2; Fig. 4b: unit 24) and a younger 20 to 30 cm thick darker unit (Fig. 4a: units 7, 8a and 8b; Fig. 4b: unit 25). During the excavation the oldest unit, which contained some Merovingian pottery sherds, was interpreted as remains of a meadow. The younger thick unit, containing some pottery dating from the 8th until the early 11th century, was interpreted as the remnants of arable land.

The medieval town of Aalst has its roots in the Early Medieval period (5th-9th c.), when a Merovingian settlement developed into a Carolingian manor, first mentioned as the *locus Aalst* in the property lists of the abbey of Lobbes, made around 868-869 (De Groote, 2010; De Groote, 2013). A *polyptycum* lists the properties of the abbey by *pagus*, mentioning *Alosta* in the *pagus Bracbattensis*. Besides that, a *discriptio villarum* is preserved, in which many details about this property are mentioned. This phrase makes it clear that it was a bipartite manor, composed of a court with demesnes, which was cultivated directly for the owner of the domain, and of farmsteads (*mansi*) with tenements or tenures, which the farmers or tenants cultivated for themselves in exchange for services

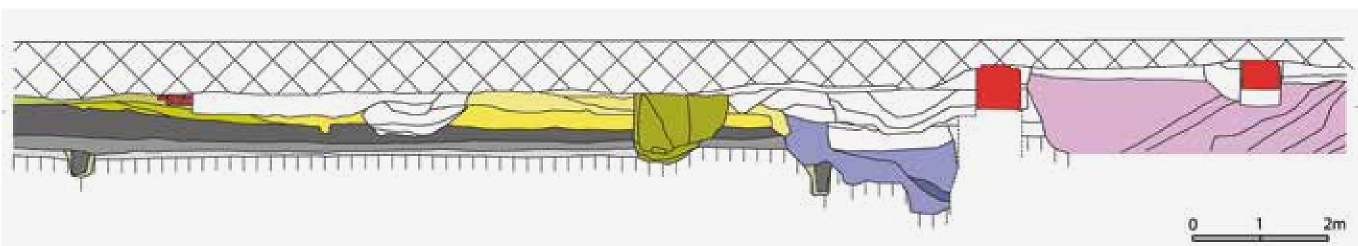


Figure 3. Northwest profile of Trench 1 (light and dark grey: Dark Earth layers covering two Merovingian postholes; yellow: remains of 11th c. earthen rampart; blue: 12th c. extraction pit; green: late medieval pit; purple: post-medieval debris pit; red: brick foundations).

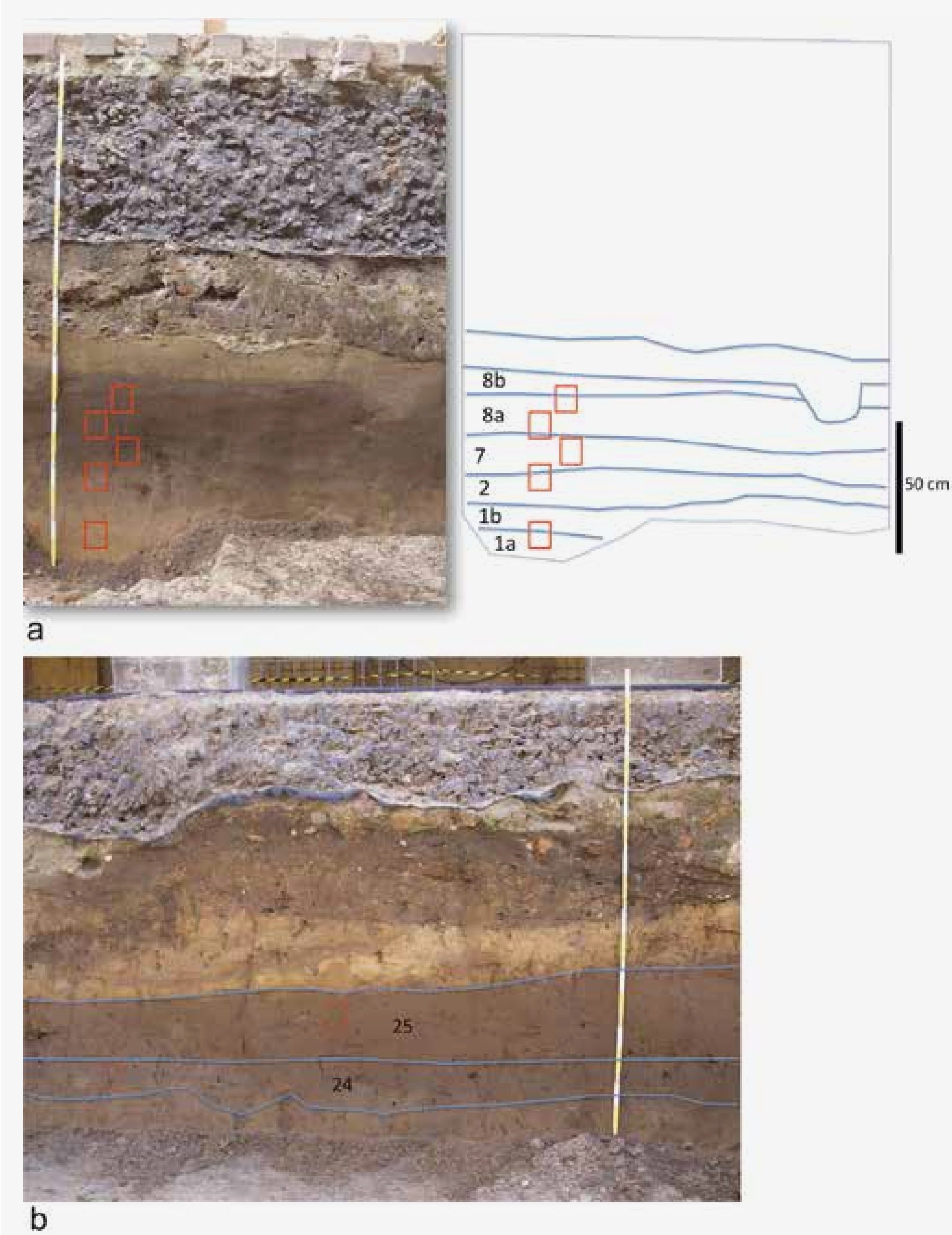


Figure 4. Analysed sections with indication of the stratigraphical units/horizons and the location of the block samples for micromorphology (a: NW profile; b: SO profile).

and payments (for military service) and goods (Callebaut, 1983). The exact location of this Carolingian settlement or its outlay is still unknown, but has to be situated in the direct neighbourhood of the St. Martins church, of which archaeological remains point at a pre-10th century origin, probably first serving as a proprietary church (De Groote, 2010; De Groote, 2013).

The excavations of 2009 revealed, for the first time, traces of a Merovingian settlement, which were preserved underneath the remains of the 11th century earthen defence wall, including a series of postholes belonging to at least one main building (De Groote et al. 2010a; De Groote et al. 2010b). All four radiocarbon analyses on charcoal from the postholes situate this occupation in the period of the 5th to the first half of the 6th century. Ceramic finds, collected from the postholes and from the lower 10 cm of the thick covering layer of Dark Earth, confirm this chronology. After the abandonment of this occupation, the area seemed to have been (re-)incorporated in the agricultural area, as could be derived from the thick humiferous layers of Dark Earth covering it. The aim of the study of these layers of Dark Earth was to unravel the occupation history between the Merovingian habitation and the construction of the first town wall.

3. Material and methods

3.1. FIELD OBSERVATIONS AND SAMPLING

Field descriptions were made according to the 'Comprehensive Field Data Bases' (Langohr, 1994) and the 'Guidelines for Soil Profile Description' (FAO, 2006). Adapted checklists were applied to describe associated features (Fechner et al., 2004). Additionally, mole galleries were counted on horizonal sections at 10 cm intervals starting from the top of the Dark Earth (Fig. 5). Undisturbed and oriented block samples were taken from the studied vertical sections for the realisation of soil thin sections (Fig. 4).

3.2 SOIL MICROMORPHOLOGY

Thin sections were prepared from the air-dried blocks in the laboratory (Beckmann, 1997). The thin sections are 8 cm long and 6 cm large. Their thickness is ca. 30 µm. Observations were made with a petrological microscope under plain polarised light (PPL), under crossed polarizers (XPL), and oblique incident light (OIL) at magnifications of 25x, 100x, 200x, 400x and 500x. The thin sections were also scanned under (UV and blue) fluorescence at 400x magnification (Van Vliet-Lanoë, 1991; Stoops, 2017). The thin sections were described following the international nomenclature of the 'Guidelines for analysis and description of soil and regolith thin sections' (Stoops, 2003). Semi-numerical counting was performed according to Macphail and Cruise (2001) and Borderie (2011).

3.3. PHYTOLITH STUDY ON THIN SECTIONS

The phytolith analysis was carried out according to Vrydaghs and Devos (2019, in press) and Vrydaghs et al. (2016a; 2017). Besides specific cases (coprolites, plant fragments, etc.), a series of squares of 5 by 5 mm were selected, based on the results of the micromorphological study. These target the phytolith content of the soil matrix thereby avoiding compiling phytoliths with other depositional histories (e.g. phytoliths within coprolites, ash remains, etc.). Within these selected areas, four fields of 0.2 mm² were systematically scanned. The phytolith analysis consisted of a four-step approach:

1. systematic recording of the distribution patterns of the phytoliths;
2. inventory of the phytoliths within each distribution pattern. The naming of the phytoliths follows the nomenclature of ICPN2.0 (ICPT, in press);
3. counting of the phytoliths within each distribution pattern;
4. description of visibility, preservation and colour of the individual phytoliths following Vrydaghs and Devos (in press).

Table 1 Field descriptions of the stratigraphic units of the studied sections

Profile	Unit	Description	
1		Recent pavement	
		Gravel layer	
		Heterogeneous levelling layer	
		Heterogeneous, loam, pale yellow to very pale brown, abrupt smooth lower boundary	Earthen rampart
	8b	Homogeneous, sandy loam, reddish gray, iron pan at lower boundary, abrupt smooth to wavy lower boundary	Dark Earth
	8a	Homogeneous, sandy loam, dark gray, clear wavy lower boundary	Dark Earth
	7	Homogeneous, sandy loam, gray, clear to gradual wavy lower boundary	Dark Earth
	2	Sandy loam, light gray, clear wavy to irregular lower boundary	Bbi
	1b	Sandy loam, pale yellow, abrupt, wavy lower boundary	E
	1a	Sandy clay loam, very pale brown	Bt
2		Gravel layer	
		Heterogeneous levelling layer	
		Heterogeneous, loam, pale yellow to very pale brown, abrupt wavy lower boundary	Earthen rampart
	25	Homogeneous, sandy loam, reddish gray, clear wavy lower boundary	Dark Earth
	24	Homogeneous, sandy loam, gray to dark gray, gradual wavy to irregular lower boundary	Dark Earth
		Sandy loam, gray to light gray	Bbi

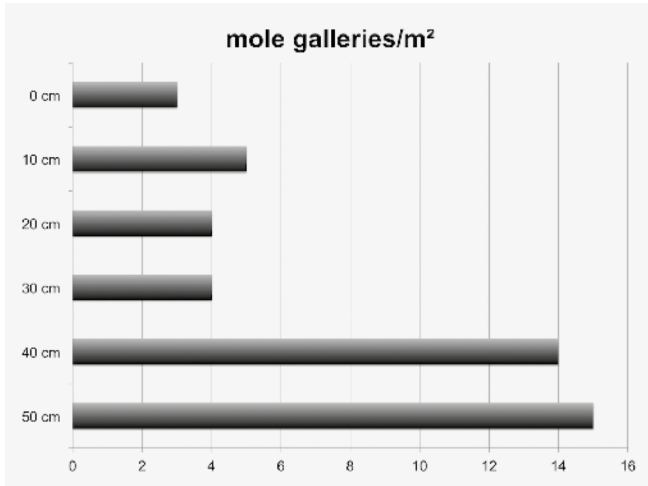


Figure 5. Counting of the mole galleries. Mole galleries have been counted each 10 cm starting from the top of the dark earth (= 0 cm) down to the base (= 50 cm). The oldest phase, corresponding to unit 2 (=40 and 50 cm) shows the highest concentration of galleries.

4. Results and discussion

Field data are summarised in table 1. The counting of the mole galleries is reported in figure 5. Micromorphological data are presented in table 2 and phytolith data in figure 6.

4.1. POST-DEPOSITIONAL PROCESSES

To understand the site history, one also needs to take into account post-depositional processes, as these can strongly affect the sedimentary matrix (Mallol and Bertran, 2010; Karkanas and Goldberg, 2019). Therefore, these will be discussed first.

The construction of the earthen rampart of the first city wall in the 11th century AD had a double effect on the preservation of the Dark Earth underneath. On the one

Table 2 Overview of the most relevant micromorphological observations and interpretations per stratigraphic unit

Unit	Main characteristics	Interpretation
1a	Moderately developed subangular blocky microstructure; chito-enaulic to porphyric; dominated by unsorted silt to medium sand sized quartz; additional minerals: feldspar, glauconite and mica; abundant limpid clay coatings	Bt
1b	Massive to poorly developed subangular blocky microstructure; chito-enaulic to coarse monic; dominated by unsorted silt to medium sand sized quartz; additional minerals: feldspar, glauconite and mica; few limpid, layered and few dusty clay coatings, common earthworm and root galleries	E, affected by biological activity
2	Welded granules to poorly developed subangular blocky microstructure; chito-enaulic to coarse monic; dominated by unsorted silt to medium sand sized quartz; additional minerals: feldspar, glauconite and mica; abundant earthworm and root galleries and excremental organo-mineral aggregates; typic iron nodules	Pasture land
7, 8a, 24 & 25	Welded granules; chito-enaulic; dominated by unsorted silt to medium sand sized quartz; additional minerals: feldspar, glauconite and mica; humic, common randomly and unoriented anthropic remains (charcoal, bone, ceramics, rounded soil fragments, ashes, including vitrified phytoliths, coprolites); abundant earthworm and root galleries; dusty clay coatings, short wavy lenses of dusty fine material, phosphatic nodules	Crop cultivation
8b	See previous, iron crust at lower boundary	Crop cultivation + compaction

hand, this cover originally composing of several meters of sediment sealed off the Dark Earth units below, thus protecting them from any posterior activity and almost all natural impact (bioturbation, etc.). This is for instance witnessed by the very sharp boundary between the top of the Dark Earth and the sediments of the earthen rampart. As such, the Dark Earth possesses a high potential to identify human activities taking place before the construction of the rampart and to estimate their impact on the environment.

On the other hand, this massive dump of material caused the compaction of the upper part of the sequence and the subsequent redistribution of iron as witnessed by a lower porosity and the presence of an iron crust.

4.2. THE PARENT MATERIAL

The basal part of the studied sequence is mainly composed of silt to medium sand sized quartz, with some glauconite, which is rather typical for Aeolian deposits in Middle Belgium (Van Ranst et al., 1982). Micromorphological observations showed that anthropogenic materials were rare and probably intrusive. The observed limpid clay coatings are associated with natural processes and stable surfaces (Fedoroff and Goldberg, 1982; Macphail et al., 1987; Mikkelsen and Langohr, 1996). Being decalcified, this parent material has – without amendments – a very limited chemical fertility (see for instance Langohr, 2001).

4.3. FORMATION OF DARK EARTH

The formation of the Dark Earth on the site of Sint-Jozefscollege is the result of a complex interplay of a series of natural events and human actions, both involving a series of processes. These processes will be outlined first.

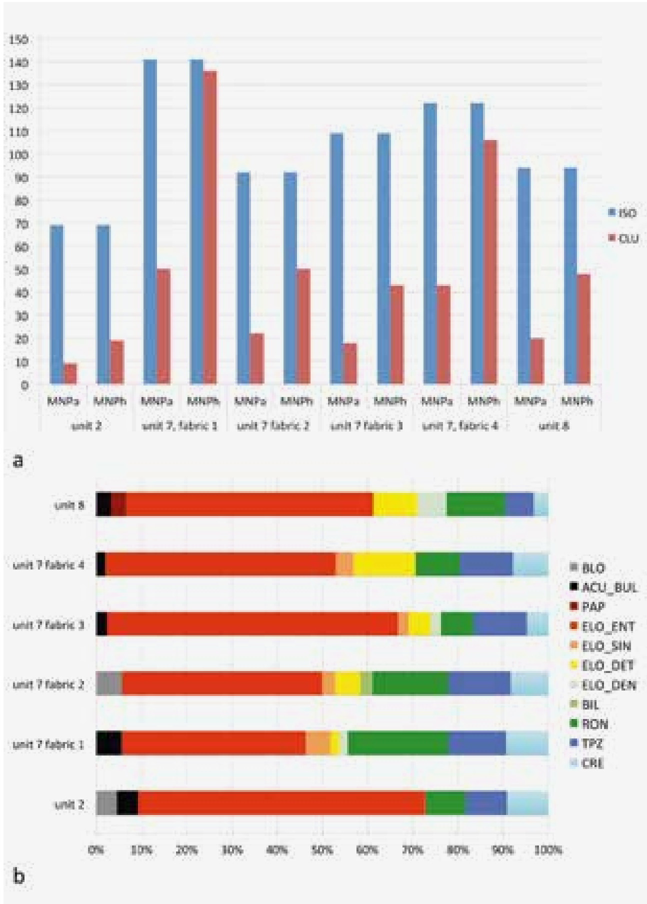


Figure 6. Results of the phytolith analysis:

a. Minimal Number of Distribution patterns (MNPa) and Minimal Number of Phytoliths (MNPh) per distribution pattern. ISO: Isolate; CLU: Cluster.

b. Frequencies (in %) of the various phytolith types. BLO: Blocky; ACU_BUL: Acute bulbosus; PAP: Papillate; ELO_ENT: Elongate entire; ELO_SIN: Elongate sinuate; ELO_DET: Elongate dentate; ELO_DEN: Elongate dendritic; BIL: Bilobate; RON: Rondel; TPZ: Trapezoid; CRE: Crenate.

4.3.1. Processes

A first process that has been observed is the accumulation of material resulting in a thickening of the Dark Earth. Main components are the input of colluvial material, household (kitchen) waste, excremental waste (coprolitic material) and construction waste (earthen-based construction materials). The household waste is identified based on the combined presence of charcoal, bone (Fig. 7a), burned bone (Fig. 7b), ceramics (Fig. 7c) and vitrified silica (Fig. 7d). The latter results from the melting of phytoliths (see for instance Gebhardt and Langohr, 1999; Vrydaghs et al., 2017). Coprolitic material, often in combination with phosphatic nodules (Fig. 7e) and fungal sclerotia, reveals the addition of excremental waste. The construction waste is mainly composed of dense rounded aggregates (Fig. 7f). These

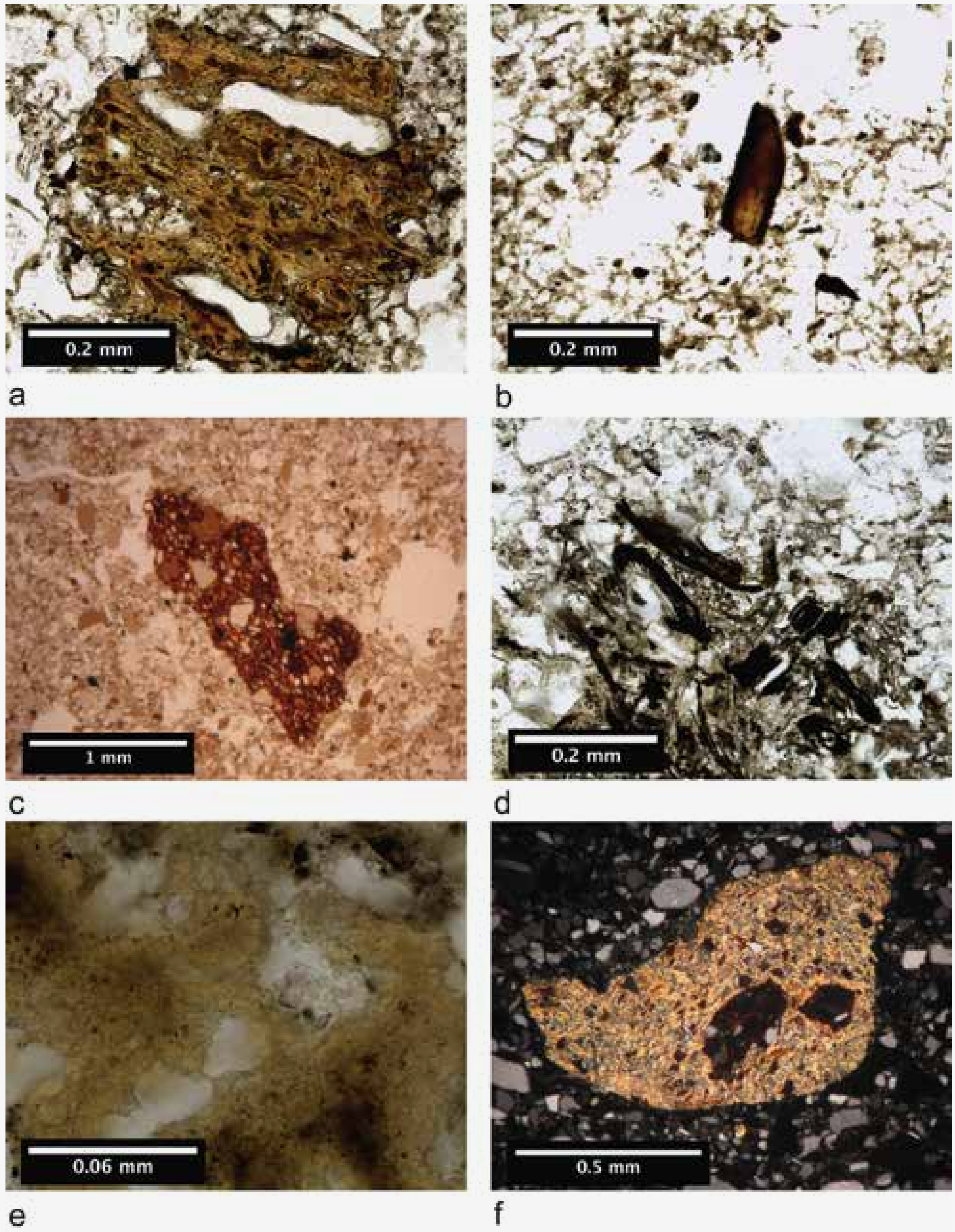


Figure 7. Photo micrographs:

a. weathered bone fragment (unit 8, PPL)
b. burned bone fragment (unit 8, PPL)
c. ceramic/brick fragment (unit 8, PPL);
d. charred plant remains including phytoliths (unit 8, PPL)
e. detail omnivore coprolite containing phytoliths (unit 24, PPL)
f. earthen based construction material (unit 8, PPL)

are microscopic fragments of earthen-based construction materials (daub, clay-floors, etc.) (Devos et al., 2013a).

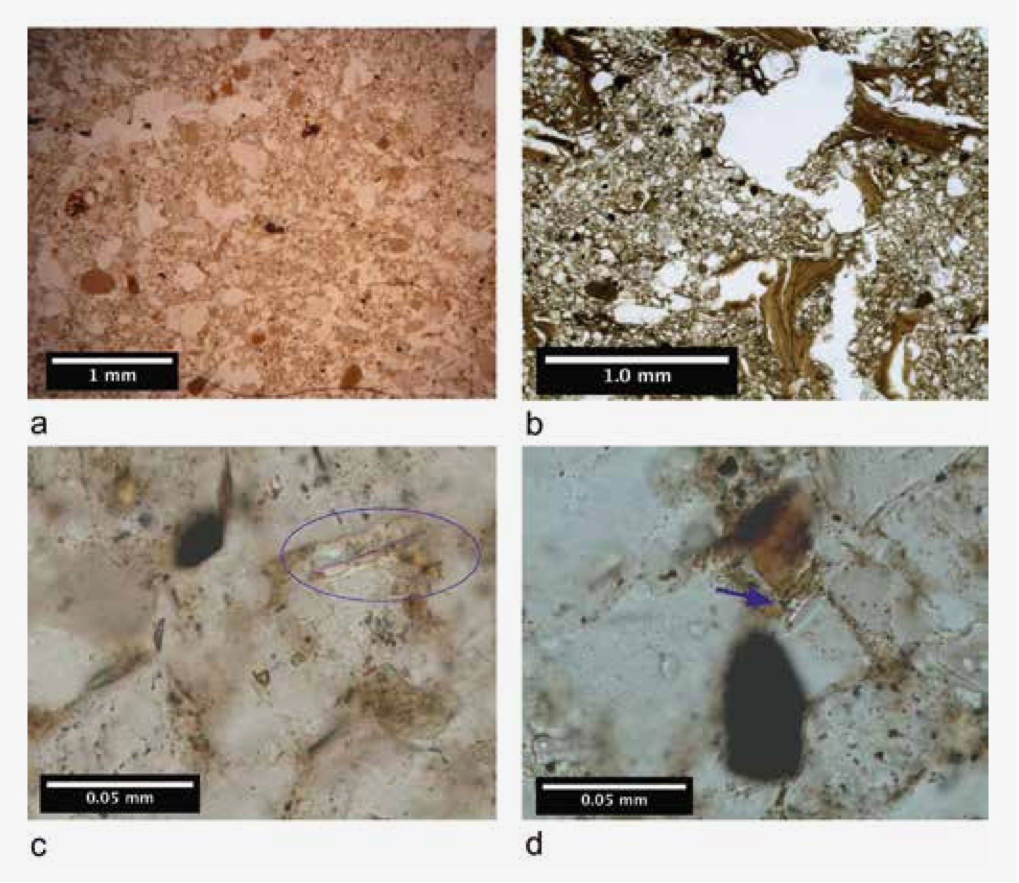
The anomalous thickness of the horizon composed of one similar, unsorted, mineral fraction, containing anorthic iron oxide nodules further suggests the input of colluvium (Mücher et al. 2018).

A second process, the eradication of the original stratification and/or horizonation is mainly due to human reworking (digging) and bioturbation (mainly moles (Fig. 5), earthworms and roots). The fully mature character of the Dark Earth indicates that the degree of homogenisation outreaches the sedimentation/accumulation rate.

We further observed the degradation of earthen-based construction materials, resulting in their fragmentation and the release of sedimentary particles (particularly of coarse silt and very fine sand) (Macphail, 2003). The well-aerated soil, in combination with a high biological activity, favours a rapid humification of organic remains (plant fragments, excrements, etc.,). Therefore only small quantities of more resistant seeds and fruits will be preserved.

Further pedogenic processes are clay translocation and oxidoreduction (see *infra*).

Figure 8. Photo micrographs:
a. organo-mineral excremental aggregates (unit 2, PPL)
b. limpid clay coating (unit 1, PPL)
c. isolated CRENATE (outer periclinal surface) observed within the soil matrix of the pasture land (unit 2, PPL)
d. isolated RONDEL observed within the soil matrix of the pasture land (unit 2, PPL)



4.3.2. Human activities

Pasture land

Unit 2 witnesses the presence of pasture land.
This unit has similar mineral composition and texture to the underlying parent material, thus indicating that this unit is the result of pedogenic processes rather than the addition of new sediments. The horizon is strongly affected by bioturbation. This is evidenced by the high quantity of mole galleries (Fig. 5), abundant organo-mineral excremental aggregates (Fig. 8a) and (root) galleries. In combination with its humic character, this indicates an ancient (near) topsoil horizon (Gerasimova and Lebedeva-Verba, 2010). The presence of abundant limpid clay coatings (Fig. 8b) further evokes a permanent soil cover. This unit shows the lowest amount of phytoliths, mostly isolated. The phytolith assemblage, composed of redundant and typical types such as CRENATE (Fig. 8c), RONDEL (Fig. 8d) and TRAPEZOID phytoliths is consistent with the identification of a grassland cover (see also Devos et al., 2013a).

Some phosphatic remains and fungal sclerotia have been noted, suggesting the presence of animals. Moreover, we observed multiple redoximorphic traces suggesting local muddy conditions, often found in association with animal trampling (Mikkelsen and Langohr, 1996; Goldberg and Macphail, 2006). Grazing can also explain the anomalous high bioturbation by common earthworms and moles (Langohr et al., 2015).

Crop fields

Traces of the presence of a crop field have been observed within units 7, 8a, 8b, 24 and 25 (Fig. 4).
The humic character, in combination with the presence of mesofaunal activity and root galleries, implies that we are again dealing with an ancient (near) topsoil horizon (Gerasimova and Lebedeva-Verba, 2010). The high mineral and textural similarity with the underlying unit indicates that they share the same sedimentary matrix (see for instance Devos et al., 2009; 2013a). The ubiquitous presence of textural pedofeatures, including dusty clay and clay-silt coatings along pores (Fig. 9a) and short wavy lenses of dusty (humus/soot rich) fine material, clearly point to the mixing of the ancient topsoil as a consequence of agricultural activities (Courty et al., 1989; French, 2003; Lewis, 2012). Complementary evidence of the physical workings of the soil are the strong fragmentation and random distribution of anthropogenic elements such as charcoal, bone and ceramics (Devos et al., 2009; 2013a; 2013b; 2017). Within the charcoal fraction for instance, we observe a clear dominance of the finer fractions (Fig. 9b), pointing to the

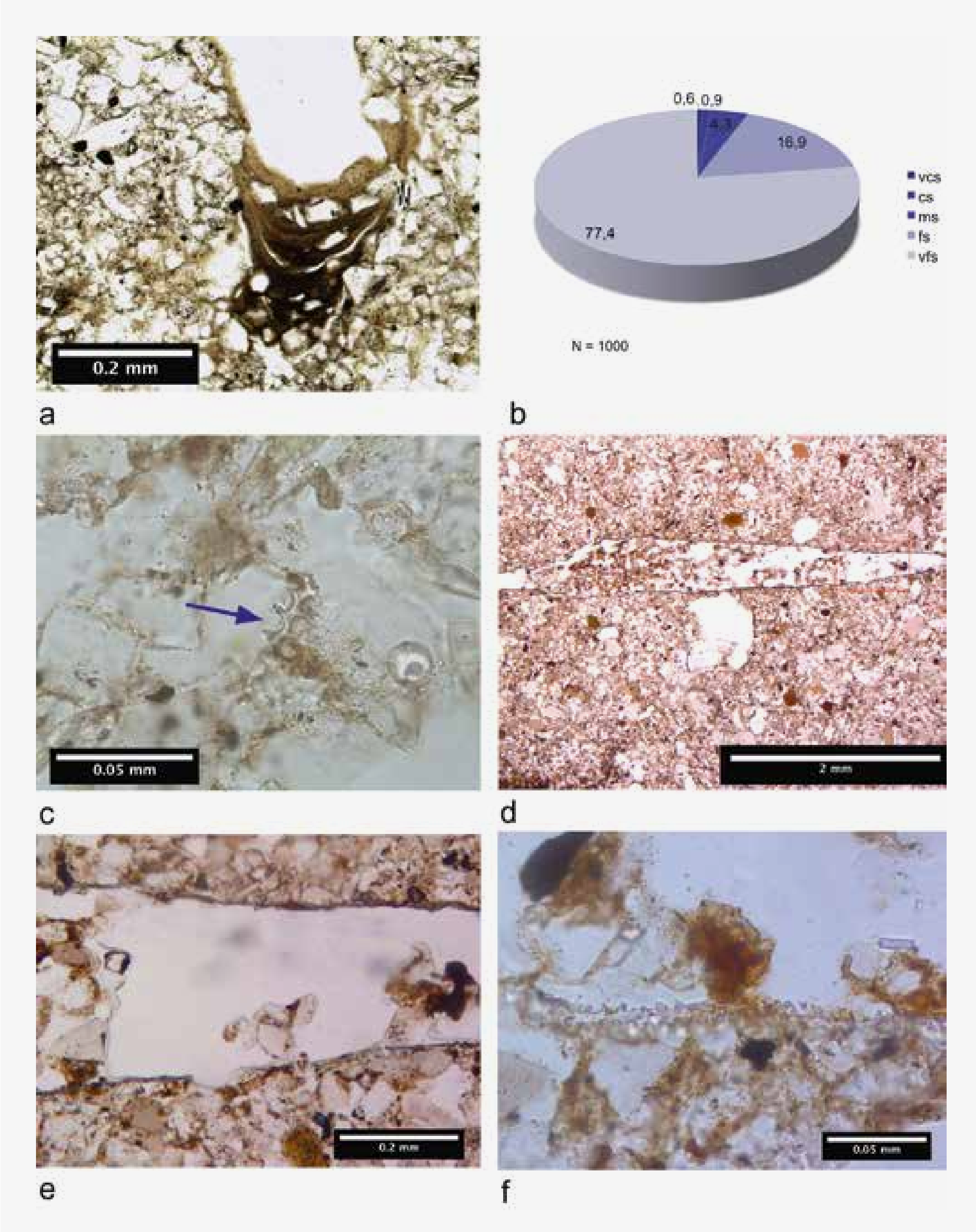


Figure 9. a. dusty clay coating (PPL)
b. graph showing the importance of the different charcoal fractions within units 2, 7 and 8; a clear dominance of the finer fractions can be noted
c. broken isolated Elongated dendritic observed within the soil matrix of the cropland (unit 7, PPL)
d. articulated Elongated dendritics (unit 25, PPL)
e. details of d
f. details of d

physical destruction of the charcoal. Furthermore, the presence of isolated and clustered phytoliths also points to physical disturbance of the soil horizon (Devos et al., 2013a; Vrydaghs et al., 2016b).

The addition of manure is evidenced by the combined presence of kitchen waste, coprolitic remains and phosphatic nodules. The anomalous thickness of the plough layer (> 10 cm) does not only result from the addition of manure, but is probably also due to the steady input of colluvium. This anomalous thickness, combined with the high degree of homogenisation further indicates the long-lasting character of the agricultural activity. The very high degree of biological activity observed in unit 7 might indicate some episodes of pasture and/or fallow.

The phytolith spectrum of the soil matrix shows the appearance of Elongate dentritics (Fig. 9c), indicating the presence of cereals. As these phytoliths can have multiple origins, a further taphonomical study was performed to confirm whether or not these phytoliths originate from locally cultivated crops. The ones that are observed within coprolites or associated with excremental remains can be related to manure. Those that show traces of heating or that are associated with charred remains indicate processing and food preparation. Clustered and isolated ones are typical for disturbed contexts (see Vrydaghs and Devos, in press) and are as such not a reliable source of information for the identification of *in situ* cultivated cereals. It is only the articulated Elongate dentritics observed within the soil matrix that indicate *in situ* decomposition of cereal remains, thus suggesting a local origin (see for instance Devos and Vrydaghs, 2009; Devos et al., 2013a; 2017) (Figs. 9d, 9e, 9f).

As the articulated systems that have been observed are not oriented in the right way, their botanical identification based on morphometric criteria was not possible (see for instance Vrydaghs et al., 2016; Wouters et al., 2019).

5. Archaeological and historical significance

Several places within the late medieval town wall hold proof of the agricultural exploitation of this area from prehistoric times until the early 13th century (De Groote 2013; De Groote 2018; De Groote and De Mulder 2018). This micromorphological study on a Dark Earth, found underneath the first town rampart and covering the early

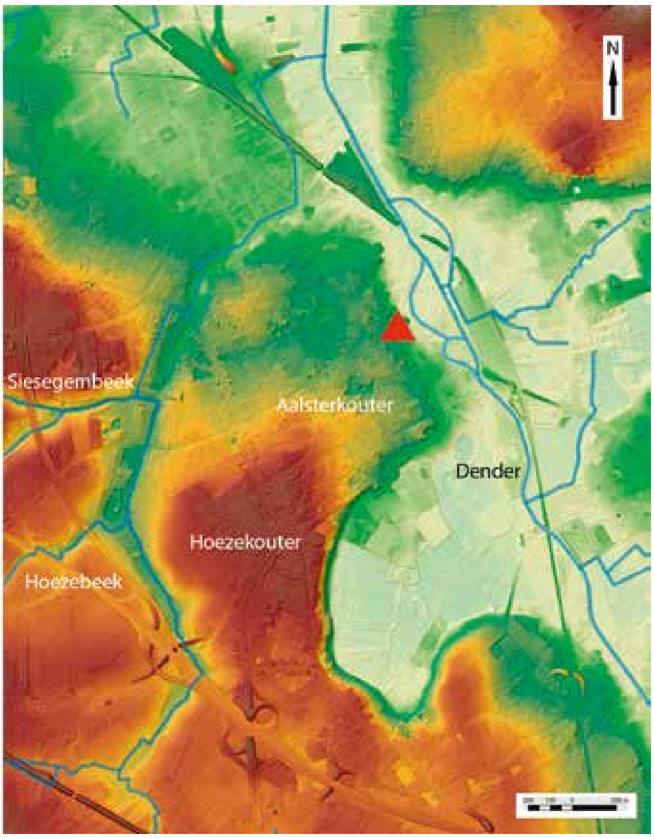


Fig. 10 Location of the "Aalsterkouter" on the digital terrain model (DTM) of Aalst (© Agiv/NGI). The oldest town centre is indicated by a red triangle.

Merovingian settlement, was a unique opportunity to analyse the agricultural activities in the medieval pre-urban period of Aalst. The oldest activities, immediately following the Merovingian habitation, point in the direction of grasslands, and possibly pasture. The traces are partly erased by later agricultural activities, dating from the Carolingian period until the middle of the 11th century. Remains of an ancient field have been documented, in particular, traces of soil working, crop growing and the application of fertilizers. The micromorphological study also suggests an intensification of anthropic impact during this period. The presence of cereal pollen (including rye) and cornflower in 11th-century parcel ditches on the same site (De Groote and Moens 1995, 137), proves the existence of crop fields in the immediate vicinity.

All these data point to how these areas were already in use as arable land in the early middle ages and before. The micromorphological study shows that the use of the area as crop field was well established from the Carolingian period on. Due to its location, it is likely that this area was part of the central field of the domain of the Carolingian *Villa Alost*. In general, as known from the historical record in Flanders, the evolution from a central field, separated from small, individual fields, to a large, joined field complex occurred in the following ages (10th-12th century) (Verhulst 1995). During this period emerged the name 'kouter' (Lat: *cultura*), mostly with the place name as a prefix. For this reason, it seems very likely that this field complex was part of the agricultural exploitation belonging to the domain farm as its *cultura*, and of which a part was known as the *cultura de Alost* in the late medieval period (De Groote 2013) (Fig. 10).

6. Conclusions

The integrated archaeological, geoarchaeological and phytolith studies conducted on the Dark Earth of the site of 'Sint-Jozefscollege' permitted the identification of the main processes behind the formation of the Dark Earth on this site. It demonstrates that its formation does not result in one single anthropic activity with slowly growing horizon thickness of the Dark Earth, but rather from a succession of different activity phases, combined with colluviation and intense bioturbation. Within the Dark Earth a succession of different human activities is identified: pasture followed by crop growing. The latter involved the addition of important quantities of fertilizer, mainly manure and household waste, to improve the fertility of the initially poor soil. The identified activities confirm the rather rural character of the area until the construction of the town wall in the 11th century.

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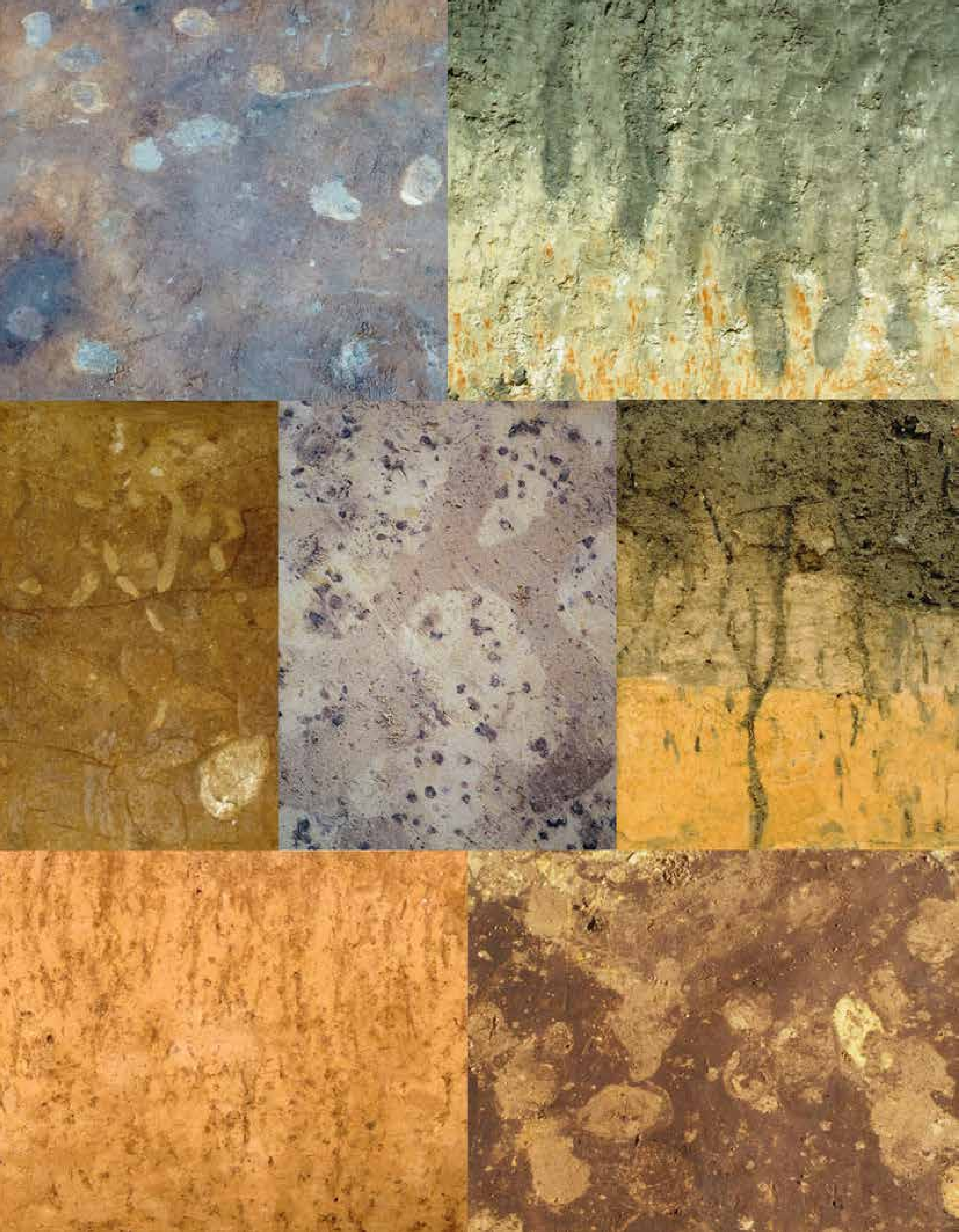

3

Archaeology and soil science, unravelling the complexity

SOILS AS RECORDS OF PAST AND PRESENT
FROM SOIL SURVEYS TO ARCHAEOLOGICAL SITES:
RESEARCH STRATEGIES FOR INTERPRETING SOIL CHARACTERISTICS

Proceedings of the Geoarchaeological Meeting, Bruges, 6 & 7 November 2019
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MÉTHODOLOGIE D'UNE RECHERCHE PALÉOENVIRONNEMENTALE EN ARCHÉOLOGIE PRÉVENTIVE

L'exemple du site de Kerkhove *Stuw* (Belgique)

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RESUMÉ
En archéologie comme dans les études paléoenvironnementales, la phase de terrain est essentielle, car elle constitue la collecte des données et du matériel qui vont servir aux études en laboratoire. Cette étape est d'autant plus délicate en contexte préventif que le temps est un facteur clé. La méthodologie employée lors des fouilles préventives du site de Kerkhove *Stuw* a permis une étude paléoenvironnementale approfondie, apportant de nouvelles informations sur l'évolution du paysage de la vallée de l'Escaut depuis la fin du Weichsélien.

MOTS-CLÉS
méthodologie, fouilles préventives, paléoenvironnement, alluvial, Tardiglaciaire, Holocène

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10.5281/zenodo.3420827

1. Introduction

R. Langohr nous apparaît comme un véritable « homme de terrain » avec toute la rigueur que cela demande dans la description minutieuse de l'objet d'étude, pour pouvoir émettre les bonnes interprétations, ou du moins, apporter les éléments nécessaires à un raisonnement scientifique sain. En archéologie comme dans les études paléoenvironnementales, la phase de terrain est primordiale, puisqu'il s'agit de collecter les données et le matériel qui vont servir aux études.

Les méthodes d'approche sur le terrain sont nombreuses, variant selon la spécialité scientifique, le contexte environnemental, les périodes archéologiques considérées, etc. Les fouilles de Kerkhove *Stuw* sont un cas particulier dans les études archéologiques et paléoenvironnementales par l'ampleur des travaux des investigations. Elles ont également permis la mise en place d'une synergie de travail entre différentes spécialités scientifiques (Sergant et al., 2018).

Dans le cadre d'un hommage aux travaux de R. Langohr, il nous apparaissait logique de discuter des méthodes employées sur le terrain. Nous allons évoquer les étapes de l'étude du site de Kerkhove dans un contexte préventif caractérisé par des inconvénients et des avantages. Après une présentation des grands traits de l'évolution de la dynamique sédimentaire du site, les avantages de la méthode présentée seront évoqués à l'aide d'exemples permettant de mieux comprendre la stratigraphie du site.

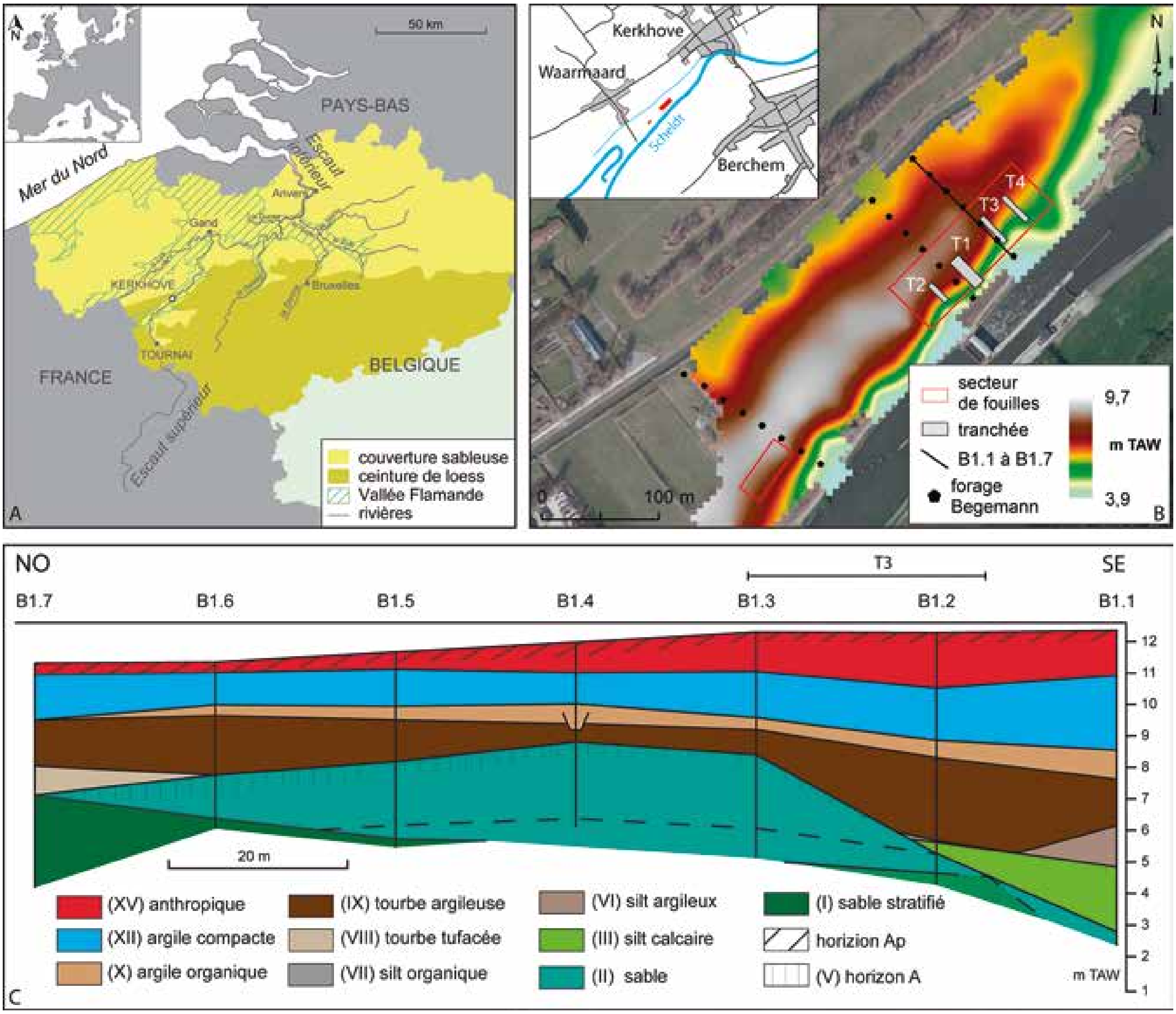

Figure 1. Localisation des sites de fouilles et des forages paléoenvironnementaux.

2. Cadre de la recherche

La recherche archéologique sur le site de Kerkhove *Stuw* a été initiée à la suite du projet de rénovation et dédoublement d'une écluse par *De Vlaamse Waterweg nv* qui est l'ancien *Waterwegen en Zeekanaal nv* (W&Z). Le secteur d'études est localisé en rive gauche de l'Escaut représentant la rivière principale drainant la Vallée Flamande (Fig. 1a). Son cours prend sa source en France et se termine aux Pays-Bas dans la mer du Nord, après avoir traversé en grande partie la Belgique.

Ce projet devait avoir un impact non négligeable sur le remplissage sédimentaire de la plaine alluviale de l'Escaut. Une prérecherche a été effectuée sous la forme de forages à la tarière. Elle a mis en évidence une élévation sableuse naturelle oblongue de plus de 400 m de long interprétée comme une levée naturelle (Bats et Crombé, 2007), enfouie sous une stratigraphie de plus de 5 m d'épaisseur composée de haut en bas d'un rehaussement anthropique, d'un niveau d'argiles compactes stratifié à sa base, d'un niveau de tourbe et de sables alluviaux avec localement un niveau argileux organique à son toit.

Dans un second temps, des forages archéologiques ont vérifié le potentiel archéologique du toit de la levée (Bats et al., 2008), amenant à la mise en place d'une fouille de sauvetage dans deux secteurs (Fig. 1b). Le premier secteur a une superficie de 7500 m² et occupe l'emplacement de la nouvelle écluse. Le second plus petit (1000 m²) est situé plus en amont sur le nouveau bief. Le premier secteur étant le plus complexe, seul celui-ci sera évoqué ici.

Les travaux ont été encadrés par une feuille de route stricte qui était, sans entrer dans les détails, un temps imparti, un budget préétabli, l'excavation rapide de l'argile pour son transport vers une briqueterie, la prise en considération de l'ensemble des sites archéologiques pouvant être rencontrés, une étude paléoenvironnementale diachronique de terrain sur le site de fouilles, des études en laboratoire du matériel tant archéologique que paléoenvironnemental, etc.

Les études de Kerkhove *Stuw* s'inscrivent dans la continuité des recherches effectuées depuis plusieurs décennies sur l'évolution de la plaine de l'Escaut et qui en décrivent les grandes phases à partir du dernier maximum glaciaire. A cette époque, les rivières se caractérisaient par un style fluviatile en tresse et le cours de l'Escaut prenait une direction sud-nord, bien à l'ouest de son tracé actuel à proximité de la ville d'Anvers. L'Escaut et ses affluents drainaient l'ensemble de la Vallée Flamande. Le changement de direction qui survient à la fin du Weichsélien est dû à une forte activité éolienne qui met en place une grande couverture sableuse au nord de la Flandre repoussant le cours de l'Escaut vers l'est (De Moor et Heyse, 1978). La végétation était celle d'une steppe arctique dépourvue d'arbre (Kiden et Verbruggen, 2001).

Le passage au Tardiglaciaire est marqué par un réchauffement climatique entrecoupé de périodes de refroidissement. L'Escaut adopte un style fluviatile méandriforme qui incise les alluvions de la période précédente. La date précise du changement de style fluviatile est inconnue (Bogemans et al., 2012). Au cours de ces divagations, la rivière dépose des barres d'accrétions de méandre, sur lesquelles, des dunes témoignant d'une activité éolienne ont été retrouvées (Bogemans et Vandenberghe, 2011 ; Tavernier, 1954). La végétation se densifie au cours de cette période avec l'apparition de saules et de bouleaux nains évoluant en une forêt semi-ouverte de bouleaux et enfin de pin. Néanmoins, un recul des forêts s'observe à chaque période de refroidissement (Kiden et Verbruggen, 2001).

La densification du couvert végétale se poursuit au cours du début de l'Holocène amenant à une réduction du débit de l'Escaut (Kiden et Verbruggen, 2001). L'ancien chenal tardiglaciaire devient la plaine inondable de la première moitié de l'Holocène et son comblement commence par le dépôt de fines particules clastiques à forte teneur en contenu organique (Kiden, 1991 ; Storme et al., 2016). A la fin du Préboréal, une activité sédimentaire de versant semble être induite par la répétition de feux de forêt (Crombé et al., 2019).

Au cours du Préboréal, une tourbification commence à remplacer les dépôts fins. La tourbe colmate l'ancien chenal tardiglaciaire avant de s'étendre sur la plaine inondable tardiglaciaire (Bogemans et al., 2012 ; Kiden, 1991). La plaine alluviale de l'Escaut représente alors une grande forêt marécageuse à aulnes. Si dans la basse vallée de l'Escaut des lentilles sableuses semblent indiquer la présence d'un système fluviatile anabranché, la morphologie de la rivière dans les autres secteurs est inconnue (Bogemans et al., 2012 ; Meylemans et al., 2013).

Les premiers défrichements importants sont observés vers 4000 BP. Ils s'intensifient, provoquant un déséquilibre entre le débit liquide et solide des rivières. Les dépôts clastiques deviennent dominants et les marécages reculent. C'est probablement au cours de la dégradation climatique située à la transition entre le Subboréal et le Subatlantique que l'Escaut incise un nouveau chenal unique (Bogemans et al., 2012).

3. Travaux de terrain et occupation anthropique

Avant la fouille archéologique, trois transects prédéfinis de 7 à 8 forages Begemann chacun, transversaux à la levée ont été effectués (Fig. 1b et Fig. 1c). Bien que ces forages permettent d'observer la stratigraphie avec précision (Fig. 2), leur localisation ne permettait pas de replacer la stratigraphie du site d'étude, dans la stratigraphie générale du remplissage sédimentaire de la plaine alluviale de l'Escaut. Pour cette recontextualisation, un transect d'environ 1200 m de long, composé de 33 forages manuels a été pratiqué dans les prolongements nord et sud du transect 1 des forages Begemann. Ce transect (Fig. 3) a également été complété à l'aide de données anciennes, notamment par un forage effectué près du forage manuel B26.

Au cours de la fouille, la recherche paléoenvironnementale et la recherche archéologique ont été combinées. La mise en place d'un complexe de bureaux à proximité des fouilles a permis la présence régulière sur le terrain de spécialistes des sciences naturelles (géologue, pédologue, paléobotaniste, zooarchéologue, etc.). Les relevés des nombreuses grandes coupes ont été réalisés à l'aide de photographies redressées (Fig. 4), complétés par des photographies classiques. Un procédé similaire a été employé pour les surfaces de fouilles au moyen d'un drone.

Cette technique de redressement et géoréférencement connue depuis plus d'une dizaine d'années dans les contextes d'études programmées (Pertlwieser et al., 2011 ; Cruz et Petit, 2012) ne se répand largement que depuis peu dans les contextes préventifs. Le site de Kerkhove *Stuw* est probablement l'un des premiers sites en Flandre, où l'emploi de cette technique a été *quasi* systématique. Cette méthode permet un gain de temps considérable et une plus grande

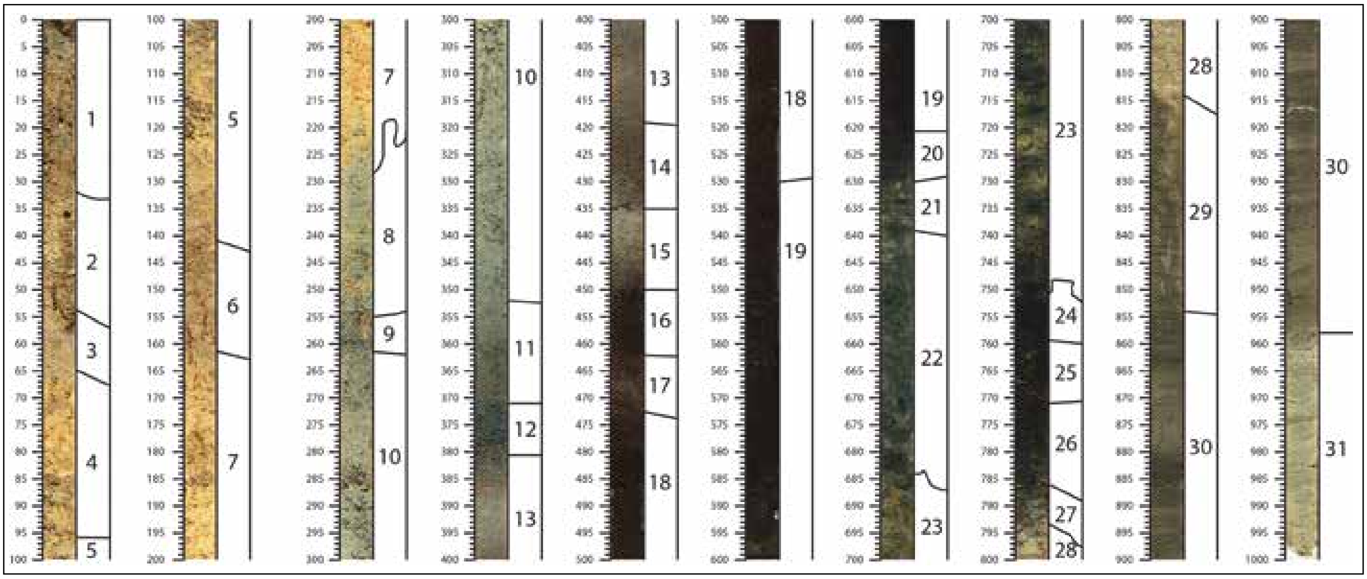

Figure 2. Forage Begemann B1.1.

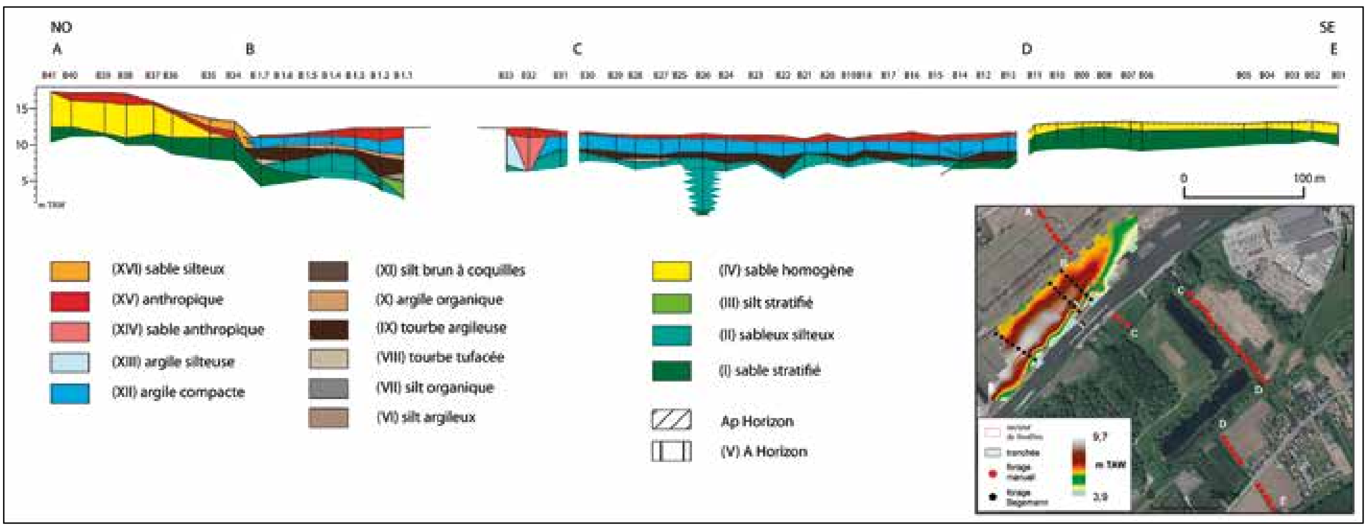

Figure 3. Transect de corrélations des forages mécaniques et manuels.

précision des relevés. De plus, la manipulation des couleurs des photographies permet dans certains cas de faire ressortir des unités stratigraphiques pour mieux en dessiner les contours (De Reu et al., 2013).

Lorsque cela a été possible, la création de longs profils a été favorisée. Ceci permet de replacer plus aisément la stratigraphie observée dans le contexte général de la fouille. Les descriptions pédo-sédimentaires (texture, couleur, horizon pédogénétique, structures sédimentaires, éléments de taphonomie, etc.) ont été relevées à même le terrain. Les coupes ont été dessinés sur ordinateur avec les photographies redressées et des schémas en appuis.

En contexte préventif, la destruction totale des séquences sédimentaires ne permet pas le retour sur le terrain au cours de la phase d'études en laboratoire. Il a donc été décidé d'effectuer les prélèvements de la manière la plus exhaustive et qualitative possible, en employant au maximum des profils en aluminium de 5 cm ou plus large pour la fabrication de lame mince. Jusqu'à 4 profils accolés ont pu être utilisés. La présence sur le site d'un conteneur frigorifique a autorisé le stockage de la grande quantité de prélèvements.

Cette façon de procéder a permis de choisir plus sereinement les études et les échantillons à étudier en laboratoire, mais également de pallier les erreurs ou oublis sur le terrain. Pour les datations radiocarbone, les éléments de végétaux datés peuvent être localisés plus précisément tout en réduisant les risques de pollution. Néanmoins, les prélèvements pour macrorestes de végétaux ou malacologiques demandant une grande quantité de matériel ont été prélevés en sacs. De même, les échantillons pour datation par *Optical Stimulated Luminescence* (OSL) ont fait l'objet d'un prélèvement spécifique.

Les travaux de terrains ont débuté par un décapage de remblais récents pour atteindre les argiles compactes, dans lesquelles a été creusé un réseau de fossés agricoles. Dans l'étape suivante, les argiles alluviales ont été excavées par phases successives d'environ 1,20 m de profondeur, comprenant chacune 4 niveaux artificiels de 30 cm. La création d'une berme centrale a permis de relever deux longues coupes. Les bords de la fouille étaient constitués de talus représentant les bords du futur bief. Il n'était donc pas envisageable d'y effectuer de coupes sans causer une possible déstabilisation de la future structure.

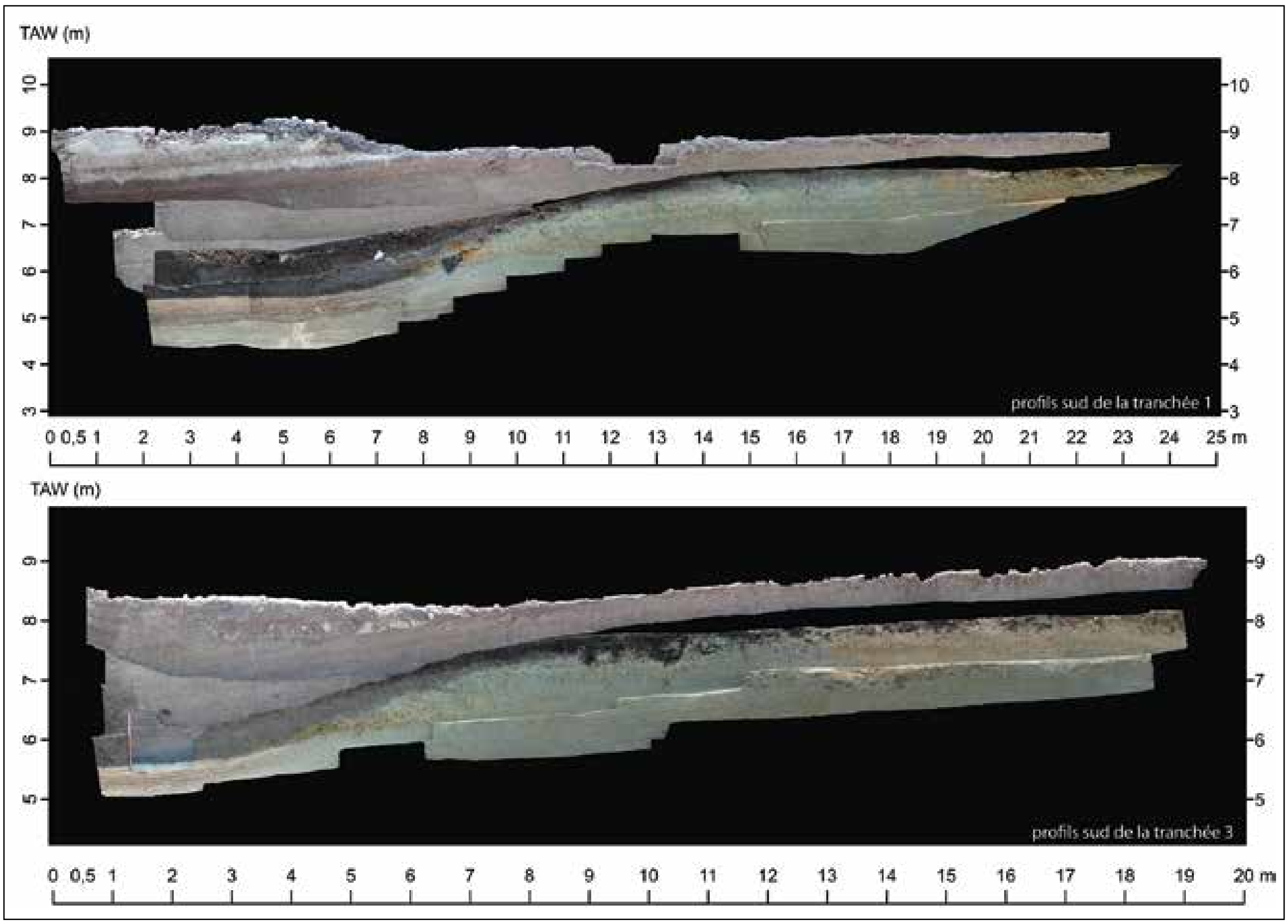

Figure 4. Orthophotographie des profils sud des tranchées 1 et 3.

Une seconde étape de la recherche a commencé au toit des tourbes. En effet, des structures gallo-romaines sous la forme de fossés parcellaires ont été découvertes. Deux larges fossés parallèles distants d'environ 8 m ont permis d'émettre l'hypothèse d'une voie desservant plus au nord un centre administratif et logistique gallo-romain (De Cock et Rogge, 1988 ; De Cock et al., 1996) et plus au sud un possible pont enjambant l'Escaut (Crombé et Herremans, 2017). Au centre de cette voie ont été retrouvés trois planches et un amas de branches. Les crues ont déposé des éléments de constructions en terre cuite et en calcaire de Tournai dans les parties basses de la voie (Sergant et al., 2019).

Après la fouille des structures gallo-romaines, les investigations se sont poursuivies d'une part par le creusement de quatre tranchées et d'autre part par le décapage des tourbes. La tranchée 1, la plus longue et la plus large, reprend la position de la berme laissée au cours de l'excavation des argiles. Cette technique a permis d'obtenir une continuité de la stratigraphie, bien que cela ne soit pas le même sens d'observation.

La tranchée 2 a été effectuée à l'ouest de la tranchée 1 et les tranchées 3 et 4 à l'est (Fig. 1). Elles ont été approfondies par passes de 30 cm avec un arrêt à chaque 1,20 m pour enregistrement des profils, jusqu'à atteindre les sables de la structure alluviale. Les profils de part et d'autre de chaque tranchée ont été décrits et ont fait l'objet de prélèvements. A partir de ce moment, la fouille du site lithique a pu commencer sur la levée, tandis que la recherche paléoenvironnementale s'est focalisée dans la partie méridionale du secteur 1. Néanmoins, au cours des fouilles, une petite coupe orientée approximativement nord-sud a été laissée pour effectuer des prélèvements en profils pour datations radiocarbone, afin d'évaluer la vitesse d'aggradation organique de la plaine alluviale.

La fin du décapage du niveau organique a été guidée à l'aide d'une gouge pour tester régulièrement l'épaisseur de tourbe restante à décaper. Cette technique a également permis de découvrir un niveau silteux noirâtre plastique recouvrant le niveau silteux blanchâtre au pied de la pente de la levée. Il a été décidé d'approfondir l'extrémité de la tranchée 1 pour mieux observer ces niveaux.

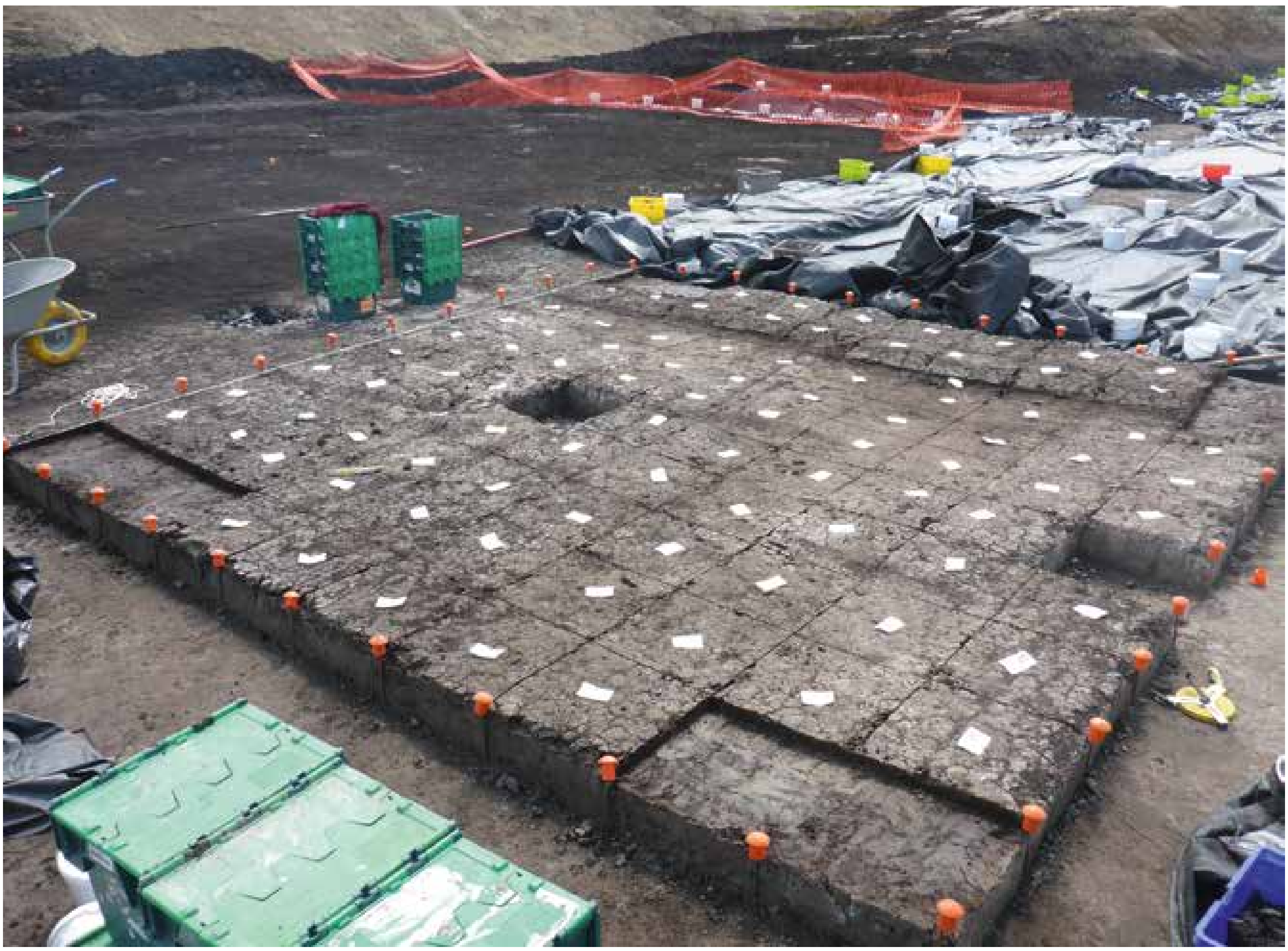

Figure 5. Fouilles par carrés de ¼ m² du toit de la levée tardiglaciaire.

Un site d'habitat de l'âge de pierre était présent au toit argileux de la levée alluvial, juste sous le niveau tourbeux. Les trouvailles (silex, pierres, restes osseux carbonisés et non carbonisés, etc.) ont été fouillées selon un carroyage de ¼ de m² par étapes. En premier lieu, des carrés tests de ¼ m² ont été effectués sur 4 niveaux de 5 cm dans un carroyage plus large de 3 m sur 3 m. Sur la base des résultats des carrés tests, il a été possible de définir dans un second temps des zones où la recherche devait se poursuivre. Les sédiments des carrés de fouilles de ¼ m² ont été prélevés manuellement (Fig. 5) avant d'être tamisés sur des grilles galvanisées de 2 mm amovibles, dans des stations de tamisages manuelles près de deux grands bassins creusés à cet effet.

Les premiers résultats de la fouille montrent la présence dans les secteurs 1 et 2 de 17 locus du Mésolithique dont 16 semblent être du Mésolithique ancien et moyen et seulement 1 (C16) du Mésolithique récent (Fig. 6). Dans le secteur 2, des artéfacts et des fragments de céramique rencontrés peuvent être datés du Néolithique moyen, lesquels montrent avec certitude une présence dans ce secteur au cours de cette période.

Vers la fin des fouilles du secteur 1, la puissance de drainage a été augmentée permettant l'approfondissement des tranchées, tant dans leur partie méridionale que septentrionale (Fig. 4 et Fig. 7). En effet, l'observation des profils dans la structure alluviale devait apporter plus d'arguments quant à sa nature. Le grand profil septentrional de la tranchée 1 a fait l'objet de prélèvements pour datation OSL.

4. Le comblement de la vallée

L'accent de la recherche paléoenvironnementale sur le terrain a donc été porté sur la multiplication des fenêtres d'études grâce à une quarantaine de grandes coupes et 48 forages. Les avantages de cette démarche sont particulièrement bien mis en évidence par l'étude d'un niveau de

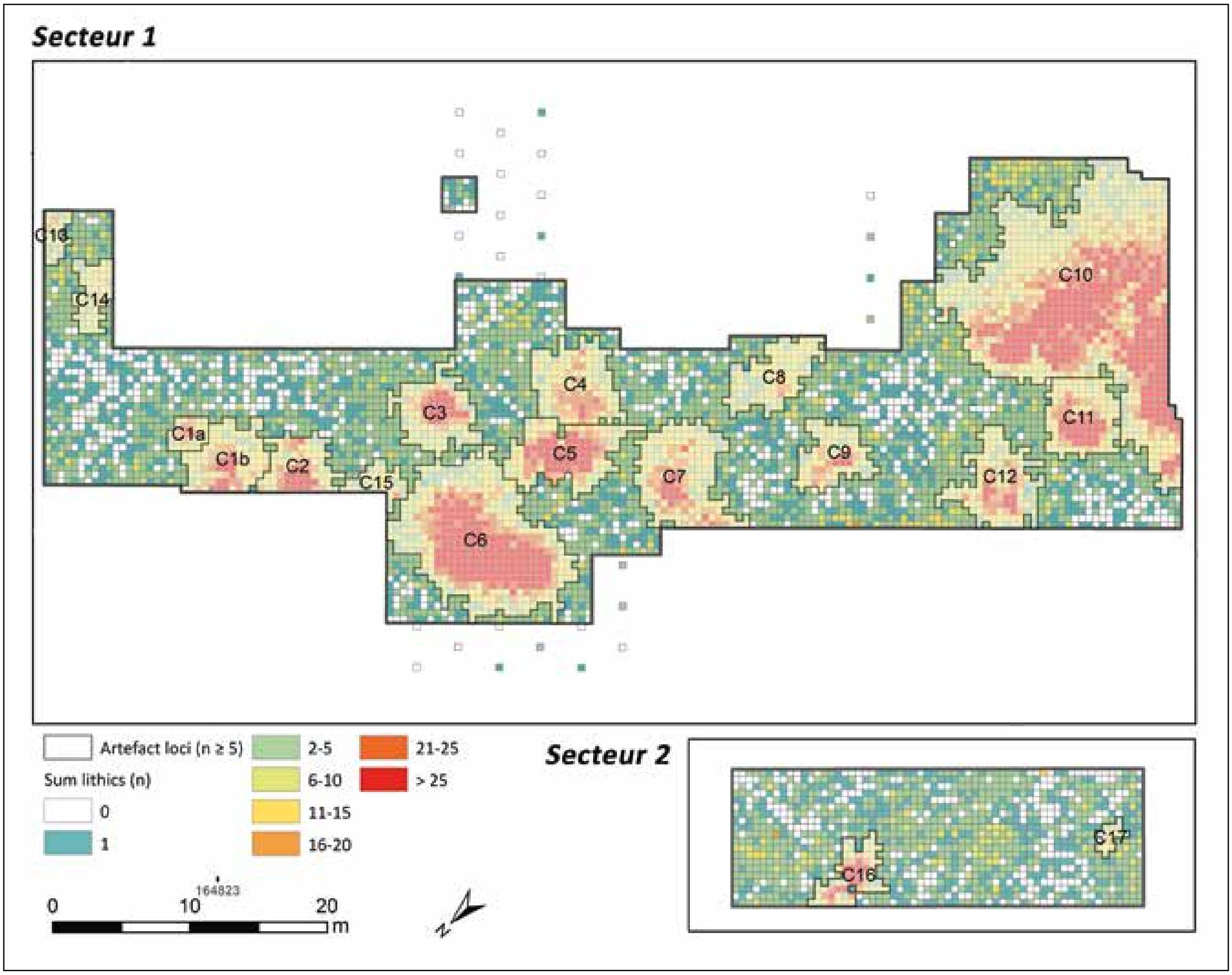

Figure 6. Répartition spatiale des trouvailles lithiques (Vandendriessche H. et al., 2019).

Figure 7. Photographie du dernier état de la tranchée 1.

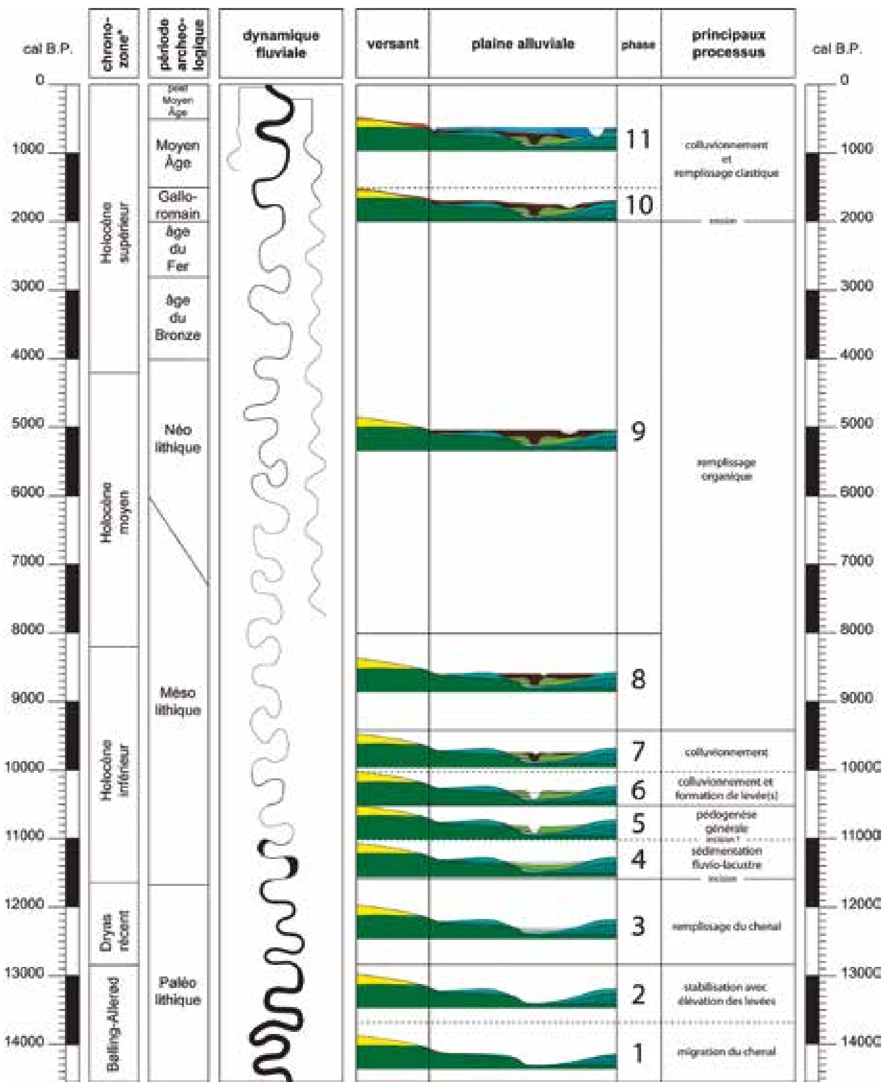

Figure 8. Evolution géomorphologique du site d'études au cours des 15 000 dernières années ; Chronologie des chronozones basée sur (Rasmussen et al., 2014 ; Walker et al., 2019).

colluvions (unité VII) déposé au pied de la structure alluviale. Néanmoins, avant d'évoquer cet exemple et d'autres en détail, il est important de replacer les niveaux rencontrés dans la stratigraphie du remplissage sédimentaire de la plaine alluviale de l'Escaut comprenant un total de 16 grandes unités (Fig. 3) allant du Weichsélien à la fin de l'Holocène (Fig. 8).

4.1. WEICHSÉLIEN

La stratigraphie étudiée de la plaine alluviale de l'Escaut sur la commune de Kerkhove commence à la base par un niveau oxydé de sables fins silteux glauconieux stratifiés beige clair à brun foncé (unité I). La stratification oblique à subhorizontale comprend des strates dont les épaisseurs observables inférieures généralement au centimètre peuvent atteindre une dizaine de centimètres. Les niveaux organiques bruns ne sont pas rares. L'unité I est interprétée comme les alluvions de l'Escaut lorsque son système fluviatile était en tresse, au cours du Pléniglaciaire Weichsélien (Bogemans, 2007 ; De Moor et Heyse, 1978 ; De Moor, 1983 ; Borremans, 2015).

Sur le transect de forages, l'unité I présente une dépression centrale d'environ 700 m de large. Aux extrémités du transect, elle est recouverte par l'unité IV composée d'un sable oxydé homogène très bien trié, interprété comme des dépôts éoliens se mettant en place à la fin du Pléniglaciaire weichsélien (Heyse. et De Moor, 1979). Des datations OSL tendent à montrer qu'une activité éolienne était également présente dans et en bordure des plaines alluviales au Tardiglaciaire (Crombé et al., 2018 ; Bogemans et Vandenberghe, 2011).

La large dépression comprise entre les dépôts éoliens est colmatée par l'unité II, un sable silteux réduit, observé à la base des forages manuels. Sur le site d'études, l'unité II est beige brunâtre stratifiée horizontalement (Fig. 9) et forme une levée marquée par une augmentation de la concentration en carbonate de la base à son sommet, ainsi que par une granulodécroissance générale. En rive gauche de l'Escaut, l'unité II est également présente avec un toit légèrement vallonné. Elle y forme aussi une levée alluviale en rebord du chenal. Ces dépôts sont interprétés comme les alluvions de l'Escaut tardiglaciaire qui présentait alors un système fluviatile méandriforme (Kiden, 1991 ; Kiden, 2006 ; Kiden et Verbruggen, 2001 ; Meylemans et al., 2013). Le chenal de cette époque marquée, par une dépression dans l'unité II, est en partie détruit par le chenal actuel. La date de la métamorphose d'un système en tresse à un système méandriforme n'est pas connue, mais pourrait être située au passage entre le Pléniglaciaire et le Tardiglaciaire (Meylemans et al., 2013 ; Kiden et Verbruggen, 2001).

Figure 9. Détail de la levée tardiglaciaire dans la tranchée 2.

4.2. HOLOCÈNE INFÉRIEUR (11 700 BP À 8 200 KA BP)

La séquence sédimentaire se poursuit dans le paléochenal tardiglaciaire de l'Escaut qui devient alors la plaine alluviale de la rivière du début de l'Holocène. Il s'y dépose au fond, un niveau calcaire stratifié de silts sableux plastiques (unité III) brun gris à coquilles de gastéropodes (Fig. 010), interprété comme des dépôts fluvio-lacustres (Crombé et al., 2019). Différents indices montrent une période chaude et par conséquent le Préboréal récent. Au toit de l'unité II, un sol noirâtre (unité V) se développe dès cette période. Il va ensuite s'étendre au toit de l'unité III. Au pied de l'ancienne levée Tardiglaciaire se met en place, du Préboréal tardif jusqu'au Boréal, un dépôt colluvial (unité VII) suite à l'érosion du sol (unité V), conséquences probables de feux de forêt naturels répétés (Crombé et al., 2019).

En direction du centre de l'ancien chenal, les colluvions (unité VII) s'interstratifient avec une tourbe brunâtre (unité IX) marquée par la présence de niveaux fortement silteux beige jaunâtre de quelques centimètres d'épaisseur (Fig. 11). Ces niveaux silteux se corrèlent stratigraphiquement avec une unité de silts argileux à sables stratifiés beige verdâtre présentant des oxydes de fer et des concrétions ferromanganiques (unité VI). Elle est interprétée comme une levée alluviale de la rivière du début de l'Holocène. Une dynamique alluviale a été également observée plus en aval sur la commune d'Oudenaarde (Storme et al., 2018). Bien que ces alluvions ne soient pas tout à fait contemporaines les unes des autres, elles témoignent néanmoins d'une activité alluviale plus forte que ce qui a été observé jusqu'à maintenant (Kiden, 1991 ; Kiden et Verbruggen, 2001 ; Bogemans et al., 2012).

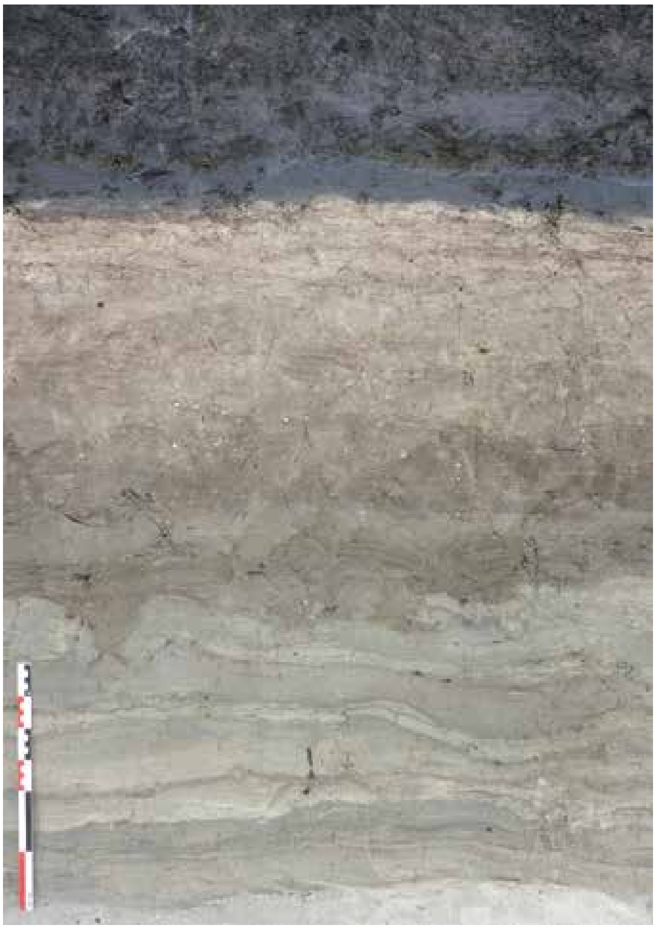

Figure 10. Partie inférieure de la tranchée 1 montrant successivement de la base au sommet les niveaux stratifiés de la levée tardiglaciaire, les dépôts fluvio-lacustres et la stratification des tourbes (unité IX) et des colluvions (unité VII).

Figure 11. Niveaux silteux dans les tourbes observés sur les coupes de la tranchée 1.

4.3. HOLOCÈNE MOYEN ET SUPÉRIEUR (8 200 BP À L'ACTUEL)

Au cours de l'Holocène, la stratification silteuse semble moins présente. Une stratification de niveaux de tourbes brunes et de tourbes noires (partie supérieure de l'unité IX) va finir de colmater le grand paléochenal, puis va s'étendre à l'ensemble de la plaine inondable tardiglaciaire. Juste en arrière des levées de la rivière tardiglaciaire, la base de la tourbe présente un faciès tufacé calcaire (unité VIII) indiquant un milieu temporairement protégé des apports clastiques de la rivière.

Sur le secteur de fouilles, la couche tourbeuse (unité IX) se termine par un niveau noir d'une vingtaine de centimètres marqués par des fentes de dessiccation formant des polygones. Les structures gallo-romaines découvertes ont été creusées au toit de la tourbe (unité IX). Les fossés parcellaires encadrant la voie semblent avoir drainé des parcelles, dont les sols étaient vraisemblablement dédiés à des prairies ou à une culture fourragère. Ces sols étaient probablement exploités par les habitants de la *mansio* située sur les sables éoliens plus au nord (De Cock et Rogge, 1988 ; De Cock et al., 1996).

Les tourbes sont recouvertes par une alternance épaisse d'environ 1 m de niveaux argileux beiges et niveaux argileux brunâtres. Ce niveau stratifié (unité X) comprend également un second état des fossés gallo-romains. Stratigraphiquement contemporain à cette couche argileuse organique, le comblement organique à nombreux fragments de bois d'un petit chenal a pu être observé en coupe. En rive droite, l'unité X n'a pas été reconnue. La tourbe se termine en rebord du chenal tardiglaciaire par un niveau de silt brun riche en coquilles de gastéropodes (unité XI).

La séquence sédimentaire se poursuit par l'enfouissement des niveaux organiques et argiles organiques sous une couche d'argile compacte (unité XII), réduite et entrecoupée de niveaux silteux blanchâtres et argileux brunâtres. Localement, elle peut comporter de nombreuses coquilles de gastéropodes. En rive droite de l'Escaut, cette unité à grande extension spatiale est interrompue par le comblement anthropique de l'ancien chenal de la rivière de la fin de l'Holocène (unité XIV) et de ses dépôts de bordure (unité XIII).

En rebord oriental de la plaine alluviale de l'Escaut, la partie supérieure des dépôts éoliens présente une forte perturbation anthropique (unité XV) probablement à l'origine de colluvions (unité XVI). L'homme intervient également directement sur le comblement de la plaine alluviale par la mise en place de niveaux de rehaussements (unité XV) et la construction de digues (unité XV) dans le cadre de l'édification de bassins de rétention d'eau pour une centrale électrique.

5. Apport de la méthode

Pour comprendre réellement les apports de la méthodologie utilisée, il apparaît plus pertinent de se questionner sur ce qui n'aurait pas été observé, si la recherche avait été plus conventionnelle. Ainsi qu'est ce qui n'aurait pas été observé :

- *si une seule tranchée au pied de la levée avait été effectuée ;*

La réponse à cette question est notamment apportée par la comparaison entre les profils des tranchées 1 et 3 qui montre le rebord du comblement du chenal tardiglaciaire (Fig. 12). En ne tenant compte que de la partie inférieure de la stratigraphie du remplissage du chenal tardiglaciaire, il est possible d'observer des différences notables entre les deux profils. Entre autres, trois points importants observables sur le profil de la tranchée 1 sont absents sur la tranchée 3 : une interstratification entre la couche de colluvions (unité VII) et les tourbes (unité IX), la présence de niveaux silteux de quelques centimètres d'épaisseur et une alternance de niveaux de tourbes noires et de tourbes brunes.

L'interstratification est le point le plus important, car dans le cas de la tranchée 3, l'interprétation chronologique de ces niveaux est une succession de phases. Les colluvions se déposent, puis viennent les tourbes avec la possibilité d'une période intermédiaire sans dépôt. Des datations radiocarbone auraient alors été effectuées au toit des colluvions et dans les premiers centimètres de la base de la tourbe en bordure méridionale de la coupe. Ces datations auraient fourni comme résultat une inversion de dates qui n'existe pas. En effet sur la coupe de la tranchée 1, l'interstratification indique une contemporanéité entre la partie inférieure des tourbes et les colluvions, montrant que le début de la tourbification est plus jeune que le toit des colluvions.

De plus, la stratification silteuse de la base des tourbes mis en évidence sur la coupe de la tranchée 1 indique dans ce contexte une forte dynamique sédimentaire alluviale qui enfouit l'unité III. Ces observations et les caractéristiques sédimentaires de l'unité VI permettent d'interpréter cette dernière observée uniquement dans le forage B1.1 comme une levée alluviale, soulignant de ce fait la présence d'un chenal avec une charge sédimentaire importante pour cette période. Ces indices vont également dans le sens de la création d'un chenal qui s'effectue au cours de la période de colluvionnement. Ainsi malgré, la densification du couvert végétale du début de l'Holocène (Verbruggen et al., 1991 ; Kiden et Verbruggen, 2001), une dynamique alluviale importante se serait opérée probablement à cause de feux de forêt naturels répétés (Crombé et al., 2019).

Avec une seule tranchée, il n'aurait également pas été possible de choisir la meilleure séquence à étudier pour l'Holocène inférieur. En effet, l'évaluation du contenu palynologique des séquences a mis en évidence que les niveaux prélevés sur le transect 3 étaient les plus favorables pour une étude détaillée. Des prélèvements uniquement sur le profil de la tranchée 1 n'auraient pas apporté des résultats aussi pertinents pour l'évolution de couvert végétale du début de l'Holocène (Crombé et al., 2019). Ceci met aussi en évidence l'importance d'un échantillonnage systématique de tous les profils.

- *si les forages mécanisés n'avaient pas été pratiqués ;*

Les forages Begemann sont des forages de grande qualité qui ne perturbent pas le sédiment prélevé et permettent d'atteindre des niveaux profonds. Sans ces forages, l'unité VI évoquée précédemment n'aurait pas été observée. De même à la base du forage B1.1, un niveau de sables propres à fragments de bois pouvant correspondre à un premier niveau de colmatage du fond du chenal tardiglaciaire aurait été manqué. Une étude sédimentologique comparative entre les dépôts calcaires (unité III) vers le thalweg et en rebord du chenal tardiglaciaire ne serait pas envisageable .

- *si le transect des forages manuels n'avait pas été effectué ;*

Deux points importants n'auraient pas pu être relevés en l'absence du transect de forages manuels. Le premier est la présence d'un niveau silteux organique à coquilles (unité XI) stratigraphiquement contemporain de l'alternance des argiles beiges et des argiles brunâtres (unité X). L'unité XI indique que la rive droite de l'Escaut est encore un milieu mal drainé pendant la période de mise en culture de la rive gauche.

Le second point est représenté par la présence de la seconde levée localisée en rive droite du chenal tardiglaciaire de l'Escaut. Bien que ce type de structure alluviale soit bien connu, les processus qui forment les levées restent mal connus (Brierley et al., 1997). Néanmoins, dans un système fluviatile méandriforme, les méandres se déplacent latéralement par érosion en rive concave et par sédimentation en rive convexe sous forme de barres d'accrétion. Les levées peuvent être présentes sur les deux rives de manière asymétrique dans le cas d'un méandre ou symétrique sur les segments rectilignes. Cependant, il existe une relation entre la migration du chenal et la taille des levées : plus la rivière est stable et plus les levées deviennent importantes. La stabilité est notamment à mettre en relation avec la charge sédimentaire (Hudson, 2008).

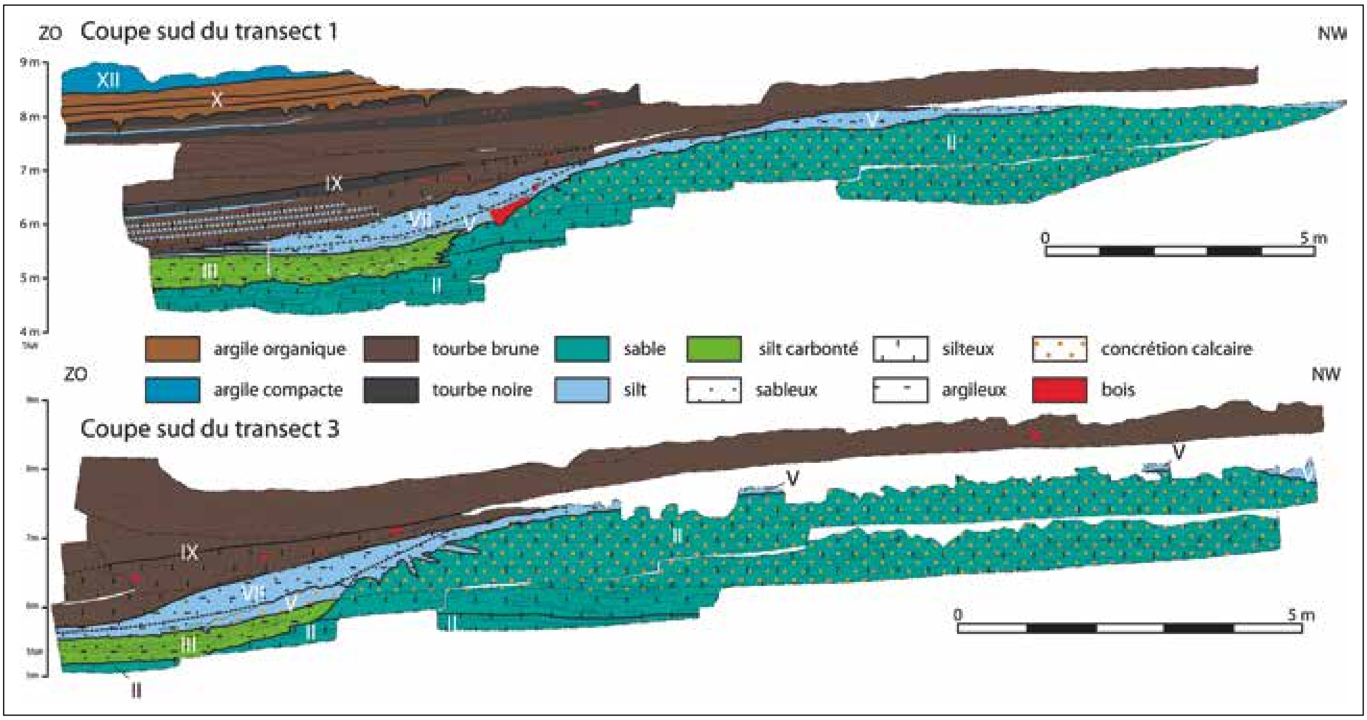

Figure 12. Stratigraphie des profils sud des tranchées 1 et 3.

Dans le cas de l'Escaut dans la région de Kerkhove, le déplacement de la rivière au cours du Tardiglaciaire est indiqué par la présence de dépôts de barres d'accrétion observés dans un ancien forage. Ce dernier met également en évidence un niveau d'alluvions sableuses surmontant le toit plus argileux des barres d'accrétion qui pourrait être à l'origine d'une forte atténuation de la microtopographie alluviale tardiglaciaire. Les sables montrent également une phase de forte sédimentation soulignée, notamment, par l'absence de processus pédologiques (horizon(s) A intercalé(s), bioturbations, niveaux oxydés, etc.) dans la masse même de la levée étudiée en détails sur le site archéologique. L'ensemble de ces éléments avec les fortes dimensions de levées symétriques représente une phase de stabilité du tracé de la rivière causée par un grand apport sédimentaire.

6. Conclusions

Les plaines alluviales sont des milieux complexes caractérisés par des variations spatiales importantes dans leur remplissage sédimentaire (Brown, 1997 ; Bravard et Salvador, 2009 ; Reineck et Singh, 1980). L'étude de ces milieux demande une grande quantité d'informations dispersées dans différents secteurs et de temps pour recueillir les informations. En contexte préventif, le temps est une contrainte majeure et l'utilisation quasi-systématique de la photogrammétrie permet un gain de temps significatif et par conséquent la possibilité de multiplier les coupes. En outre, cette technique a également un impact positif sur la qualité de l'enregistrement.

La mise en place d'un transect de forages manuels et mécanisés dans le voisinage du site a permis la récolte d'un nombre conséquent d'informations supplémentaires. Ces forages ont notamment autorisé une recontextualisation du site archéologique dans son environnement local, mais ils ont également permis d'apporter de nouvelles informations sur la variation spatiale et l'évolution dans le temps des environnements de dépôts dans la plaine alluviale de l'Escaut. Cette recontextualisation n'est que rarement effectuée, car l'aménageur ne paye généralement que les études sur le site même.

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STUDY OF PAST AND PRESENT RECORDS IN SOILS FROM LORRAINE (FRANCE)

A geoarchaeological approach in the context of rescue archaeology

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ABSTRACT
This paper presents some aspects of past and present records gathered during the last two decades, examining soil profiles in rescue archaeological contexts in Lorraine. After a general presentation of the regional geomorphological context, the paper will report and discuss some results collected through both archaeological prospection and excavation phases. Finally, this report is an opportunity to make some conclusions on the possible geoarchaeological approach to rescue archaeology in Lorraine (France).

KEYWORDS
rescue archaeology, geoarchaeology, case studies, Lorraine, France

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Foreword

The French heritage code (section L510-1, 2016) defines archaeological heritage as all kinds of traces of past human existence, including the context in which they occur, amongst which the protection and study allows the understanding of the development of human history and its relation to the natural environment. So, as an integrated part of French rescue archaeology, the geomorphological approach is supposed to serve as a reference for the surrounding forthcoming operations and to contribute to the understanding of man/natural habitat interactions at the investigated site (Speller, 2008). Since 2017, the INRAP (Institut de Recherche en Archéologie Préventive) job description categorises all the earth science specialists (geomorphologists, geologists, soil scientists, micromorphologists) as 'geoarchaeologists', whose mission is to identify the different litho-pedo-sedimentological processes related to archaeological remains, implementing all the geoarchaeological tools (geology, geography, geomorphology, pedology, stratigraphy, micromorphology, petrography, pedochemical analysis, sedimentology, geophysical survey…). The geoarchaeologists help outline the scientific strategy (prospection/excavation) and the design process for data collection, necessary to contribute to the knowledge of links between human societies and their environment.

1. Introduction

This paper describes some aspects of past and present records, gathered during the last two decades, examining soils in rescue archaeological contexts in Lorraine. After a general presentation of the regional geomorphological context and the methodological approach of rescue archaeology in France, the results of four case studies are reported and discussed. The first ones are from two kinds of archaeological prospection types: (i) a rescue archaeological small surface prospection (Chamagne, 7 ha), (ii) a linear prospection (Cerville, 3 km of geomorphological observations along the landscape of a 13 ha prospected surface), (iii) Bulgnéville, 4,5 ha of archaeological excavation, (iv) an archaeological investigation at a structure scale (a *Grubenhaus* at Montigny-les-Metz, 350 m²).

All these examples present different uses of the geoarchaeological approach as a help to understand human settlements, their evolution and interaction with the natural environment. The conclusion discusses how, in spite of time and administrative constraints, even scattered geoarchaeological data from rescue archaeology can be used in a research framework.

2. General contexts

The Lorraine area (Fig. 1), extends in the west from the eastern part of the Paris Basin to the Vosges mountain in the east. Mesozoic geology forms a characteristic landscape made of calcareous escarpments oriented north/south, which structure the main hydrographic network (Rivers Moselle, Meurthe and Sarre; Lexa-Chomard et Pautrot, 2006; Le Roux, 2007). The surface formations (Carcaud, 1992; Flageollet, 2002; Cordier et al., 2004) mainly result from Quaternary glaciations (valley alluvial deposits, alluvial terraces and loamy drift cover), but Tertiary and Quaternary slope deposits are also present. The superficial loamy cover, mostly of a regional origin, is of a mixed alluvial, aeolian and colluvial sediment (Caillier, 1977; Gury, 1990).

The climate is temperate to slightly continental. Precipitation ranges between 750 mm/year along the middle Moselle river valley to 2400 mm/year at the Ballon d'Alsace (Wahl, 2007). Except in mountainous areas, the quite uniform Lorraine climate does not have a sensitive influence on soil evolution, which is more strongly controlled by geological parent material and topography.

Therefore, brownification (brown soil evolution) and leaching seem to be the main pedological processes of the well-drained soils on the *Lorraine plateau*. *Brunisols* and *Luvisols* (Baize and Girard, 2008; *Cambisols* and *haplic Luvisols* from WRB, 2015) have a wide extension in Lorraine (Jamagne, 2011), even if clayey Tertiary and thick weathered rock layers strongly inhibit local drainage. The resulting set of processes can prevail over leaching and darkening. On the calcareous parts of this *Lorraine plateau* (upper and middle Trias), the lack of water rather dominates pedological processes. On thick loamy covers and ancient alluvial terraces, soils are more or less highly sensitive to leaching, clay translocation and weathering. Upper Mushelkalk, Keuper and Lias clayey formations generate heavy, compact, plastic, wet/sticky or dry/hard and fissured soils, which are very sensitive to meteorological and seasonal variations. These soils are difficult to plough and often strongly water saturated. Such hydromorphic soils are used as meadows and forest. Apart from the better drained slopes, excess water management is the most important challenge for agricultural development on clayey/marly substrate (Jacquin and Florentin, 1988; Jamagne, 2011). On the thick loamy cover (> 50 cm) overlying the Keuper clayey substrate, soils are *redoxic Neoluvisols* and *Luvisols* (Baize and Girard, 2008; *luvic Cambisols* and *haplic Luvisols*, WRB, 2015), affected by a low permeability of the Bt horizon; as such during the wet season temporary perched water tables are present (Jamagne, 2011). Those soils are characterized by a degraded glossic Bt horizon with large reddish iron oxide patches cut by vertical whitish tongues from the upper albic E horizon (Caillier, 1977; Gury, 1990; Florentin, 2005). Where there is a thinner (20 to 30cm) loamy cover overlying the clayey substrate the Bt horizon is thin; however the substrate's poor porosity still induces water saturation during the wet season. The rivers (Seille, Nied and tributaries) carry fine decarbonated clayey and loamy material, which accumulates in the valley, with colluvium. The soils, affected by temporary or permanent water tables are thicker, darkened, degraded Luvisols (Baize and Girard, 2008; *glossalbic Luvisol*, WRB, 2015). In the main valleys, the alluvial sediments of the rivers (Moselle, Meurthe, Sarre and tributaries) are coarse, and the soilscape is characterised by *Fluviosols* (Baize and Girard, 2008; *Fluviosols*, WRB, 2015). Bordering the valleys, from alluvial plains to up slope locations, terrace soils evolved from slightly leached *Neoluvisols* (*luvic Cambisols*, WRB, 2015) at younger sites, to thick leached argilic truncated paleosols on older landscape. On middle terraces there are *redoxic Luvisols* (Baize and Girard, 2008; *gleyic Luvisols*, WRB, 2015), sometimes compacted with glossic/fragic pedofeatures (Caillier, 1977; Gury, 1990).

3. Material and methods

In the studied region, geoarchaeologists are supposed to participate in both archaeological phases: investigation and excavation. Trial trenches, dug by a mechanical excavator having a 2 m wide smooth-edged bucket, are best aligned perpendicular to the valley. Trenches (25x2 m in size and 1 m deep) offset in a staggered pattern, represent 6% of the investigated landscape. For safety and time reasons, observations on deeper profiles (>1,20 m) are carried out from the top of the trench (photo and measurement of each unit's thickness) before immediate refilling of the hole. In the case of archaeological excavation, surface horizon stripping is done, until the archaeological features appear (often at the interface between dark organic and lighter coloured more minerogenic subsoil horizon). The geoarchaeologist is usually not present at this stage and only has access to profiles on rare central plots and on the edges of the excavation. This sometimes makes understanding of the general morpho-sedimentary context difficult.

In the field, each profile is described as a succession of units. Following pedo-sedimentary criteria, these units are interpreted and grouped into sequences corresponding to homogeneous sedimentary or pedogenetic phases. Sequence limits are boundaries resulting from changes in sedimentary or pedological processes. Soil horizons are described based upon classical macroscopic criteria (colour, texture, structure, etc.; Duchaufour, 1976; Baize and Jabiol, 1995).

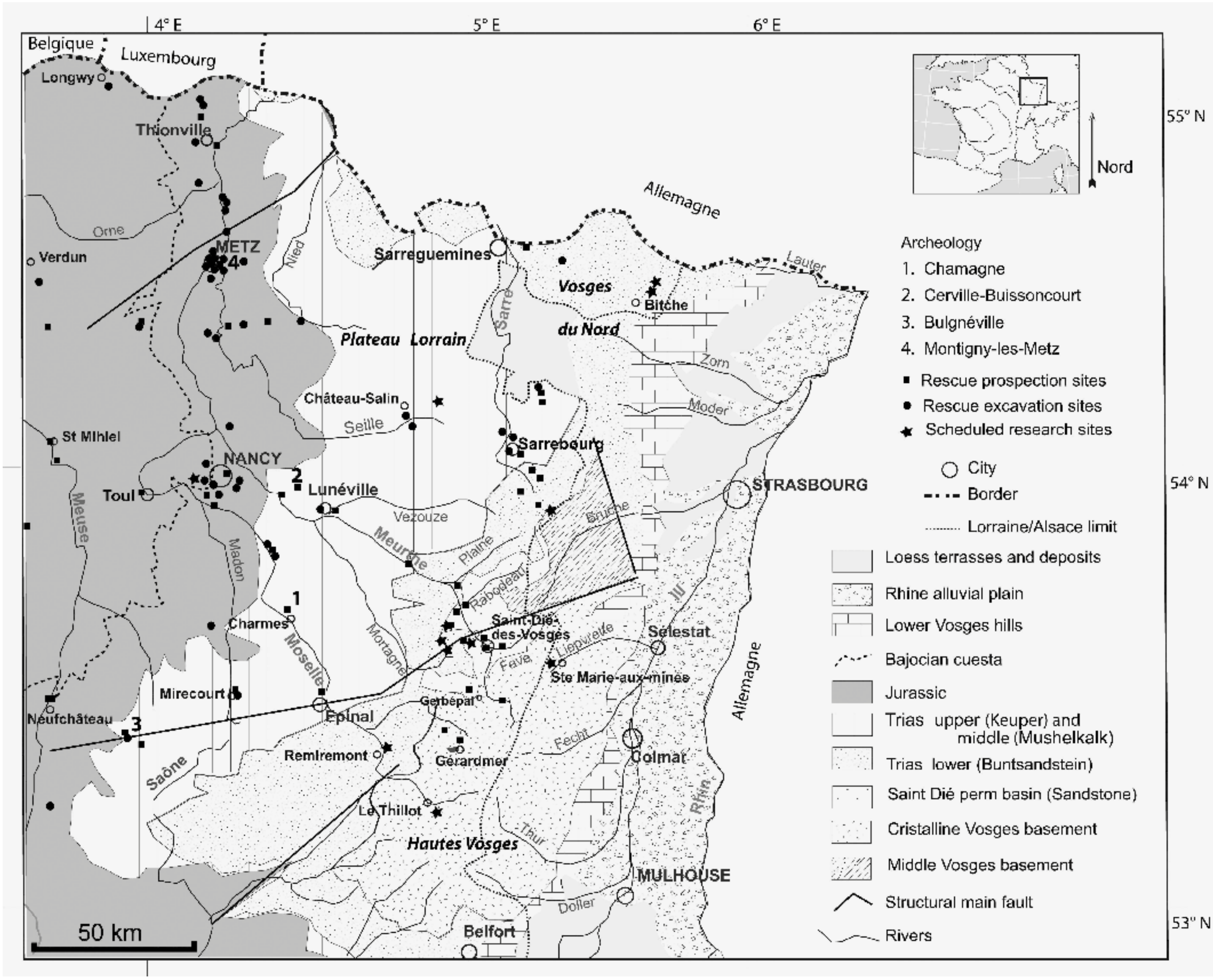


Figure 1. Location of all the studied sites on the geological map of the area (simplified from Lexa-Chomard and Pautrot, 2006; Sell et al. 1998), with special reference to the 4 examples detailed in this paper. The crystalline rocks of the Vosges correspond to the base, the 'sandstony Lorraine' to the Permian and lower Trias sandstones, the 'Plateau lorrain' to the middle and upper Trias, respectively.

The descriptions of the sites discussed here are reported in tables 1 to 5. Soil classification follows the French Soil Classification System (Baize and Girard, 2008) with the equivalences to the World Reference Base (WRB, 2015) being reported in this paper. On archaeological sites, observations are sometimes extended through micromorphological investigations of the soil. Thin sections are then described following international soil thin section description methods (Bullock et al., 1995; Stoops et al., 2010) and interpretation (Macphail and Goldberg, 2017; Nicosia and Stoops, 2017).

The distribution of the seemingly random pattern of the locations of the prospected and excavated sites researched by the author (Fig. 1), can be explained by the spatial and economic planning related to city expansion and valley urbanisation along the major routeway network (fast train, highways, etc.), and on the prescribing rate of the archaeological regional state service which also depend on the regional archaeological risk map. The main geoarchaeological studies are spatially recorded in the *Arkeogis* database, with references to associated reports and published papers (Bernard, 2012).

4. Case studies

In Lorraine, geoarchaeological studies sometimes feature approaches at different scales: the site scale (archaeological features), the middle scale (the site itself) and a larger scale, as a river basin in the frame of large prospection areas or the regional synthesis of several small investigated plots.

Pedo-sedimentary profiles include more or less eroded soils, fossilized under valley colluvio-alluvial accumulations or slope colluvial deposits. Valley infills often have inverted profiles, characterized by dark thick horizons covered by less dark loamy sediments derived from ancient mineral horizons eroded upslope. After abandonment, man-made excavations, like hollow ways, ponds, ditches, post-holes, etc. can locally trap microscopic eroded horizon fragments that provide true indications of past environments and their evolution, related or not to past human activities (Gebhardt, 1996). Furthermore, the study of man-made structures at the site scale gives information about ancient lifestyles or human artefact taphonomy (Gebhardt and Langohr, 1999).

4.1. GEOARCHAEOLOGY IN RESCUE ARCHEOLOGICAL PROSPECTIONS

4.1.1. Chamagne: a small surface investigation

This small investigated surface, covering around 7 ha, is located on an ancient terrace along the Moselle valley, (Bois de Genêt, Chamagne, Vosges; Fig. 11, Fig. 2a). After some unsuccessful attempts at corn growing, this ancient wood, cleared in the sixties, is now used for grazing (Rachet and Gebhardt, 2017). Around 20 m above the river, and on the right at a height of 285 m, this middle-Würmian alluvial terrace overlies the dolomitic Mushelkalk limestone which outcrops along the Moselle at Bout du Pont (Minoux et al.,1978). It is made up (Table 1) of roughly bedded sandy gravels including pebbly to sandy layers with clayey lenses (Fig. 2b, U3b). Locally, the sequence shows periglacial dumb-bell type involutions (Fig. 2c, U3a). A dark reddish manganese concretion layer (Fig. 2b, U3c) is observed at around 1,5 m depth, at the boundary with the lower sands (Fig. 2b, U3d). The coarse series (Fig. 2, U3), made of sand, gravels and pebbles, correspond with the highly dynamic stream of the Moselle river, alternating with clay sedimentation formed in oxbow lakes (Carcaud, 1992).

U3 formations are overlapped by an irregularly (0 to 2 m) thick moderately compact fine clay-loamy layer, U2 (Fig. 2c). From top to bottom, this loamy sequence shows a homogeneous loamy light grey level reworked in the 40cm thick ploughed horizon (U1). Downhill, this layer is thicker and probably related to historical agricultural colluviation. Beneath this colluvium a compact clear-brown-orange loamy-clay occurs, affected by the formation of deep and narrow whitish tongues (Fig. 2c). The horizontal section of this unit shows a small irregularly reticular polygonal network pattern (of around 5/10 cm diameter, Fig. 2d) becoming larger (up to 50 cm) with increasing depth (Fig. 2e). Modern drainage crosses those features (Fig. 2h), but a large ditch infill, less clayey and more bioturbated than the surrounding sediment, is slightly affected by those glossy features (Fig. 2f, 2g). The sherds found indicate that this ditch is linked to an ancient protohistoric occupation.

At the regional scale, it appears that this soil degradation mainly occurs along hillside deposits at the border of wetlands, or on the plateau on thick loam covers over clay substrate. The development of this glossic network has already been described as altered *Luvisols*, possibly associated with cracks in the ground (Caillier, 1977; Gury, 1990; Florentin, 2005). This feature may result from hydric stress on regularly water saturated loamy clay soils from Lorraine. Jacquin and Florentin (1988) noticed that those features are better developed under forest, with trees desiccating the soil by evapo-transpiration. In fact, giving a particular attention to this type of pedogenetic features, linked to other dated sites from the North Eastern part of France, we found that in long sedimentary sequences, those glosses/cracks features are mainly affecting Roman levels (from the beginning of the first millennium of our era), cross structures dated to the Iron-Age or older, and are cut by early medieval or later occupation. The good quality for agriculture of those hydromorphic degraded *Luvisols,* when ameliorated, has been known for a long

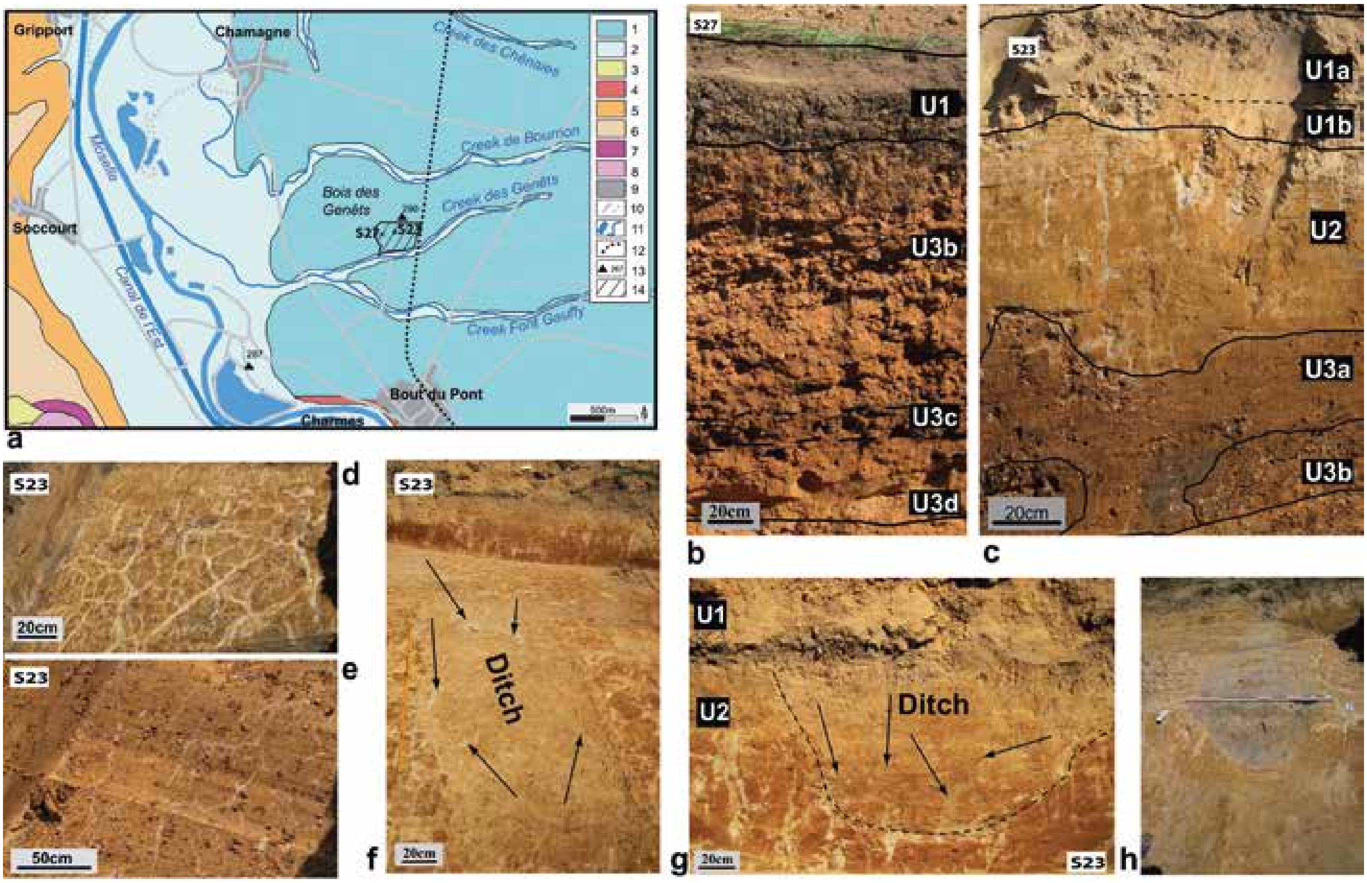


Figure 2. Chamagne (Vosges, France):

a. locations of the site on the synthesised geological map: 1. middle-Würm lowest of the old terraces, 2. younger alluvial terrace 3. loamy deposits 4. dolomitic Muschelkalk 5. lower and middle keuper marls, 6. upper Keuper clay, dolomite and marl 7. rhetian sandstone and clays, 8. hettangian-sinemurian limestone 9. urbanized zones, 10. roads, 11. river, canal and lakes 12. railway 13. altitudes 14. investigated surface

b. profile S27 with sandy/gravel sequence (see description table1)

c. profile S23 with upper loamy sequence

d. S23, horizontal section with upper small size polygonal network; upper part of the profile

e. S23, horizontal section of the polygonal network; lower part of the profile

f. horizontal sections of the ditch with polygonal network traces (arrows)

g. idem in profile

h. modern drainage

Table 1 Field description of the prospected site Chamagne (Vosges, France)

Unit		Field description	Pedo-sed interpretation)
U1		40cm thick dark brown crumby sandy loam level, many fine + some big roots. Structure and color sharp limit with U2.	ploughed horizon (LA)
U2		40cm thick brown-orange sandy-clayey loam, scattered gravels, fine roots, vertical 'glosse' type digitations network with greyish to whitish infill crossing the protohistoric ditch infill, fragmented very small rounded charcoals at the top. Sharp texture and colour limit with U3.	Reworked superficial loamy blanket
U3		Sandy to gravely formation with pebbles and clayey lenses.	Ancient alluvial terrace sediments
	U3a	Compact orange-brown clay, green-grey with depth. Sharp textural limit with U3b.	
	U3b	Pebbles and gravels in sandy matrix.	
	U3c	Idem 3b but manganese black coloured. Colour sharp limit with U3d.	
	U3d	Sand with scattered gravel.	

time. In that way, the Seille valley, for example, is nowadays, still a good place for growing vegetables (Florentin, 2005) and has been occupied and drained since Roman times (OIivier, 2002; Riddiford, 2012).

The formation of these irregular polygonal network pattern was largely discussed in a recent paper (Gebhardt et al., 2018) and the origin of many of these well-marked regional degradations/desiccations of soils can now be interpreted as both anthropogenic and/or climatic. For each site, further research is required to investigate the local climate more precisely and to monitor the land use changes during this period. If these correlations are confirmed, this level of integrated investigations could be a useful milestone for rescue archaeological prospection in Lorraine.

4.1.2. Cerville-Buissoncourt: an example of linear prospection

The prospected site of Cerville-Buissoncourt (Meurthe-et-Moselle; Forelle et al., 2012; Fig. 12, Fig. 3a, Table 2) crosses, north/south, an undulating landscape culminating at 240 m high. 53 profiles, spread across 5 areas running from south towards north (Fig. 3b,c), allowed the observation (Table 2) of the local pedo-sedimentary sequence and human impacts. The creek l'*Etang Le Comte*, regulated/canalised for modern agronomical purposes, is cut in a 2 m thick yellow/beige light sandy loamy-clay cover derived from quaternary sedimentary processes affecting the greyish Domerian marl beneath. The origin of the loamy fraction (aeolian or weathered substrate) is still not clear (Haguenauer et al., 1978). In this location, pedogenesis is strongly influenced by the impermeable marl.

Transect **Tr.c** runs on the upper part of the line of prospection, along a north-east facing gentle slope above the valley of l'*Etang Le Comte* creek. On top of the hill (S307, Fig. 4a); the hardened Liasic sediments outcrop as a hard fractured fine grey calcareous sandstone bed, alternating with small clayey layers (U5). Above this substratum, the paleosol (U3/U4/U5) buried under a thin colluvial sequence (U2) is a *Brunisol* (Baize and Girard, 2008; *Cambisol*, WRB, 2015), with well-developed structural IIS and organic IIA horizons. In this buried sequence, abundant man-made structures (ditches, post-holes), bones, charcoal and unabraded pottery sherds from the Bronze Age were found. It would have been interesting to analyse this well-dated buried sequence in terms of environmental human impact (deforestation, cultivations, grazing, erosion), but during the prospection phase, it was impossible to proceed with further pedo-sedimentary analyses, like soil micromorphology, to describe the sequence in more detail.

The next transect, **Tr.d**, is in continuity with the previous one and S382 shows a last thin occurrence (U4) of the IIA buried horizon (Fig. 4b), rich in charcoal, and probably related to U3, observed in the previous transect (Tr.c, S307). The sequence is topped by a colluvial deposit (U2/3) and affected by strong gleying processes; these were described as *Reductisol* (Baize and Girard, 2008; *Gleysol*, WRB, 2015).

The transect **Tr.b** crosses the valley bottom and the wooded south facing slopes. In the middle of the slope, in profile S132 (Fig. 4c) the uppermost part of the marl (U5) is covered by oxidized sandy channel beds (U4); both are slightly disturbed by quaternary periglacial features. The profile is buried under colluvial deposits (U2) and affected by oxido-reduction at the base (U3). On the wooded top of the hill (S452, Fig. 4d), a typical *Reductisol* (Baize and Girard, 2008; *Gleysol*, WRB, 2015) developed on the calcareous marl (U4) and has no colluvial cover. In this area, there are several drainage ditches filled with an oxidized/oxido-reduction sediment containing scattered Bronze Age material. Abundant modern drains cut the clayey horizons (U2/3).

Tr.e continues facing north, from the wood downslope to pastures, separated by hedges. There, the profile S425 (Fig. 4e) reveals the development of redoximorphic horizons at the base (U3/4) (*Reductisol*, Baize and Girard, 2008; *Gleysol*, WRB, 2015) on the marly substrate (U5/4). Colluvial deposits (U1/U2) cover the marl, except on the very top of the hill. These accumulations appear thicker on the slope at the field limit, the sediment being retained by hedges (many large vertical root channels can be observed in U2).

The last transect **Tr.a** is localised offset on the north facing slope and crosses Le Bois-des-Moines forest. As is the case for S53, profiles reflect strong waterlogging effects with a well-structured subsurface horizon, which is locally strongly mottled with iron/manganese impregnations and concretions (U2, Fig. 3g), developed on greyish reduced horizons (U3/U4). In the U2 horizon, traces of undated cart wheel tracks (Ct, Fig. 4g,h) and a couple of horseshoes (Hs, Fig. 4i) have been found. Here, orange mottling indicates an old compacted traffic-induced soil pan (Gebhardt and Langohr, 2015; Rentzel et al., 2017; Macphail et al., 2016; Macphail and Goldberg, 2017).

This example of topotransect (or *catena*) gives an idea about the relationship between landscape, soil development and human activity. A remain of a paleosol reveals that in Bronze Age times, people settled on the well-drained top of the hill. Later, at an undefined period, the valley was drained for agriculture, which probably triggered erosion and colluviation at this site. Local intensive use of wheeled vehicles pressed the trackway sediment into a thick compacted layer, which developed into stagnic *Reductisol* (Baize and Girard, 2008; *Gleysol*, WRB, 2015).

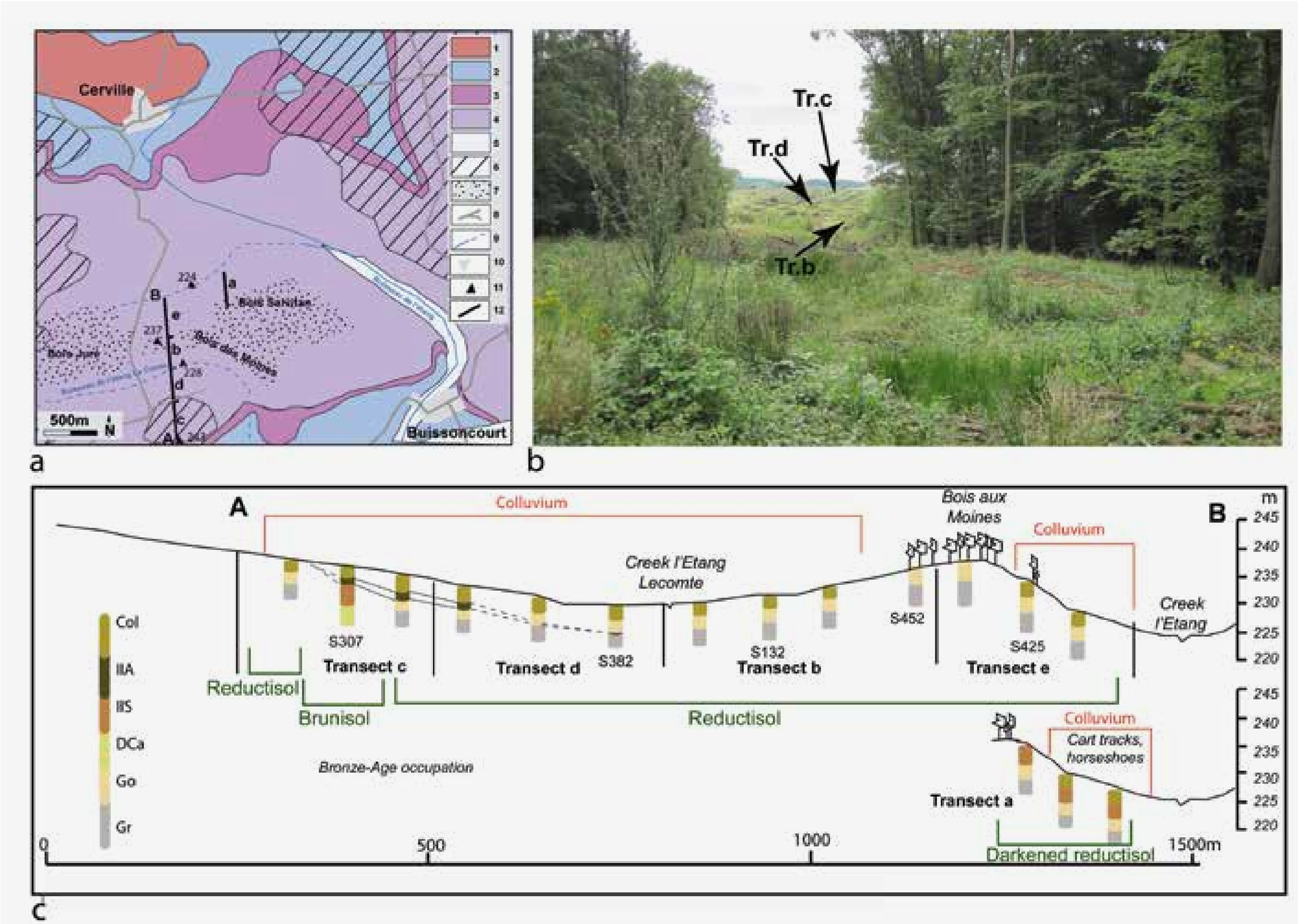


Figure 3. Cerville-Buissoncourt (Meurthe-et-Moselle, France):

a. locations of the site on the synthesised geological map: 1. hettangian-sinemurian limestone; 2. lotharingian clay; 3. carixian limestone; 4. domerian marls; 5. younger alluvial terrace; 6. loamy deposits; 7. woodland; 8.roads; 9. rivers; 10. urbanized zones; 11. altitudes; 12. transects

b. general view of the landscape

c. cross section of the landscape with location of the transects and soil profiles Col: colluvium, IIA: organic paleosoil horizon IIS: organo-mineral paleosoil horizon DCa: substrate Go: oxidized gley horizon Gr: reduced gley horizon

4.2. GEOARCHAEOLOGY IN A RESCUE ARCHAEOLOGICAL EXCAVATION

4.2.1 Les Longues Royes site

The polyphased archaeological site of Les Longues Royes (Boulanger et al., 2018) is situated in the Bulgnéville district (Vosges, Fig. 13, Fig. 5a). Three main cultural phases follow each other, represented by a La Tène culture enclosure (I^{st} c. BC) and two phases of Roman occupation from a farm (I^{st} c. AD) to a villa (II^{d}-III^{d} c. AD).

The geology of the area (Fig. 5a) is characterized by Keuper marl, topped with lower liasic moderately compacted dark paperschist layers covered with a homogeneous whitish dolomitic sandstone bed. The latter is a porous formation, and this type of geology can be strongly resistant to erosion, yielding a consistent groundwater supply (Minoux, 1967). The homogenous irrigated marl outcrops are often furrowed by gullies. Recent valley infillings are clayey-marly sands, with some pebbles (from the lower Trias). Irregular loamy slope deposits cover the Lias and Trias outcrops.

The site is divided into 3 sectors: the *pars urbana* with the villa on the top of a gently sloped west/north-west oriented plateau (Sector 1), the *pars rustica* on the slope below, with two farm buildings overlooking the creek des Fossés (Sector 2), and a third one (Sector 3) being an entrance building linking the two other sectors with less well-drained ground near a spring (Fig. 5b).

Although the excavations had to be accelerated because of financial and time constraints, thorough investigations were carried out thanks to a committed, perceptive and dedicated archaeologist who called for

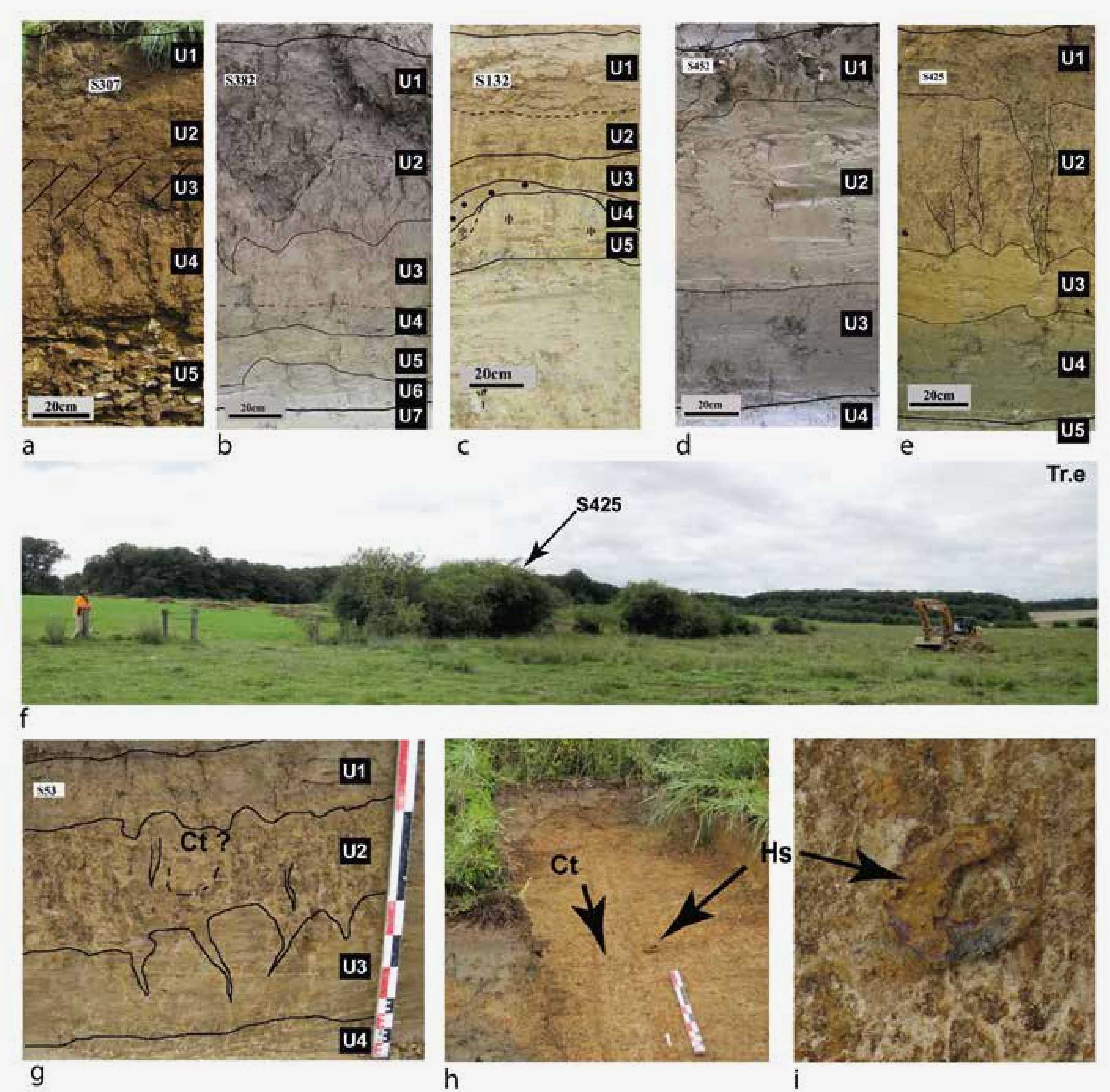
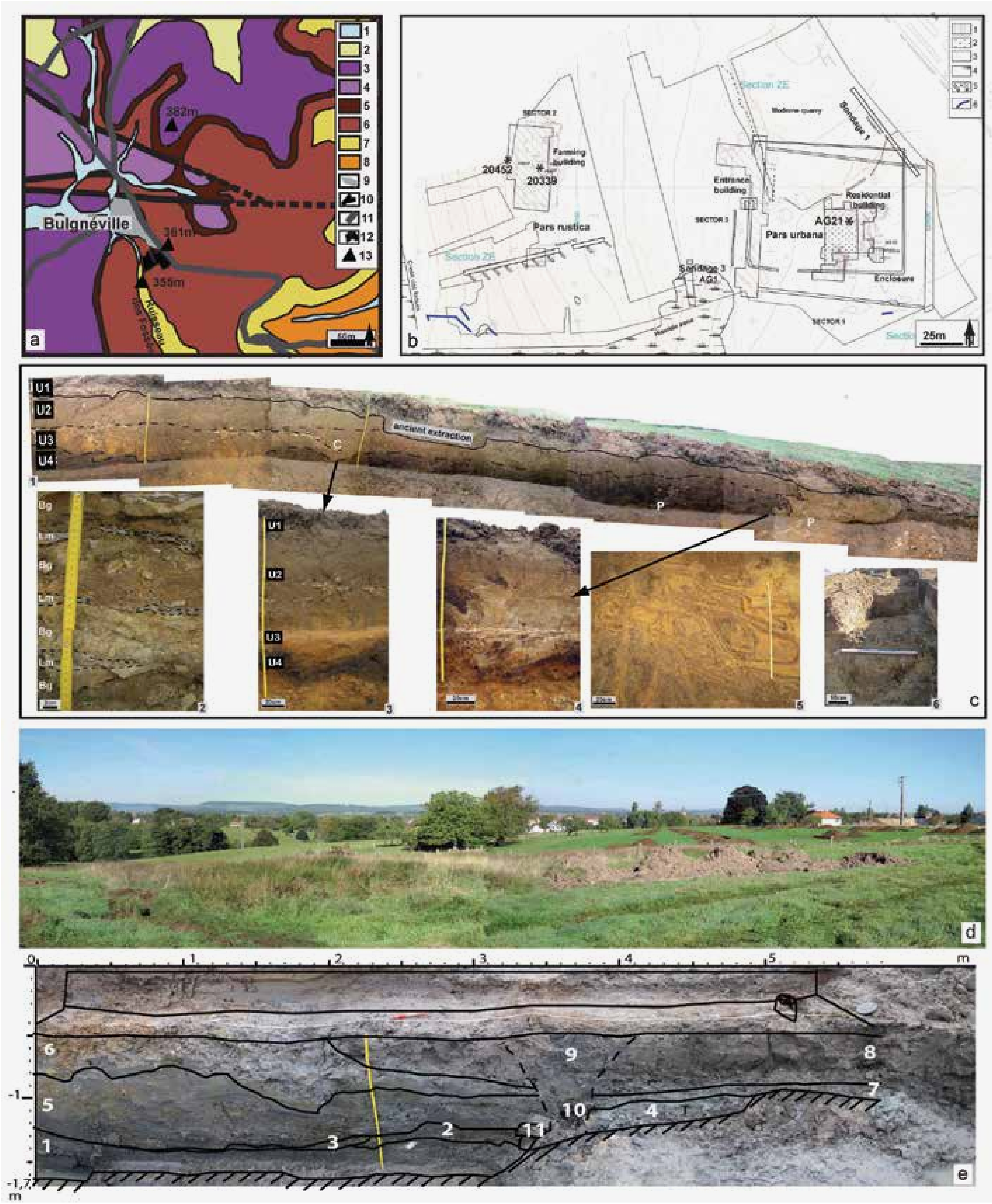


Figure 4. Cerville-Buissoncourt (Meurthe-et-Moselle, France):

a. transect c / profile 307, with the paleosol (U3/U4)
b. transect d / profile 382
c. transect b / profile S132
d. transect b / profile 452
e. transect e / profile 425
f. general view of transect e in the facing north slope with old hedges
g. transect a -profile S53 with cart track in profile (Ct)
h. transect a, horizontal section of the cart track (Ct) and horse shoe (Hs)
i. horse shoe (detail)

Table 2 Field description of the prospected site Cerville-Buissoncourt (Meurthe-et-Moselle, France)

Unit		Field description	Pedo-sed interpretation	
Tr.c	**U1**	40cm thick black-brown loamy-clay, crumby/fluffy structure, many roots and mouse galleries, big recent pottery fragments and tiles fragments, HCl<0. Organic horizon probably ploughed. Sharp strait structural limit.	ploughed horizon (LA)	
S307	**U2**	20cm compacted homogeneous brown loamy-clayey, some small pinkish quarzitic (ancient vosgian terrace?) and calcareous gravels. Abundant reddish tile/brick millimetric fragments. HCl<0. Sharp color/structure limit.	colluvial horizon	
	U3	20cm of dark brown-grey loamy-clayey, well marked angular polyhedral structure. Some gravel rounded Abundant Bronze-Age pottery fragments. Undulated gradual limit with the next level. HCl<0. Sharp textural limit.	organic paleo-horizon (IIA)	Cambisol
	U4	40cm light polyhedral pale brown-grey loamy-clay, local biogalleries, HCl<0.	mineral paleo-horizon (IIS)	
	U5	Fractured mesoliasic domerian calcareous sandstone substrate (HCl>0) with fine clay levels between blocks.	domerian calcareous sandstone	
Tr.d	**U1**	40cm thick dark brown-grey crumby sandy loam level, many fine roots, some bigger, organic plough horizon. Structure/colour sharp limit with the next level.	ploughed horizon LA)	
S382	**U2**	20cm homogeneous brown-grey loamy-clayey, light polyhedral structure, small pinkish quarzitic (old vosgian terrace) and calcareous gravels. Abundant reddish tile/bricks millimetric fragments. HCl<0. Gradual and waved colour limit.	upper colluvial horizon	
	U3	20cm light grey-brown loamy-clayey homogeneous level, quite compacted structure, small pinkish quartzite and calcareous gravels, reddish tile/bricks millimetric fragments. HCl<0. Gradual colour/structure limit.	deep colluvial horizon	
	U4	20cm light angular polyedral darker brown-greyish loamy-clay. Some rounded gravels, abundant very small charcoals fragments. Undulated gradual limit with U5.	organic paleo-horizon (IIA) with hydric level variation	
	U5	15cm homogeneous brown reddish clay, iron/manganese concretions and impregnations. HCL<0. Gradual colour limit.	hydric variation (Go)	Gleysol
	U6	15cm homogeneous compact reduced grey-whitish clay, oxidised sand lenses. HCl<0.	permanent watertable (Gr)	
	U7	Compact calcareous clay + some small calcareous nodules.	domerian marly substrate.	
Tr.b	**U1**	30cm thick dark brown-grey crumby sandy loam level, many fine roots, some bigger. Sharp structure/colour limit.	ploughed horizon (LA)	
S132	**U2**	20cm quite compacted homogeneous light brown loamy-clay, small pinkish quartzite and calcareous gravels, millimetre reddish tile/brick. HCl<0. Gradual colour/structure limit.	colluvial horizon	
	U3	Same as U2 with localised iron/manganese concretions and impregnations. HCl<0. Gradual colour/structure limit.	hydric variations in colluvial horizon	Gleysol
	U4	10/5cm brown-reddish oxidised layered sands, ± channelized. Periglacial deformations.	domerian marly substrate.(Go)	
	U5	Compact calcareous clay + some small calcareous nodules. Periglacial deformation.	domerian marly substrate. (Gr)	
Tr.b	**U1**	20cm dark dark-grey well structured clayey-loam, big roots, dominant. HCl<0. Sharp structure/colour limit with U2.	upper organic horizon (A)	
S452	**U2**	50cm homogeneous light grey loamy-clay, quite compacted, localised iron/manganese concretions and impregnations. HCl<0. Gradual color and structure limit with U3.	hydric variation (Go)	
	U3	15cm homogeneous compact reduced grey-whitish clay, oxidised around sandy lenses. HCl<0	permanent watertable level (Gr)	Gleysol
	U4	Domerian marly substrate. Compact calcareous clay + some small calcareous nodules.	Mm: domerian marly substrate.	
Tr.e	**U1**	30cm thick dark brown crumby sandy loam, fine roots, filled roots galleries. HCl<0. Sharp structure/colour limit with U2.	organic plough horizon (LA).	
S425	**U2**	40cm of brown homogeneous compacted loamy-clay, Abundant reddish tile/bricks millimetric fragments. HCl<0. Quite sharp color/structure limit with U3.	colluvial horizon	
	U3	20cm of light yellowish homogeneous clayey-loam, quite compact, very localised iron/manganese concretions and impregnations. HCl<0. Sharp colour limit with U4.	hydric variation (Go)	
	U4	Unoxidized grey homogeneous compact clay. HCl<0	permanent watertable level (Gr)	Gleysol
	U5	Domerian marl substrate. Compact calcareous clay with small calcareous nodules fissured and recalcified (septarias?), grypheus, belemnite rostrum.	domerian marly substrate.	
Tr.a	**U1**	25/30cm thick grey-brown crumby sandy loam, many fine roots. HCl<0. Sharp structure/color limit with U2l.	ploughed horizon (LA)	
S53	**U2**	40cm light polyhedral thick brown loamy clay, strong iron mottling impregnation/concretions, biogalleries. HCl<0. Sharp oxidation limit.	Sg	
	U3	20cm compact light brown homogeneous clayey-loam, iron/manganese concretions/impregnations. HCl<0. Sharp colour limit.	hydric variation (Go)	Gleysol
	U4	Unoxidized grey homogeneous compact clay. HCl<0.	permanent watertable level (Gr)	



a
Bulgnéville
382m
381m
355m
1
2
3
4
5
6
7
8
9
10
11
12
13
b
SECTOR 2
Farming building
20452
20339
Pars rustica
Section ZE
Entrance building
SECTOR 3
Residential building
AG21
Pars urbana
Sondage 3
AG1
Enclosure
SECTOR 1
Sondage 1
25m
c
U1
U2
U3
U4
ancient extraction
C
P
Bg
Lm
d
e
m

Figure 5. Bulgnéville (Vosges, France), a La Tène culture enclosure (Istc. BC) with two phases of Roman occupation from a farm (Istc. AD) to a villa (II^{d}-III^{d} c. AD):

a. locations of the site on the synthesised geological map: 1. younger alluvial terrace 2. loamy deposits 3. sinemurian-hettangian limestone 4. upper sinemurain limestone 5. rhetian clays 6. infralias sandstone 7. upper keuper marls 8. lower keuper marls 9. urbanized zones 10. faults 11. roads 12. investigated surface 13. altitudes

b. 1. La Tène enclosure (Istc. BC), 2. first roman farm (Istc. AD), 3. Roman villa (II^{d}-III^{d}c. AD) 4. humid zone 5. investigated trenches and profiles 6. drains

c. transect1 1. general profile 2. infraliasic sandstone substrate made of irregular and brittle sandstone beds (Bg) alternating with fine marly beds (Lm) 3. windthrown tree depressions 4. residual patches of vivid brown whitish heterogeneous marly-sand, with periglacial injections (P) 5. geometrical alteration probably due to ante-pleistocene tropical humid conditions 6. gullies

d. general view of the humid zone at the slope failure

e. succession of natural and anthropogenic materials, accumulated in a small natural depression 1. residual black schists 2/3. alternating fine and coarse clayey dark discontinuous late-glacial surface flushed material 4/5. protohistoric colluvium 6/7/8. dumped earth 10. Roman wooden water extraction pipe 9. trench of the wooden pipe dug through the anthropogenic sediments 11. stones fixing the pipe

geoarchaeological collaboration from the very onset of the excavation. As soon as the top soil was removed, the locations for the profiles/trenches were strategically chosen and observations were carried out (Table 3). As a result, the geoarchaeological approach was comprehensive in that it extended from investigating the paleo-environmental context to studying specific archaeological structures.

The infra-liasic sandstone substrate was observed in the long lateral eastern trench 1 (Sondage 1, Fig. 5b, Fig. 5c-1). It is composed of irregular and brittle sandstone beds (Bg, Fig. 5c-2) alternating with fine marly beds (Lm, Fig. 5c-2). The weathering of the upper parts of these formations can produce approximately 1 m thick of mottled red-black (U4) to yellowish-orange (U3) sands, which show clear geometrical alteration probably due to pre-Pleistocene tropical humid conditions (Fig. 5c-5). This sand seems to have been used by the small modern quarry industry near the site (Fig. 5b). Residual patches of light brown/whitish heterogeneous marly-sand (Fig. 5c-4) can be seen in these formations. This substrate is strongly affected by quaternary periglacial processes (Fig. 5c-1, P; Fig. 5c-4). Erosion-inducing, late-glacial/early Holocene climate-related events led to solifluction and gullying on the slopes (Fig. 5c-6). Windthrow tree depressions were observed (Fig. 5c-1, C; Fig. 5c-3) in the marly outcrop. Lastly, a mixture of colluvial rhetian fine sands and periglacial loams, which include some protohistoric sherds, locally covers the slopes (U2/U1, Fig. 5c-1). This last

Table 3 Bulgnéville (Vosges, France), field description of trenches S1 and S3

Units		Field description	Pedo-sed interpretation
S1	U1	40cm of dark well- structured grey loamy sands.	plough layer (LA)
	U2	60cm of beige sandy loams including protohistoric sherds.	Colluvium
	U3	20/40cm heterogeneous residual brown-whitish marly sand patches, periglacial deformation.	Ante-pleistocene alteration of infraliasic sandstone and marly sands
	U4	10/20cm irregular red-black/yellowish-orange strongly oxidized sand, plane geometrical concentric alterations.	
	Bg	Irregular and brittle 10/15cm thick sandstone beds.	Infraliasic substrate levels
	Lm	Thin 1/2cm marly beds.	
S3	11	Dolomite stones used to stall the pipe.	Trench for roman water adduction pipe
	10	Wooden pipe still driving water.	
	9	Mixture of sands and yellowish clays.	
	8	Grey-brown clayey sand.	Man perturbated
	7	Grey clayey matrix with many stones (equivalent to 6?).	
	6	Stones + grey less clayey matrix. Sharp wavy limit with U5	
	5	Homogeneous grey-orange clay rich in organic matter fragments and oxidation spots (equivalent to 4?).	Colluvium?
	4	Grey clayey sand (with sherds).	
	3	Stony lens with yellow-brown clay matrix.	Periglacial erosion
	2	Homogeneous black clay lenses.	
	1	Compact black brittle clay hard schists.	Paperschists Keuper

occurrence can be related to the Iron Age climatic degradation combined with strong agricultural pressure, as can also be observed elsewhere in western Europe (Fechner et al., 2014, Gebhardt et al., 2014).

Investigation of the humid zone of the sector 3, at the junction between the slope (sector 2) and the flatter sector 1 (Fig. 5d), showed a succession of natural and anthropogenic materials, accumulated in a small natural depression (Fig. 5e). The rhetian sandstone, here is totally eroded and only represented by relict black schists (1), and is covered by alternating fine and coarse clayey dark discontinuous layers interpreted as water-laid late-glacial surface material (2, 3). The depression was then filled with protohistoric colluvium (4, 5) and dumped soil (6, 7, 8). A wooden water extraction pipe dating from Roman times (10), which still carries water, was discovered at the interface between the clay and the sand, in a trench (9) dug through the anthropogenic sediments.

Soil micromorphological expertise was used to find an answer to several questions concerning selected periods: What was the pre-Roman landscape like, and are there any clues for differentiating specific activities areas in the farm building?

The soil before Roman occupation

An important characteristic of the multiphase occupation at Bulgnéville is the fossilization of older soil plots found under the Roman buildings. First, a *terrazzo* from the first residential villa (Ist c. AD), sealed the ancient Iron Age enclosure's soil sequence. From top to bottom, this AG21 plot (Fig. 6a-1) shows, under the lime concrete and stone cover (U0), a succession of compact brown weakly bioturbated sands (U1, U2), which become brown reddish downwards (U3). The limit between U2 and U3 is not very well marked. At the base of U1, a fine blackish spotted transition horizon of iron/manganese impregnation soil was observed. Thin section studies reveal that the top of the sediment includes many abraded artefacts: charcoal, ashes, lime mortar (Fig. 6a-3), and other calcareous fragments associated with the *terrazzo* construction.

The ferro-manganese staining of lime and micrite precipitations (Fig. 6a-4) probably indicate wetting and drying phases associated with lime concrete floor manufacture. Abundant small charcoal fragments (mainly from deciduous trees, Fig. 6a-2) scattered in U2/U3 indicate clearance cultivation practices (Deak et al., 2017; Macphail and Goldberg, 2017), although the abundant dusty coatings

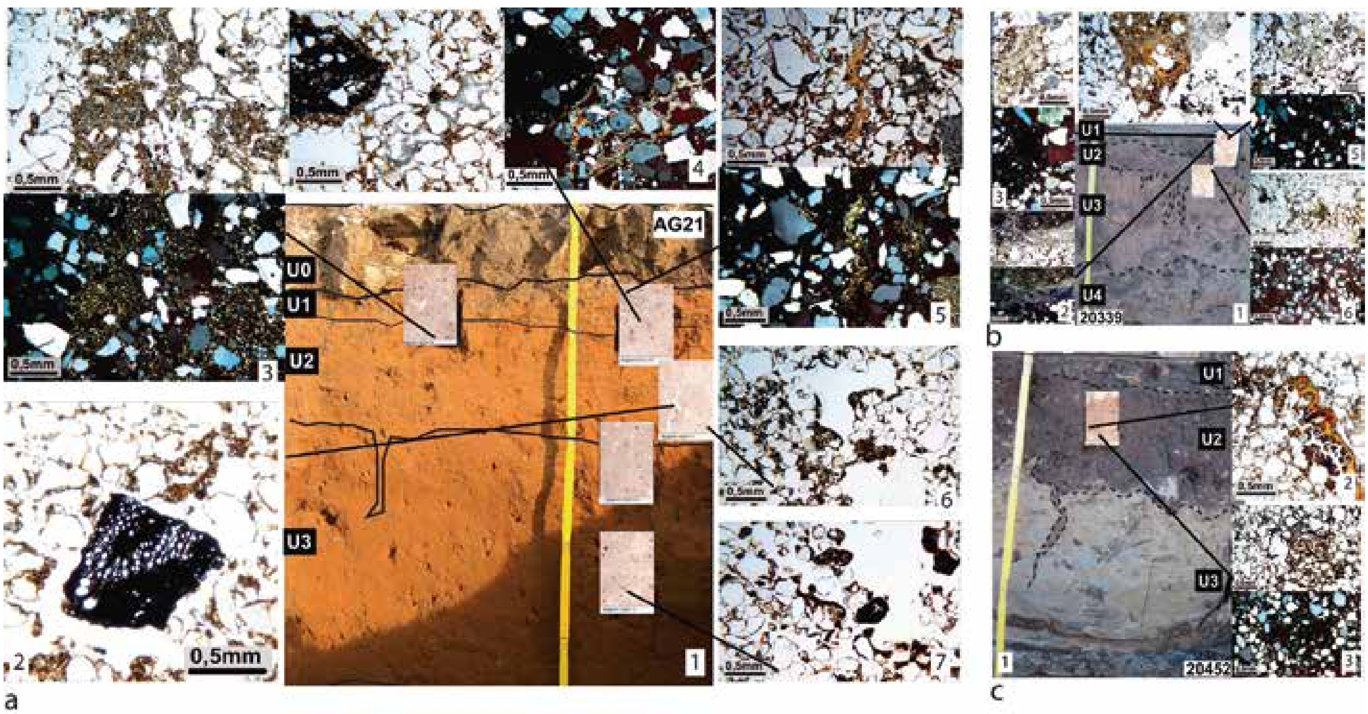


Figure 6. Bulgnéville (Vosges, France), main soil micromorphological features:

a. AG21, profile in the early iron age enclosure soil sequence under the terrazzo from the first residential villa (Ist c. AD) 1. lime concrete (terrazzo) and stones cover (U0), successions of compact brown weakly bioturbated sand (U1, U2) to brown reddish downwards (U3) 2. charcoal from deciduous trees 3. Lime mortar 4. micrite precipitation, 5/6/7 dusty coatings;

b. 1. farm building man-made floor profile (20339) 2. limestone mortar 3. bone 4. rounded soil fragment 5. omnivore dejection 6. organic non birefringent coating;

c. western gallery (20452) 1. soil profile 2. crystallisation of goethite 3. organic coatings.

(Fig. 6a-5/6/7) could attest to rainsplash effects on bare soil within the Latenian Iron Age enclosure. The 20 cm thick colluvium between the Gaul farm basement and the first Roman construction phases associated with the observation of microscopic disturbed horizon fragments, can be related to erosion/colluviation processes resulting from cultivation (Gebhardt, 2014).

Some indications of anthropic activities in the Roman era

Micromorphological investigations of the farm building's constructed floor (20339, Fig 6b-1, Table 4) revealed many anthropogenic artefacts like lime mortar (Fig. 6b-2), adobe/cob fragments, bones (Fig. 6b-3), abraded pottery fragments trapped in the soil material. The latter was shown by the presence of rounded soil fragments (Fig. 6b-4). Several phytoliths could suggest the use of straw, while the omnivore coprolites (Fig. 6b-5) indicate the passage of pigs, dogs (or rats). Organic non-birefringent «coatings» and voids infills (Fig. 6b-6) are probably issued from the abundant decayed organic material strewn on the floor (Macphail and Goldberg, 2017). These observations fit well with the archaeological results and we can interpret the place as a domestic cooking area used by farm workers.

In the western gallery (20452, Fig. 6c-1,) the sharp boundary between the dark occupation level and the fissured marly substrate is remarkable, and suggests that the natural top soil horizons were cleared. Crystallisation of goethite (Fig. 6c-2) reveals strong humidity (Gebhardt and Langohr, 1999) probably due to liquid animal waste and decaying organic matter. Amorphous organic coatings are abundant (Fig. 6c-3). The absence of dusty clay coatings, of trampling and of compacted soil structures could suggest that this gallery was a well-drained cattle stalling area, probably with a wooden floor and protected by a roof to avoid mud formation.

In conclusion, we see that the early farmers knew how to deal with the natural geological conditions of the area. The first Gaul farm was conveniently established on the very top of the hill, in order to take advantage of well-drained sandy soils suitable for cultivation, and of the proximity of spring water. Also, it is not surprising to see that during Roman times, this first farm expanded into a villa on the same dry location, while wetter slopes were better suited as meadows and as a location to build barns and stables.

4.2.2. Geoarchaeology at settlement scale

In most cases, the geoarchaeologist is only called in to help provide a clearer understanding of specific anthropogenic accumulations or archaeological structures. This may concern the formation and use of undefined subsoil hollow structures (windthrowns, dumping pits, ponds, workshops, *Schlitzgruben*, ditches, hollow-ways, *Grubenhäuser,* cattle

Table 4 Bulgnéville (Vosges, France), field and microscopic description of AG21, S20339 and S20452

Units		Field description	Soil micromorphological description	Pedo-sed interpretation
AG21	U0	Compacted Dolomite stones and lime concrete		Terrazzo
	U1	Dark-brown compacted sands with abundant calcareous fragments, underlined by a black iron/manganese oxidation line.	Compact microstructure, low pedality, intergrain low porosity (40%). Quarzitic angular sand (250µm, 40% to 500µm, 5%), rock fragments (0,5 to1cm, 5%): dolomite, sandstone, fossil shells fragments, prophyric low birefringent dusty silty groundmass, limestone, bones, limpid clay coatings fragments, ashes? Sparite precipitations, iron concretions.	Fossilized La Tène enclosure soil
	U2	Brown (10YR 4/6) compact sand, some biogalleries, diffuse unsharp limit of structure with U3.	Better microstructure and pedality, inter aggregates fissure porosity. Same mineral compound as U1, gefuric middle birefringent dusty silty groundmass, some charcoals. Seldom dusty clay coatings. Rounded iron concretions.	
	U3	Homogeneous brown-reddish (2,5YR3/4) sand with some blunt sandstone fragment, fine roots, rare biogalleries.	Same microstructure, mineral compound and groundmass as U2, calcite bionodules, very fine micro-charcoals, unlayered compact thin dusty clay coatings. Iron concretions.	
S 20339	U1	Dark brown (10YR 3/4) clayey sand, abundant calcareous stones level at the top with limestone fragments, charcoals and sherds.	Granular microstructure, good pedality, good intergrain porosity (40%). Quarzitic angular sands (250µm, 40% to 500µm, 5%), sandstone, dolomite fragments (0,5 to 1cm, 40%) gefuric dusty silty groundmass, low to no birefringence. Clay fragments, limpid clay coatings? BT reworked fragment?	Domestic cooking area
	U2	Yellowish-brown (10YR 6/8) clayey sand, big blunt stones. Diffuse colour limit with 3.	Same microstructure and mineral compounds, non-birefringent chitonic/gefuric dusty silty groundmass.	
	U3	Light grey (10YR 7/2) marly sand slightly bedded, big stones, redox traces at the bottom.		
	44	Yellowish (10yr 7/8) sandy marl substrate.		
S 20452	U1	Aboundant stones level.		Stalling area probably on wooden floor
	U2	Yellowish-brown (10YR 3/4) clayey sand, some calcareous stones, limestone fragments, charcoals and sherds	Granular microstructure, low pedality, good intergrain porosity (40%). Angular quartz sands (250µm, 40% to 500µm, 5%), sandstone+dolomite fragments (0,5 to 1cm, 40%), non-birefringent chitonic dusty silty groundmass, fresh roots, calcite bionodules, omnivore dungs, limestone fragments, pots sherds, some small micro-charcoals. Goethite nodules.	
	U3	Light grey (10YR 7/2) marly sand slightly bedded, big stones.		

path, etc.) or accumulation layers (dark earth, gardens, raised cultivation beds, terraces, fire installations and all kinds of Anthrosols, etc.; Gebhardt, 2005, 2008; Macphail and Goldberg, 2017). Even if some microscopic environmental data can be gathered from these structures (about soil erosion, landscape, etc.; Gebhardt, 2000) the main expectation of archaeologists is often to add information to their comprehension of the site (are sediments *in situ* or not? are there indications of cultivation, stabling, housing, workshop, ritual activities, tracks, etc.?).

The Montigny-les-Metz (Moselle, Fig. 14) site is located on Seille river alluvium composed of fine sands and loams. The first Merovingian occupation is followed by the construction of three *Grubenhäuser,* partly dug into the soil without walls (Fig. 7-1/3). The infill of the best preserved one, dated from 944-1020 BC, contains numerous pottery fragments and many domestic faunal remains (Carron et al., 2008). Here, the fill sediments seem to be *in situ* (Fig. 7-3), and not reworked, as would be the case in the relict shell of an abandoned house that has been filled with sediments from another house. As a consequence, all the micromorphological features observed can be clues to document the house's occupation. It is then possible to tell an interesting story by studying this infill left after abandonment.

Micro-investigations (Table 5) detected occupation debris such as compacted adobe fragments (Fig. 7-4), small abraded pottery sherds, bones remains, eggshell (Fig. 7-5), numerous small charcoal, dung (Fig. 7-6) and abundant phytoliths (Fig. 7-7).

Researchers cannot yet link avian eggshells to specific birds (Canti, 2017) but the diet of the rural society was probably mostly based on hen's eggs, along with goat or sheep milk. In the dung fragments, the presence of sometimes articulated phytoliths suggest the presence of herbivore dung (Brönnimann et al., 2017), probably from goats or sheep. Phytoliths occurring in the sediment may originate from straw roofing or mottle walls (Fig. 7-1), floor bedding, and fuel materials (Vrydaghs et al., 2017).

If sediment looks homogeneous and is left in situ after abandonment, as in some dark earth deposits (Nicosia et al., 2017), organic material can be strongly reworked by bioturbation. These features can also be related to cattle herding, associated with increased soil fertility. Earthworms, which activates soil bioturbation, can move anthropogenic artefacts down-profile (Schwartz and Gebhardt, 2011). The numerous organic materials present (mainly small roots) attest to the nutritive availability of this plot.

Nevertheless, herbivore dung in the sediment is consistent with keeping of stock (Shahack-Gross, 2017) and so the house could be interpreted as a small cattle stable (sheep, goats) with possible hen nesting. But it is also possible that dry dung was used as fuel for domestic heating (Canti and Brochier, 2017). With the many food residues present this *Grubenhaus* can also be interpreted as a living house or a cool larder as in Poland (Fig. 7-2). However, in absence of loom weights (Zimmerman, 1982) the simple observation of a small post hole does not indicate weaving practices. Generally, the *Grubenhaüser* infill reflects mixed practices from rural life (Macphail et al., 2006; Macphail, 2017) and many uses and phases can be considered, surely following each other as the same house was used for domestic purposes before sheltering stock, after which a new one was constructed for human use.

5. Conclusions

Twenty years of geoarchaeological experience in Lorraine allows us to give a detailed geoarchaeological overview of the region. The multi-scale approach permitted us to gather a huge amount of very diverse data collected from varied geomorphological contexts. The diversity of the collected data, the themes and the chronology make it difficult to find a common thread among the nearly hundred sites investigated, with sites spanning the last 10,000 years. Nevertheless, finding correlations between the scattered proxies is still feasible. Also, after a literature review, it is possible to make general considerations on soil genesis, erosion and anthropisation phases dating from the second half of the Holocene (Gebhardt et al. 2014; Fechner et al., 2014) and on soil desiccation and degradation features during the Subatlantic (Gebhardt et al., 2018).

As the spatial distribution of prospected and excavated rescue archaeological sites is the result of local economic parameters, the additional opportunity to follow scheduled archaeological research projects helps provide a more complete geoarchaeological database. This permits access to non-threatened sites, for example in forested areas, and to gather information on past human impact on forested mountain landscapes (Gebhardt 2007a, 2007b, 2017; Gebhardt et al., 2009; Gebhardt et al. 2015; Gebhardt et al., 2018).

At the settlement scale, the challenge is to solve several individual archaeological questions. For example, determining pedo-sedimentary features in order to interpret levels of occupation (Gebhardt, 2005) or our understanding of agricultural structures (Gebhardt, 2008; Georges-Leroy et al., 2009). One interesting challenge was to find micromorphological characteristics differentiating rolling and ploughing traces (Gebhardt and Langohr, 2015; Rentzel et al., 2017). As soil micromorphology is based on specific feature observations, it is necessary to complete the observations with the study of ethnological/reconstructed analogues or to make comparisons with a wider range of similar archaeological situations (Gebhardt, 1999; Gebhardt A., 2007a; Deak et al., 2017; Macphail et al., 2004). As contract archaeology is restricted to investigating threatened sites, there are constraints on soil micromorphological reference material acquisition. This unfortunately negatively impacts on improving our research base.

Nevertheless, because of its extensive field database collection, the French National Institute for Preventive Archaeological Research INRAP should now be able to reach the status of a true research institute. But in order not to remain at a simple 'stamp collections' level, an integrated multidisciplinary approach is required and written resources should be taken into account (Macphail et al., 2016). This aim is more and more difficult to achieve, because attaining substantial interpretations is time consuming as reading, synthesising and publishing takes up a great deal of time. Furthermore, the current necessity of carrying out administrative duties has to be taken into account. In spite of a warmly encouraged collaboration between INRAP agents and University/CNRS research teams, and the integration of a wide range of research themes (for instance human/environment interactions or landscape dynamics) in the huge geoarchaeological database, the internal frugality and pyramidal management of working time strongly complicates and hinders the research part of the job, which currently depends solely on the geoarchaeologist's obstinacy, perseverance and willingness to work more than 'nine to five'.

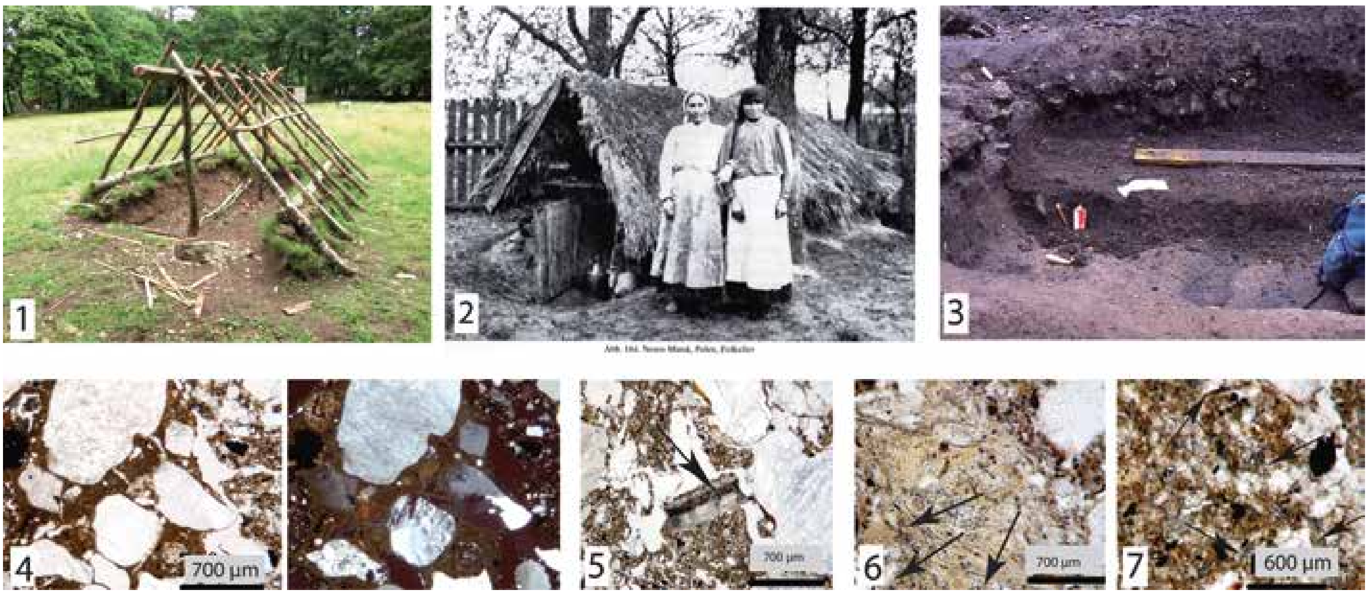


Figure 7. Grubenhaus and thin section studies:

1. partially reconstructed early medieval Grubenhaus (Melrand, Morbihan, France; courtesy: J.-M. Blaising)
2. cool larder (Poland; ancient postcard, courtesy: J.-M. Blaising)
3. archaeological grubenhaus sediment infilling at Montigny-les-Metz (Moselle, France)
4. compacted adobe fragments (a. plainlight, b. crosspolarised light)
5. eggshell
6. dung with abundant phytoliths (arrows)
7. phytoliths (arrows)

Table 5 Field and microscopic description of a grubenhaus infill at Montigny-les-Metz (rue Franiate, Moselle, France)

Field description	Soil micromorphological description	Pedo-sed interpretation
alluvial deposits of the Seille river: sandy-clay infill: 20cm of dark black-brown fine and homogeneous sandy loam, some roots.	Well-developed microstructure; good porosity: well-connected biogalleries, chambers, and fissures, good pedality: several millimetre sized aggregates. Rounded quartz/quartzite sands (250µm to 1mm, 50%), angular fine quartz (25µm to 200µm, 10%), some heterometric calcitic fragments (fossils, calcitic sand, 5%), dusty porphyric speckled groundmass, low birefringence; numerous small fresh organic residues, phosphate nodules, a lot of anthropogenic artefacts: microcharcoals, sandy adobe, herbivore dungs, eggshell, bones, pottery sherds, very numerous phytoliths (5%). No specific pedofeatures.	Infill of a *Grubenhaus* dug in the alluvial deposits of the Seille river

Final note

A career is built on numerous and diverse experiences and human encounters. Some are more powerful than others. In 1993, my time in the *Corridor* as a French 'postdoc', working on the 'Study of active and relict anthroposoils in Belgium, in comparison with other sites in Western Europe' (European Community fund 'Human capital and Mobility'), was of great significance. With my limited soil micromorphology background, experienced mainly on some archaeological sites in Brittany (France), I had the major opportunity to be initiated into *The Book* of archaeopedology. But that is not all... Besides the joy of being a team player and the amazing thrill of being recognized as a research peer, I met colleagues and friends from all over the world and discovered Ghent. Now, the *Ketje*, the *beguinages*, the *frietkots*, the *pralines*, the *moules-frites*, the *spare-ribs*, the *jenever* (sorry, I don't like beer), ... belong to my heritage.
Sincere warm thanks to you, Roger.

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RECONSTRUCTION DES MODES DE VIE AU NÉOLITHIQUE ET AU BRONZE ANCIEN

Synopsis des apports récents des études pédologiques entre Rhin et Seine

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RESUMÉ
La zone entre Rhin et Seine a été étudiée avec l'aide de pédologues depuis les années 50, avec un focus particulier sur les périodes néolithiques et de l'âge du Bronze. Depuis les années 90, les auteurs ont été actifs en continu sur les sites d'archéologie préventive et proposent un état d'avancement sur une série de sujets étudiés depuis sur le terrain et par des analyses de laboratoire et/ou des lames minces. Il s'agit de remplissages de fossés et de palissades, de fosses de différentes tailles y compris les Schlitzgruben, les horizons de surface bien datés hérités et transformés par les humains, comprenant horizons naturels tardiglaciaires et début holocène des milieux bien drainés, surfaces d'activités et de mise en culture, et pour finir les enclos, avec un focus sur les cartographies de phosphate.

MOTS-CLÉS
analyses physico-chimiques, micromorphologie, phosphore, Europe du nord-ouest, Mésolithique, Néolithique, âge du Bronze, fossé, palissade, fosse, Schlitzgruben, four, foyer, pédogenèse tardiglaciaire, horizon de surface, labours, fertilité, «sol» d'occupation, jardin, champs, chasse, rituel

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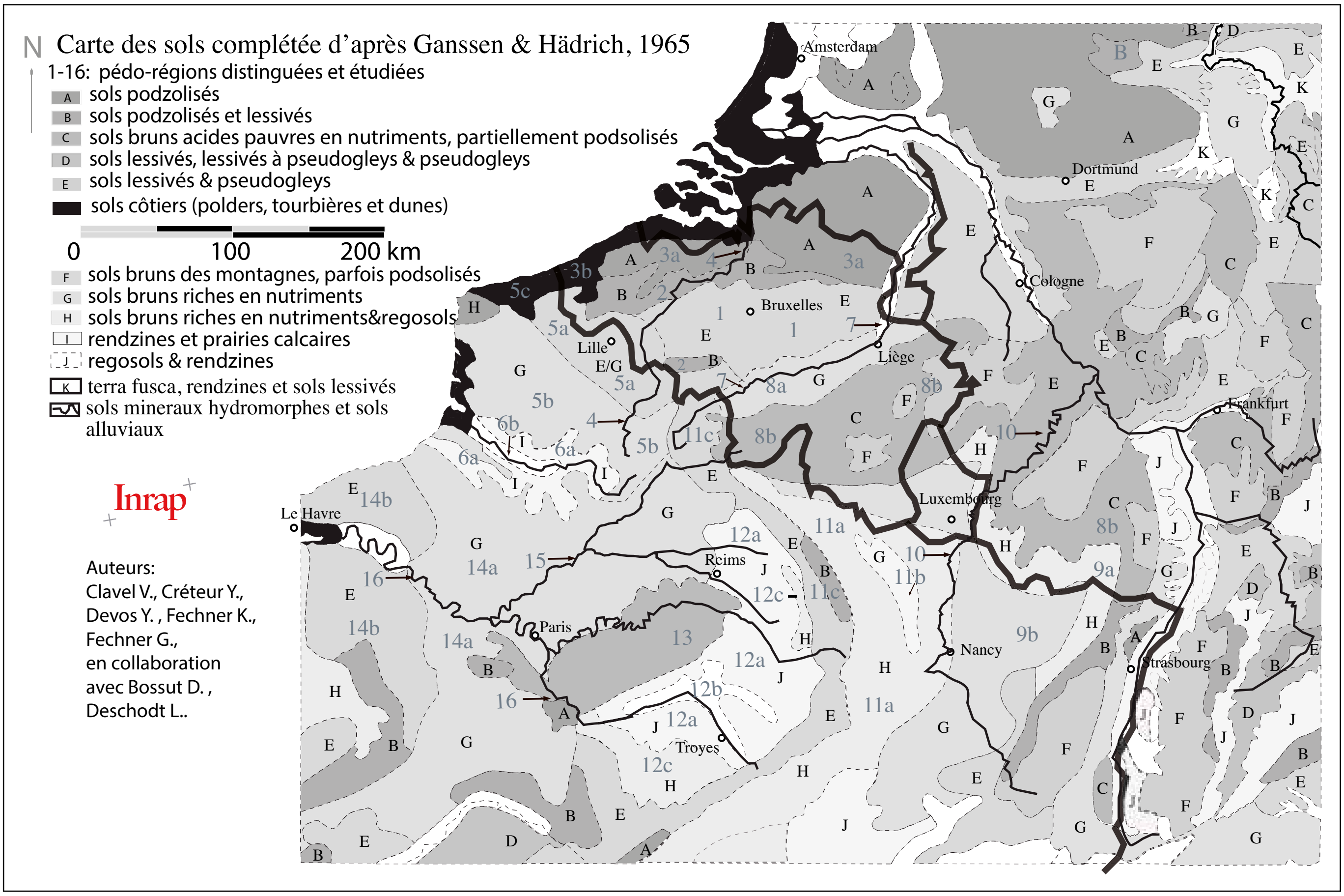

Figure 1. Répartition des 16 pédo-régions concernées par les études (selon Gansen et Hädrich 1965, complété).

1. Introduction et méthodes

Le présent article choisit délibérément de proposer une vue d'ensemble des apports diversifiés de l'archéopédologie à la connaissance archéologique sur une période et un espace géographique délimités, et non une étude de cas ou de thème plus détaillés. L'objectif est d'illustrer le passage des études individuelles à une synthèse plus transversale basée sur cette approche. Nous ne mentionnons que les références des publications, le reste correspondant à des données originales rassemblées dans la thèse du premier auteur (Fechner soumis[1]). Les résultats pour de nombreux sites étant issus de rapports inédits, nous vous redirigeons vers le site internet *Dolia* de l'INRAP (http://dolia.inrap.fr) pour les données plus détaillées et les auteurs de la fouille.

Dès le terrain, l'archéopédologie contribue à préciser la nature des activités de l'homme dans le passé, sa particularité résidant dans le fait d'observer dans le sol les indices *in situ* des activités ou des micro-environnements. Ils sont confrontés et isolés des traits naturels antérieurs ou postérieurs et des explications causales peuvent ensuite être émises (méthodes e. a. selon Devos et al., 2011; Fechner et al., 2004; Langohr, 1994; Baize, 1988; Bullock et al., 1985[2]).

Nous prenons comme champs de recherche le Néolithique et le Bronze ancien et l'espace entre le Rhin et la Seine, comparé aux régions adjacentes. Pour commencer, ce propos est illustré par des collaborations multiples sur le fonctionnement de divers types de structures : les fossés, enclos et enceintes, les habitats et unités architecturales, les fosses. Ces thématiques sont similaires à celles de synthèses archéologiques comme celles de Julian

1 Ensemble des études, résultats, références aux rapports, figures, données de terrain, lames minces et analyses.

2 Les observations et analyses doivent pour cela être bien encadrés par la collaboration avec les autres acteurs et avoir, en particulier sur le terrain, tenus compte des variations observées dans le site, les coupes, les décapages. C'est en effet la meilleure façon de sélectionner les endroits les plus représentatifs pour effectuer les analyses de laboratoire et en lames minces qui viendront confirmer ou préciser la corrélation entre ces indices et les activités sensées être à l'origine de leur formation.

Tableau 1 Description simplifiée des 16 pédo-régions de figure 1

Numéro et nom de pédo-région	*Substrat dominant*	*Matériaux parentaux/ particularités sur les sites traités*
1. Moyenne Belgique lœssique:	Tertiaire ancien et couverture de lœss	Une certaine homogénéité en matière de matériaux parentaux et de sols.
2. Moyenne Belgique limono-sableuse (Brabant et Hainaut):	Tertiaire ancien et couverture de sable et limon	D'espaces compris au sein de la région 1, mais aux sols parfois légèrement différents, car développés sur sable limoneux ou limons riches en sable
3. Basse Belgique :	Tertiaire ancien et couverture de sable	S'il s'agit très largement de sables, on note des différences dans leur finesse qui déterminent différents types de sols.
4. Fond de vallée de l'Escaut :	Surtout alluvions	Cette vallée importante est caractérisée par des sols liés aux alluvions, mais aussi à des contextes très spécifiques, telles que p. ex. d'anciennes dunes de sable.
5. Nord-Pas de Calais (France) :	Alluvions, Crétacé supérieur, Tertiaire ancien	Mélange des caractéristiques géologiques et pédologiques des régions 1 et 6, de part et d'autre de celle-ci. De plus, on y trouve de nombreuses zones d'alluvions et des dépôts caractéristiques des littoraux.
6. Somme (France) :	Crétacé supérieur et couverture de lœss	Fait partie intégrante du Bassin parisien, mais comprend aussi une zone littorale et toute la vallée alluviale de la Somme.
7. Fond de vallée de la Meuse (Belgique) :	Surtout alluvions	Les versants importants de certains secteurs de cette vallée expliquent l'interprétation des dépôts de versants avec les alluvions. Ces alluvions peuvent parfois être pré-holocènes. Sur la bordure nord-occidentale, une alternance de différents dépôts du Primaire, dont certains sont calcaires, explique la plus grande fertilité des sols de par rapport aux régions de part et d'autre.
8. Haute Belgique:	Primaire et couverture de lœss	Forte variabilité spatiale des sols et des substrats, étroitement associée aux variations de relief.
9. Lorraine orientale (France et Luxembourg) :	Secondaire (Trias, souvent du grès)	S'étend jusque dans le nord du Grand-duché de Luxembourg, avec une domination des grès et des sables.
10. Fond de vallée de la Moselle (France, Luxembourg) :	Surtout alluvions	Dans les sites étudiés, on observe notamment des alluvions pré-holocènes, couvertes parfois de lœss.
11. Lorraine occidentale (France et Luxembourg, partie orientale: bassin du Rhin; p. occidentale: bassin de la Seine) :	Surtout Secondaire (Jurassique, souvent marne et calcaire)	Marne, craie, grès; rares couvertures de lœss de la fin du Quaternaire.
12. Champagne (France, bassin de la Seine) :	Surtout Secondaire (Crétacé, surtout calcaire et craie)	Substrat surtout calcaire, localement légèrement décalcifié, rares phénomènes de dissolution. Couvertures très locales de lœss de la fin du Quaternaire surtout le long de grandes vallées (Seine and Marne).
13. Tardenois (France, bassin de la Seine) :	Tertiaire (sables set argiles Eocène et Oligocène)	Couvertures de lœss locales de la fin du Quaternaire, sinon substrat surtout calcaire avec phénomènes de dissolution.
14. Région de Paris et Haute Normandie (France, bassin de la Seine) :	Surtout Tertiaire ancien et Crétacé supérieur, souvent crayeux	Surtout couvertures de lœss de la fin du Quaternaire, affleurement local de substrat surtout calcaire avec phénomènes de dissolution.
15. Fonds de vallée de l'Oise, la Vesle et l'Aisne (France, bassin de la Seine) :	Surtout alluvions	Alluvions du Quaternaire (surtout Holocène).
16. Fonds de vallée de la Seine et de la Marne (France, bassin de la Seine) :	Surtout alluvions	Alluvions du Quaternaire (surtout Holocène).

Thomas (1999) pour la Grande Bretagne, de Peter Bogucki (2000) pour le centre-nord de l'Europe, de Heike Fock (et al., dir., 2008) pour la Wallonie, de Corrie Bakels (2009) pour la région lœssique d'Europe du nord-ouest, d'Emmanuelle Martial et d'Alain Henton (2015) pour le Nord-Pas de Calais, de Thomas Otten (et al., dir. 2015) pour la Rhénanie-Westphalie, pour n'en citer que quelques-unes, exemplaires en la matière. À ces sujets, nous ajoutons des études plus spécifiques sur les sols naturels rencontrés par ces premiers agriculteurs, sur leur transformation graduelle, leur mise en culture, leur fertilité physique et chimique initiale et leur fertilisation et enfin sur divers types de « sols » d'occupation. Sur tous ces sujets, le prisme particulier est celui des études pédologiques de terrain, pédo-analytiques et micromorphologiques, ainsi que celui de la prise en compte des contextes pédologiques initiaux propres à chaque site. Pour ces contextes, il a été proposé de mettre en place un cadre de 16 pédo-régions qui correspondent à autant d'aires géographiques aux potentiels d'utilisation et aux assemblages pédologiques différents (Tableau 1, Figure 1, selon Fechner et al. 2014; basé sur Gansen et Hädrich, 1965). Cela n'empêche pas qu'au sein de celles-ci, des plus ou moins grandes variations puissent parfois être constatées d'un site à l'autre. Dans ce qui suit, nous ne précisons la pédo-région que quand elle est jugée indispensable, notamment pour les différences en matière de nature originelle (§3.1), fertilité et affectations humaines des anciens horizons de surface (§3.2-3.4). Les résultats obtenus sont présentés pour chacun des types de structures analysés séparemment avant de proposer, en fin d'article, les amorces d'une contribution à une synthèse sur le mode de vie des sociétés du Néolithique et de l'âge du Bronze ancien.

2. Structures en creux: morphologies, distribution et données archéopédologiques

2.1. FOSSÉS AUX HISTOIRES COMPLEXES

L'analyse fine des traits pédologiques et micromorphologiques des fossés montre qu'ils présentent des histoires du comblement plus ou moins longues et complexes (Figure 2, Fechner, 1998 ; Broes et Bosquet, 2007 ; Monchablon, 2014 ; Fechner soumis[3]). On distingue d'une part, des histoires longues avec aménagement en bois, comme à Carvin (F.) au Néolithique moyen et à Ath (B.), sans doute aussi au Néolithique moyen, ou avec entretien répété, comme à Voroux-Goreux et Remicourt « En Bia Flo » II (B.), au Néolithique ancien. Les traits pédologiques contribuent ainsi significativement à la prise en compte *d'hiatus*, de périodes de stabilisation qui reflètent une utilisation ou un aménagement prolongés à la base ou au sein des comblements.

D'autre part, on identifie plus rarement un rebouchage plus ou moins immédiat après le creusement, fait en une traite, dans le fond du fossé du Bronze ancien de Louvencourt (Figure 2b : séquence I) et probable dans le

3 Indices de stabilisations de surfaces, de curage, de stagnation d'eau, laminations noires ou remplacement par des carbonates secondaires: Monchablon dir. 2014; Fechner et al. 2015a.

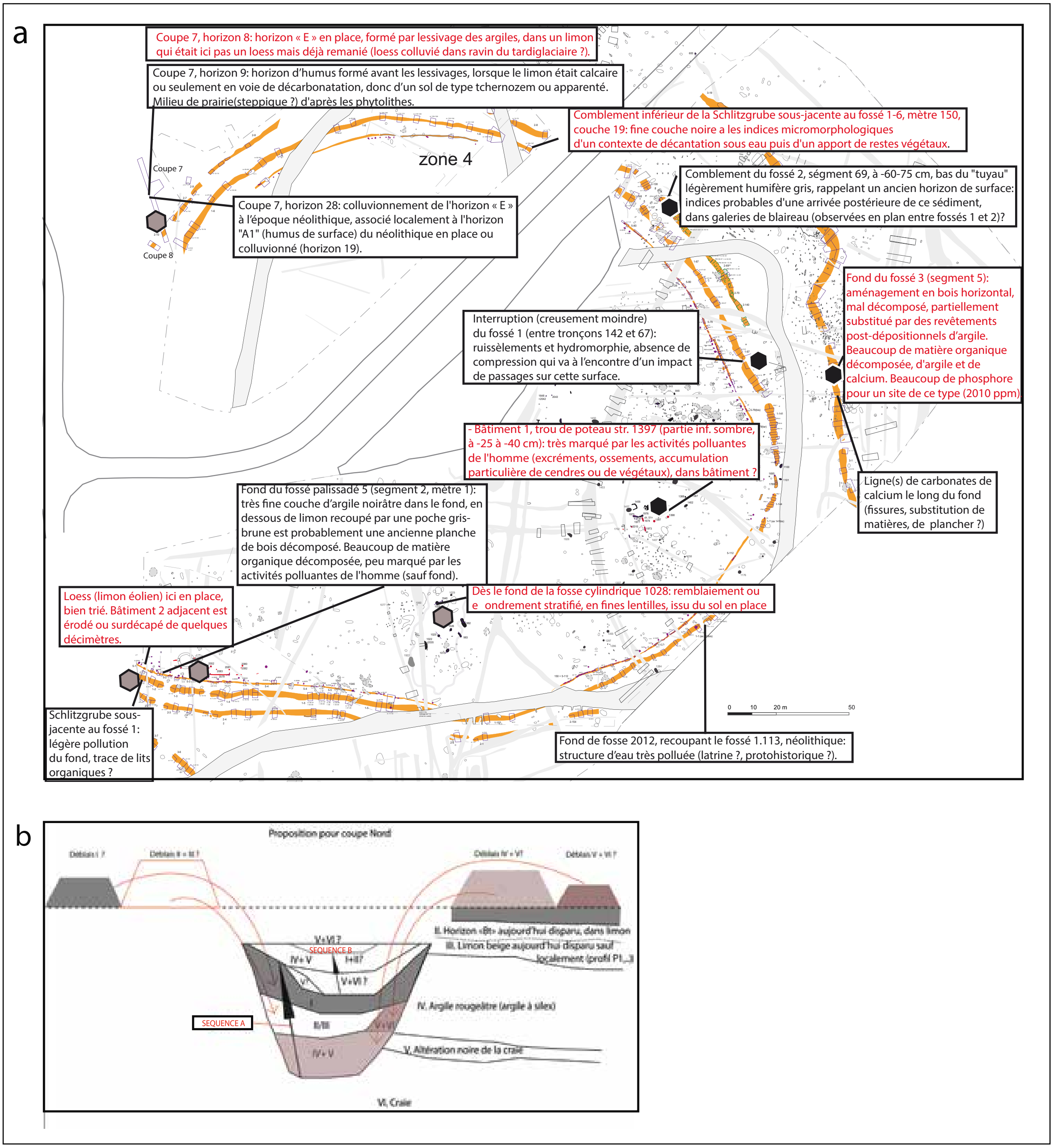

Figure 2. Exemples d'études pédologiques de fossés (coupes transversales) et de tranchées palissadées (coupes longitudinales) : a) plan du site de Carvin « Gare d'Eau » avec commentaires issus des études pédologiques et répartition des zones plus affectées par le phosphore (point noir : très pollué; point gris : légèrement pollué ; C. Monchablon, INRAP © K. Fechner) ; b) Reconstitution schématique de la séquence initiale (A) des évènements dans le fossé de Louvencourt : creusement, séparation des déblais, rebouchage rapide. La séquence B semble correspondre à une répétition des mêmes procédés (N. Buchez, INRAP © K. Fechner).

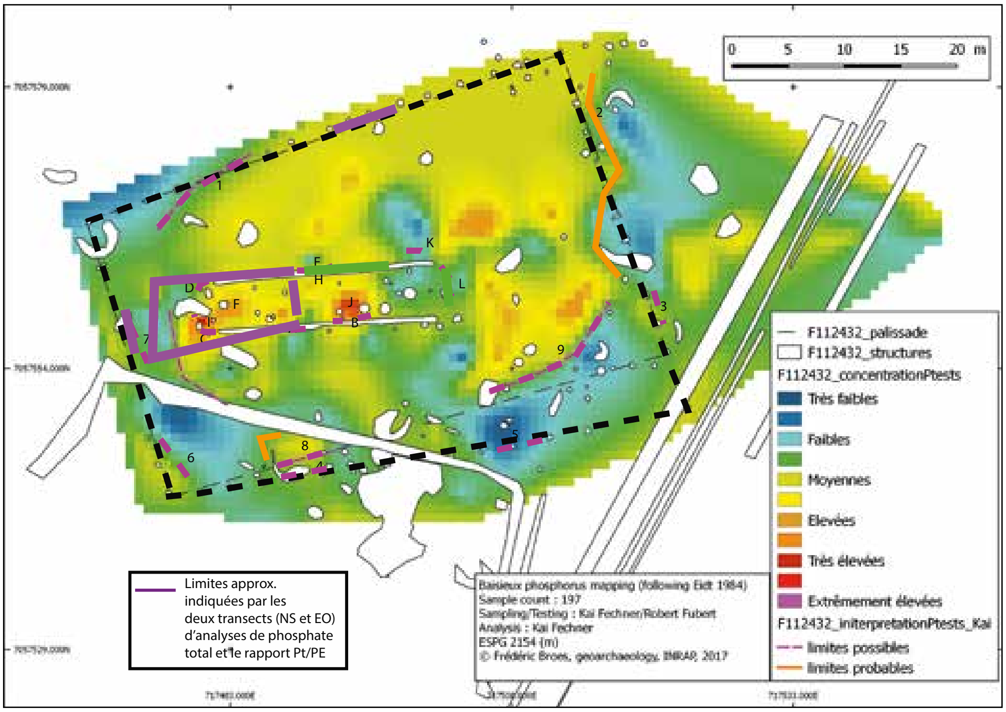

Figure 3. Exemples d'études pédologiques d'espaces palissadés : plan avec cartographies du phosphore et transects d'analyses de Baisieux, confirmant le lien entre l'enrichissement léger et l'enclos, et entre l'enrichissement plus marqué (plus de 1600 ppm de P total) et la partie occidentale du bâtiment 1 (E. Martial / I. Praud, INRAP © F. Broes, K. Fechner).

fossé du Néolithique moyen de type *causewayed camp* de Chaussée-Tirancourt (F.). Enfin, si la plupart des fossés sont multi-phasés avec une histoire de comblement relativement longue, cela n'empêche pas les deux cas du Néolithique ancien étudiés par la pédologie de présenter un comblement final massif et rapide, qui est le reflet d'un abandon délibéré (Voroux-Goreux et Remicourt « En Bia Flo », B.). On y observe aussi des particularités locales, différentes selon les tronçons : dans les deux sites, une de ces particularités est propre aux extrémités de fossé, de part et d'autre d'un dispositif d'entrée, dont il est question plus loin (cf. § 2.5). L'autre particularité est la présence de couches de comblement particulièrement homogènes et sombres, d'origine agricole, dans le tronçon aval du fossé de Remicourt « En Bia Flo » II (cf. 3.3). Les fossés conservent ainsi des traces différentiées de l'activité aux alentours immédiats (p. ex. Enines, B., au Néolithique moyen : *cf. infra* ; Burnez-Lanotte et al., 1994 ; Fechner soumis). Certains sites ont conservé des traces aux sols qui permettent, elles, de parler des activités de l'entièreté ou de larges parties du site. On a ici, pour le Néolithique moyen, des cas de pollutions importantes par les activités qui produisent beaucoup de phosphore (Carvin, F., Figure 2a, Monchablon, 2014 ; Monchablon et al., 2015) et d'autres qui en sont largement dénués (Boitsfort, B.[4]).

2.2. PALISSADES AU FONCTIONNEMENT MIEUX DÉFINI

Pour les enclos palissadés (Figure 3), on distingue les alignements de poteaux implantés sans fossés et les fossés palissadés, servant de calage aux poteaux (Bausier et al., 2018 ; Burnez-Lanotte et al. 1994 ; Fechner 1998 ; soumis). Les résultats pédologiques portent, successivement, sur la mode de construction et sur le mode et la durée d'utilisation. En étudiant en détail les semelles de compression autant que les traces effectives de poteaux dans les fossés palissadés, on est frappé par les distances parfois importantes entre les poteaux qui posent question en matière de mode de construction et de fortification (Enines au Néolithique moyen : Burnez-Lanotte et al., 1994, Bruyelle au Néolithique final, B. : Bausier et al., 2018). Qu'ils soient le reflet de courtes ou de longues utilisations, les interfaces comme la couche de fond peuvent conserver des indices chimiques d'une activité ou d'un rejet/ dépôt particuliers qui précède le comblement partiel ou complet. Ainsi le fond du fossé palissadé du Néolithique final de Bruyelle est marqué chimiquement par la présence probable d'ossements dans le calage[5].

Le taux de phosphore est également particulièrement élevé dans le fond de la tranchée palissadé d'Enines (Néolithique moyen), contrastant avec celui du fossé interne de ce site fortifié. Enfin un enclos palissadé du

4 Par opposition à la richesse nette en phosphore des comblements de fossés de ce site, liée à des dépôts ou remblais qui doivent être de nature très différente, mais restent à déterminer.

5 Les analyses au microscope à balayage et par microsonde chimique pourraient y indiquer la présence passée d'ossements.

Figure 4. Exemples d'études pédologiques de fosses de petite taille :

a. Fosse 134 au profil évasé, avec recreusement (récupération des matériaux) et fine lamination de fond (flèches) à Alleur « Domaine militaire » (J.-Ph. Marchal, SPWallonie © K. Fechner).

b. Fosse 115 à parois verticale, avec fin lit organique et oxydoréduction dans le fond (flèche) à Remicourt « En Bia Flo » II (D. Bosquet, SPWallonie © D. Bosquet).

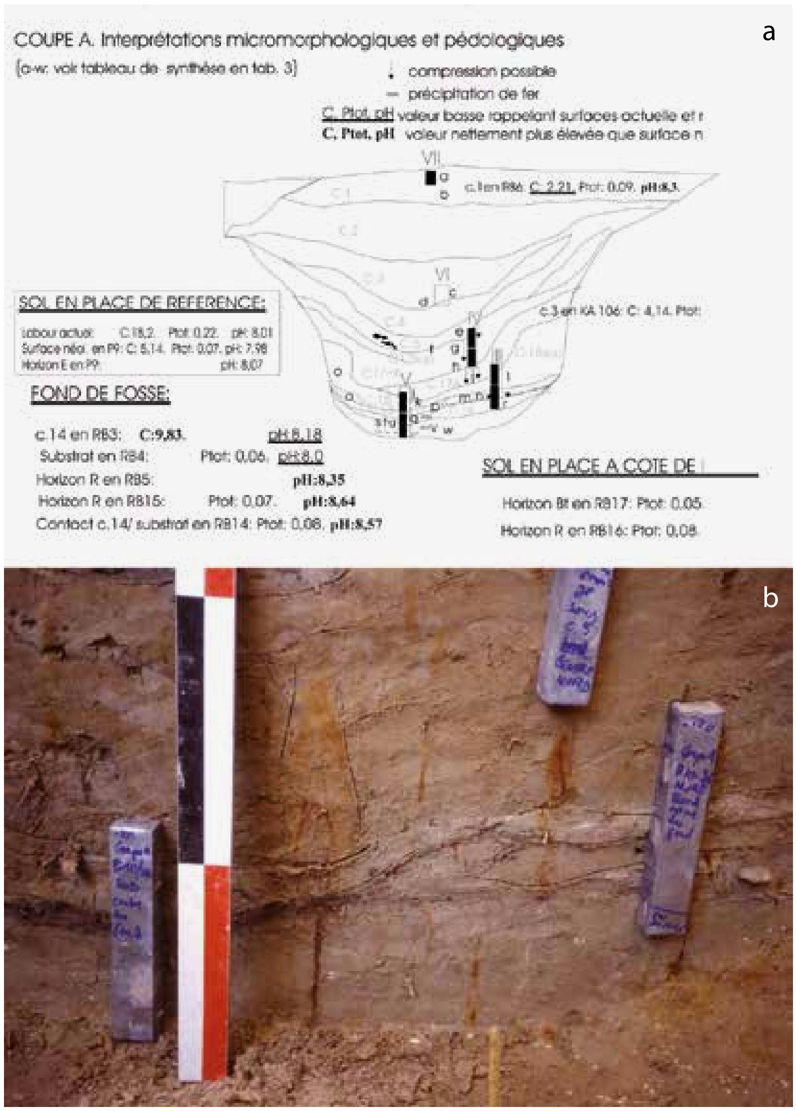

Figure 5. Exemples d'études pédologiques de fosses de taille nettement plus importante :

a. Indications pédologiques sur une des coupes dans la fosse allongée n°300 d'Houplin-Ancoisne « Rue Marx-Dormoy » (E. Martial/ I. Praud, INRAP © K. Fechner).

b. Vue du fond de cette coupe avec fine couche organique initiale et prélèvements (© K. Fechner).

Néolithique final montre une affectation au taux de pollution intermédiaire (Baisieux, F.), avec une présence de phosphore qui est juste un peu plus importante que le signal du sol naturel des alentours de l'enclos (Figure 3). Cela va dans le sens des hypothèses d'activités agricoles (cultures ?), comme dans des enclos antérieurs du Néolithique ancien et moyen en Allemagne (Baales et al. 2015), et à l'encontre de celles parlant d'enclos à bétail (*ibid*., pour un autre site allemand du Néolithique ancien).

2.3. FOSSES DE PETITE TAILLE AUX FORMES ET INDICES RÉCURRENTS

Dans l'étude des fosses (Fechner et Langohr, 1993 ; 1998 ; Fechner et al., 2003 ; 2006 ; Laurent et al., 2012 ; Fechner soumis), l'étude des traits pédologiques, rapidement évoqués ci-dessous, montre des types et fonctionnements de fosses communs à plusieurs sites.

De plus, une fois reconnues, ces fosses présentent des positions apparentées dans le plan archéologique. Les résultats présentés ci-dessous portent, successivement, sur le fonctionnement de fosses en forme de bouteille, de fosses à parois proches de la verticale (« cylindriques »), de fosses à parois verticale mais plus allongées et de fosses aux parois obliques, plus évasées, enfin sur la question des fosses à couches de fond laminées noirâtres et argileuses. Pour le Néolithique ancien, surtout en Moyenne Belgique, on peut bien caractériser en tant que silos à grain les fosses en forme de bouteille (Alleur, Remicourt « Fond de Momalle » et « En Bia Flo » II, tous en B.[6]).

Les fosses cylindriques, à parois verticales et fond plat, sont interprétées comme caves ou cellier, avec un fond qui montre les indices répétés d'un plancher (Fechner et al., 2006 ; Remicourt « En Bia Flo » II ; Figure 4b). Elles sont plus rarement liées à la récolte d'eau (Alleur), y compris peut-être depuis les toitures de bâtiments[7] (Remicourt « En Bia Flo » II, B., Fock et al. 2008 : 89)

Certains cas du Néolithique moyen pourraient également rappeler ces « caves » (Enines, B.). On trouve aussi pour le Néolithique ancien des fosses à fond plat plus évasées, à interpréter en fonction des indices : soit comme des caves ou celliers plus larges soit pour préparer du sédiment ensuite recoupé, récupéré (Figure 4a, Fechner et Langohr, 1998; cf. aussi Heim & Jadin, 1992: étude palynologique d'une fosse à Alzingen, L.). Certaines de ces fosses contiennent ainsi un sédiment qui est moins argileux et moins riche en phosphore que les torchis analysés en comparaisons sur les mêmes sites (Alleur et Ormeignies, B.). Ici, plutôt que de préparation de torchis, il s'agirait peut-être de celle d'autres matériaux de construction ou de pourrissage d'argile pour la céramique (Figure 4a, Ormeignies, Alleur, B. ; Gavisse, F.). Enfin, des petites fosses au comblement initial constitué de laminations argileuses noirâtres ont les stigmates microscopiques du bois et présentent parfois un pH très bas. On a affaire soit à un plancher soit à des restes liées à une activité de tannage, expliquant l'acidité et la préservation (Fechner et al., 2015a; Doutrelepont et al., 2012, Doutrelepont, comm. pers.; Fechner soumis).

2.4. FOSSES DE GRANDE TAILLE AUX FONCTIONNEMENTS VARIÉS

Les fosses du Néolithique ancien de taille nettement plus grande (Figure 5**,** Martial et Praud, 2007 ; Fechner et Langohr, 1998 ; Fechner et al., 2006 ; Fechner soumis) correspondent dans le cas de Verlaine (B.) à une mare à faible pollution par le phosphore qui a sans doute servi dans un second temps à la décantation délibérée d'argile et à sa récupération. Un second cas de décantation d'argile est suspecté à Remicourt « Fond de Momalle ». Les fosses ayant servi avant tout de fosse d'extraction du limon argileux apparaissent sur plusieurs sites (Ay-sur-Moselle, F., Remicourt « En Bia Flo » II, Alleur, Waremme « Vinâve », B.). Dans ce dernier site, la fosse a dans un second temps été recreusée (peut-être en relation avec des activités liées au feu) avant de servir finalement de poubelle. Au Néolithique moyen, on trouve également des fosses qui ont les traits pédologiques et la forme qui indiquent des fosses d'extraction du limon argileux (Enines, B.). Au Néolithique final, un cas de fosse très allongée montre des indices pédologiques (altération acide du sol sous-jacents, mise en eaux et assèchements successifs, ...) qui rappellent ceux d'une fosse de rouissage (Houplin-Ancoisne, F., Figure 5). Les indices paléobotaniques pourraient confirmer cette interprétation (Martial et Praud, 2007 ; Martial, 2008). Au moins un des cas particulièrement profonds de *Schlitzgrube* (cf. ci-dessous) présente des indices pédologiques compatibles avec la fonction de rouissage proposée par les études de botanistes et des micro-morphologues, peut-être en réutilisation (Maurecourt, F.; résumé dans Fechner et al., 2011).

2.5. FOSSES DE TYPE *SCHLITZGRUBE*, CARACTÉRISTIQUES PÉDOLOGIQUES ET CONFIGURATIONS

Au sein des fosses, le cas particulier des *Schlitzgruben* (dites en fente ou au profil en 'Y') est caractérisé par des parois sub-verticales, une forme allongée et une étroitesse marquée (moins de 50 cm, voir le plus souvent moins que 30 cm) sur toute ou une partie inférieure plus ou moins importante de la profondeur (Figure 6-7**,** Fechner et al., 2011; 2015a ; Lemaire et al., 2015 ; Achard-Corompt et Riquier, 2013 ; Achard-Corompt et al., 2013 ; Achard-Corompt, 2017 ;

6 Entre autre par un taux de phosphore d'env. 1000-1500 ppm, présence d'un fond de phytolithes en lame mince.

7 Ici, dans un second temps d'utilisation d'après l'étude des lames minces.

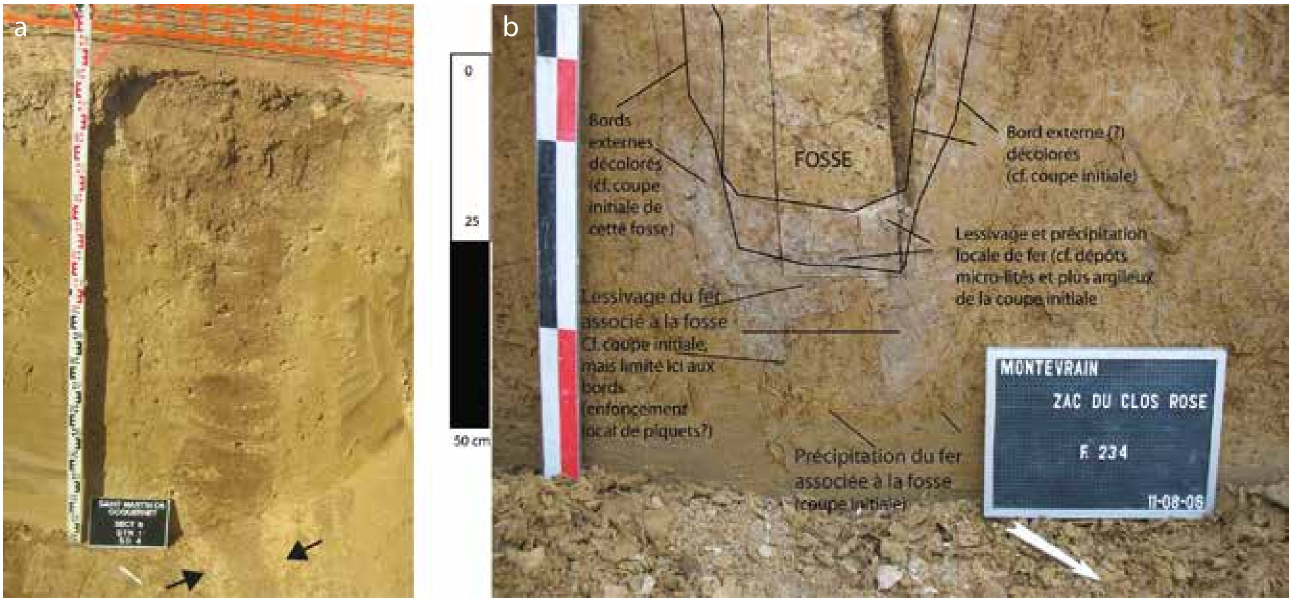

Figure 6. Exemples d'études pédologiques de *Schlitzgruben* :

a. Coupe transversale de la fosse 62 de Saint-Martin-sur-le-Pré « Goguernet » (flèches : oxydoréduction avec déplacement du fer depuis les bords longitudinaux vers l'extérieur (paroi de matière organique ?); M. Kasprzyk, INRAP © K. Fechner).

b. Détail du fond de la coupe transversale de la fosse 234 de Montevrain « Clos Rose » (A. Berga, INRAP © K. Fechner).

Achard-Corompt et al. 2017 ; Fechner soumis). Dans ce qui suit, on décrit certains des indices pédologiques qui permettent de préciser l'interprétation des *Schlitzgruben*, mais avant cela nous proposons de distinguer les trois configurations spatiales rencontrées au sein des nombreux cas étudiés par la pédologie: alignées, disposées en cercle ou isolées. Pour commencer, les cas de *Schlitzgruben* alignés se retrouvent à toutes les périodes du Néolithique et de l'âge du Bronze. On peut notamment citer nos caractérisations pédologiques à Nogent, Buchères et Maroeuil (F., cf. aussi le cas de Sélestat, Alsace, fouillé par Yohann Thomas, comm pers.). D'autres cas étudiés sont suspectés être de tels alignements, comme à Pont-sur-Seine/ Marnay-sur-Seine, Oiry, Saint-Martin-sur-le-Pré, Romilly-sur-Seine, Montevrain, Villenoy-Chauconin (F.) ou à Hannut et Remicourt « Fond de Momalle » (B.). Ces fosses succèdent parfois à des alignements de fosses mésolithiques dites "à tétons", également marquées par une pointe centrale ou un trait pédologique central sous le fond, caractéristiques d'un poteau (Pont-sur-Seine/ Marnay-sur-Seine ; Languevoisin, F.), renvoyant sans doute au cas remarquable de Récy (F., Achard-Corompt 2017) qui montre une juxtaposition et une orientation identique des alignements des fosses mésolithiques et néolithiques. Pour les fosses alignées, largement majoritaires, un nombre conséquent de cas a été traité selon différentes approches (phosphore, phytolithes, malacologie : Fechner et al., 2011; Lorin et al., 2013 ; Bontrond et al., 2013 ; Eckmeier et al., 2017) pour arriver à des conclusions parfois contradictoires en matière d'environnement. Le comblement inférieur étant souvent fait d'un remblai anthropique, plus ou moins épais, ce dernier peut en effet refléter des environnements antérieurs ou mélangés. Quelques cas ont révélé le calage, par ce remblai, de grands poteaux au cœur ou aux extrémités de la fosse (Remicourt 'Fond de Momalle', B., au Néolithique ancien; fosses « au profil longitudinal en W » de Buchères, au Néolithique final, de Pont-sur-Seine/ Marnay-sur-Seine, aussi entre autres au Néolithique final, cf. aussi Garmond et al., 2014, tous en F.) ou de piquets le long des parois (Montevrain non-datée, Figure 6b ; sans doute Romilly-sur-Seine au Néolithique final/ Bronze ancien; F.; Fechner et al., 2011; Achard-Corompt et al., 2013, tous en F.). La présence occasionnelle de fantômes de bois humifères (à Romilly-sur-Seine, à Bourguignons, F., cf. aussi Sélestat, *op. cit.*) et d'effet de compression ou de décomposition de matières organiques le long des parois (Saint-Martin-sur-le-Pré, F., Néolithique final, Figure 6a) vont aussi dans le sens d'une utilisation de la partie étroite des *Schlitzgruben* pour le calage de superstructures boisées, comme tentent de le confirmer nos premières expérimentations (Fechner et al., 2015a). Les espaces alignées entre chaque structure pourraient présenter d'autres éléments (haies, terrées ou structures superficielles, éléments naturels tels que berges, pentes, …), dont certains peuvent être comparés à des exemples ethnographiques (Olsen, 2013 ; Friederich, 2013 ;

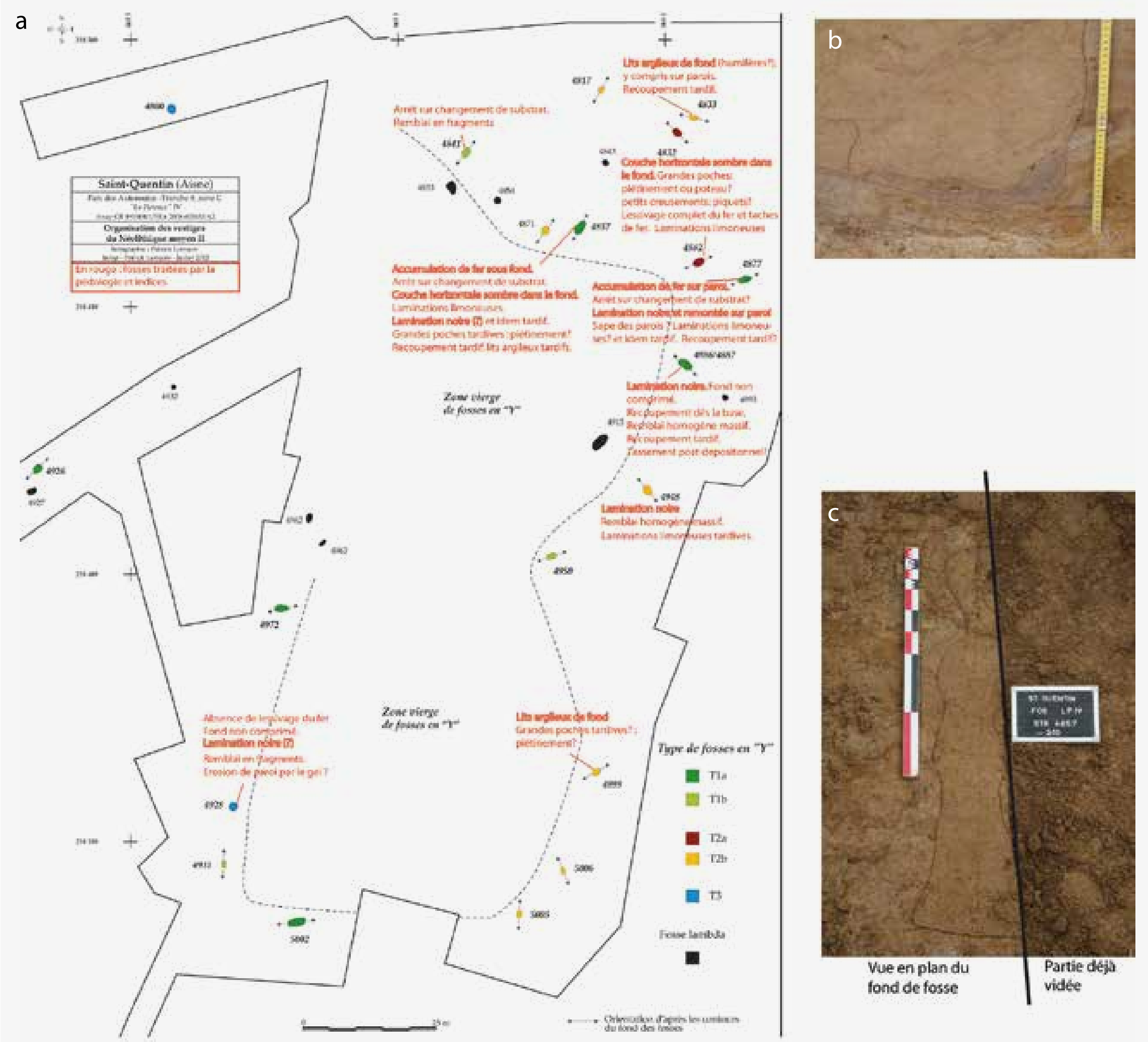

Figure 7. Exemples d'études pédologiques de *Schlitzgruben* formant un plan d'ensemble ovalaire à Saint-Quentin « Parc des Autoroutes » (P. Lemaire/ F. Bostyn, INRAP) :

a. Plan avec commentaires pédologiques © P. Lemaire, K. Fechner.

b. Coupe du fond de la fosse 4857, avec de haut en bas, lamination sombre argileuse, compression et oxydo-réduction (cette dernière déjà visible le long de deux ou trois poches traversant le comblement moyen de la fosse) © K. Fechner.

c. Vue du fond de cette fosse en plan (présence au minimum de deux poteaux ?) © P. Lemaire.

Brochier, 2014 et comm. pers.), les animaux ayant naturellement tendance à rester d'un côté de cet alignement. Au moins un des cas étudiés pourrait évoquer des éléments de superstructure sous la forme de traces de terre crue (étude de lame mince de J. Wattez à Oiry, Néolithique final, F.). À Buchères (F.), toujours au Néolithique final, des spherulites dans la couche de fond pourraient indiquer la présence d'excréments de grands mammifères (piégeage?). En Région Champagne-Ardenne, les datations systématiques et le traitement par la méthode bayésienne permettent de proposer une certaine périodisation et d'envisager des espaces du paysage bien définis (Achard-Corompt et al., 2013). D'autres régions n'ont pas encore fait l'objet d'une étude aussi systématique.

Une seconde configuration est celle où l'ensemble de ces *Schlitzgruben* forme un plan grossièrement ovalaire. Si divers cas sont connus, notamment en Allemagne (Achard-Corompt et al., 2013: fig. 55 ; Friederich, 2013: fig. 4 et 6) et peut-être ailleurs en France (Achard-Corompt et al., 2013: fig. 42 ; Lorin et al., 2013: fig. 7), leur étude pédologique est limitée à un seul cas, celui de Saint-Quentin (F., Lemaire et al., 2015; Figure 7). Ses fosses sont en position radiale, c'est-à-dire orientées vers l'intérieur du cercle, comme dans les sites de comparaison de Bad Friedrichshall-Kochendorf et Freiburg-Hochdorf (Bade-Wurtemberg, D., Friederich, 2013) et dans la fouille ancienne de l'habitat fortifié du Néolithique ancien de Köln « Lindenthal » (Achard-Corompt et al., 2013). Dans les fosses de Saint-Quentin, on note la présence répétée de laminations argileuses noirâtres, vraisemblablement à nouveau dues à un plancher ayant couvert le fond, et le comblement final qui, chose rare, est régulièrement riche en artefacts, permettant de dater ce dernier apport du Néolithique moyen. Ce cas rappelle ce que la littérature ethnologique et archéologique présente comme un lieu de rassemblement d'animaux, situé au bout du couloir qui est matérialisé par les autres fosses (et obstacles), les y amenant. Un plan similaire est reconnaissable sur des sites ethnographiques pour lesquels cette fonction est identifiée (Olsen, 2013; Friederich, 2013).

Enfin, certaines *Schlitzgruben* sont isolées dans l'interruption de fossés entourant des habitats du Néolithique ancien et moyen et correspondent à une troisième configuration spatiale (Fechner et al., 2006; Bosquet et al., 2013; Monchablon, 2014). Il s'agit de deux cas de fosse dans l'interruption des fossés d'enceinte (Remicourt « En Bia Flo » II et Voroux-Goreux, B., cf. aussi Bosquet et al., 2013: entrée du site fortifié de Darion). Les deux cas liés aux interruptions d'enceinte étudiés sont, eux, dénués du moindre indice pédologique lié à la présence de poteaux ou de piquets. Il s'agit d'une mise en place initiale d'un dépôt pauvre en phosphore et de nature organique peu homogène, rappelant un remblai, sans indices de stabilisation ni d'aménagement de surface. On retrouve un dépôt apparenté dans les amorces de fossé de part et d'autre, ayant livré des meules dans un cas (Remicourt « En Bia Flo » II), une très grande céramique complète dans l'autre cas (Voroux-Goreux). Ce type de comblement en lentilles et fragments humifères marque aussi la *Schlitzgrube* située à une des extrémités de segment d'un fossé d'enceinte du Néolithique moyen (Carvin « Gare d'Eau », F.: remblai organique sur et sous céramique[8]). La *Schlitzgrube* rencontrée à une autre extrémité de segment présente également une couche sombre dans le fond, toujours sans indices de poteau ou de piquet. Dans tous ces cas, on retient à la fois une configuration spatiale et un fonctionnement fort différents de ceux des fosses alignées ou disposées en cercle mentionnées plus haut, malgré une similitude morphologique évidente.

8 En lame mince, un ensemble de très fins dépôts de matière organique (feuilles ?) ne correspond que, très ponctuellement, à un dépôt sous eau. Le tout recouvre un tesson posé à plat.

3. Des modifications naturelles puis anthropiques des horizons de surface

3.1. IMPACT DES SOLS NATURELS ANTÉRIEURS SUR LE NÉOLITHIQUE

Les sols sur lesquels se sont implantés les sites des agriculteurs du Néolithique et du Bronze ancien étaient peu ou pas modifiés par des activités humaines depuis le Tardiglaciaire (Figure 8). Ce sujet a été très largement abordé par Dr. Roger Langohr et son équipe (p. ex. Langohr et Sanders, 1985; Langohr et Pajares, 1983; Van Vliet et al., 1992; Van Vliet-Lanoë, 1990) et nous n'en abordons ici que des exemples nouvellement traités et en relation directe avec notre sujet. Les résultats présentés portent successivement sur les sols en milieu profondément décarbonaté et en milieu plus calcaire (Fechner, 1996; soumis; Louwagie et Langohr, 2000 ; Fechner et al., 2010 ; 2015b ; Durand et al., 2014). On bénéficie pour ce faire de plusieurs horizons-repères (Figure 8-9) qui permettent de différencier également les contextes pédologiques: pour commencer, nous avons surtout étudié de nombreux cas sur limon décarbonaté qui présentent les reliquats d'un ancien horizon « IIB21 t da" épais, hérité du début du Tardiglaciaire (Figure 9a). Ici nous poursuivons et systématisons les travaux pionniers de Louwagie et Langohr (2000) sur le site d'Annoeullin (Nord). Cet horizon appelé B sombre se développe après la fin de la mise en place des dépôts de lœss (vers 19.000 BP selon Haesaerts et al., 2016), alors toujours calcaires, sans doute au plus tard au Bølling (Fechner et al., 2015b ; L. Deschodt, comm. pers.). Il se forme par intégration de matière organique dans la pédoséquence, sans doute par la faune du sol des milieux steppiques (voir aussi biochimie sur le site d'Erre, analyses de phytolithes à Carvin, F.). Son antériorité au Néolithique est notamment confirmée par les recoupements et horizons de surfaces mésolithiques (Fechner, soumis; L. Deschodt, comm. pers.) et néolithiques, notamment à Carvin « Gare d'Eau » et à Annoeullin (F., pédo-région 5 du Tableau 1, Monchablon, 2014 ; Louwagie et Langohr, 2000). L'horizon reste aujourd'hui préservé localement, surtout dans des bas de versants et des fonds de vallée plus ou moins bien drainés[9], mais aussi des chablis et des comblements de structures archéologiques des positions plus hautes dans le paysage. Etant donné cette répartition des restes, cet « horizon IIB sombre » était présent plus largement dans ce type de milieu non gorgé d'eau à l'origine.

Par la suite, à l'Allerød et au tout début de l'Holocène, l'horizon est affecté par la pédogenèse postérieure d'un

9 Sa préservation semble liée à la capacité du sédiment à maintenir localement un degré d'humectation suffisant pour permettre la préservation de la matière organique donnant son faciès foncé.

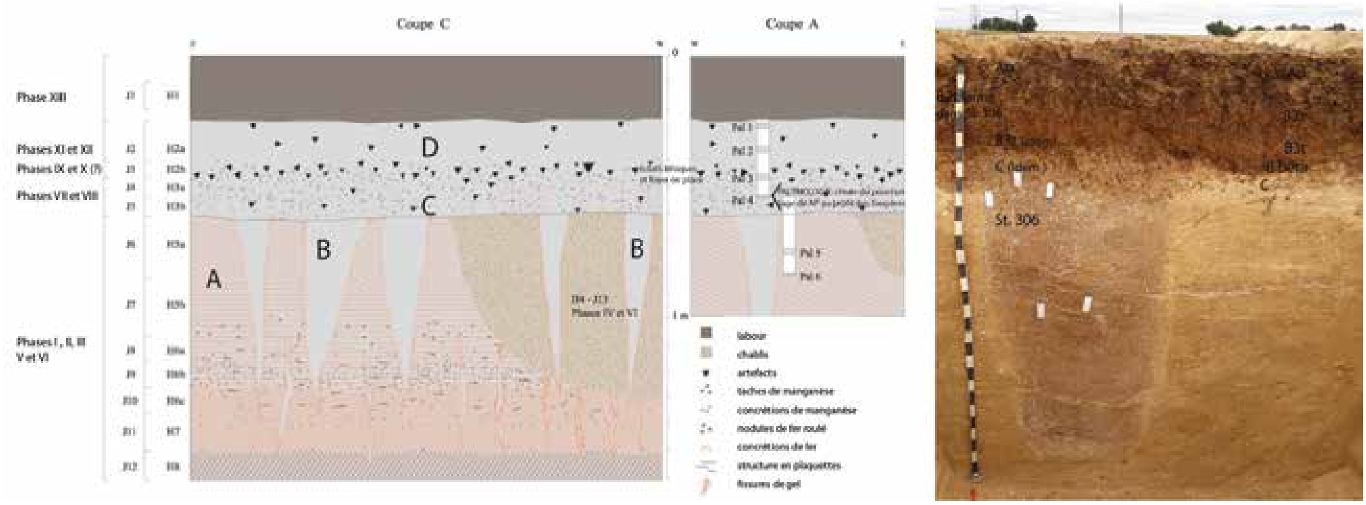

Figure 8. Exemples d'études pédologiques de sols hérités et rencontrés par les Néolithiques :

a. Profil de référence de Rebecq « Spinoi », avec artéfacts du Mésolithique ancien non déplacés, au-dessus de la formation de type *Luvisol* (A-D : événements successifs; D. Bosquet, SPWallonie, étudié avec la coll. de G. Louwagie et H. Mestdagh).

b. Profil de référence LOG 3.4 de Nogent-sur-Seine « Cardinal » II (C. Godart, INRAP), montrant une *Schlitzgrube* 306 « de type mésolithique » (dates C14 en cours) traversée à son sommet par la formation d'un *Luvisol* (« B2t ») et la décarbonatation partielle et la re-carbonatation sous-jacentes.

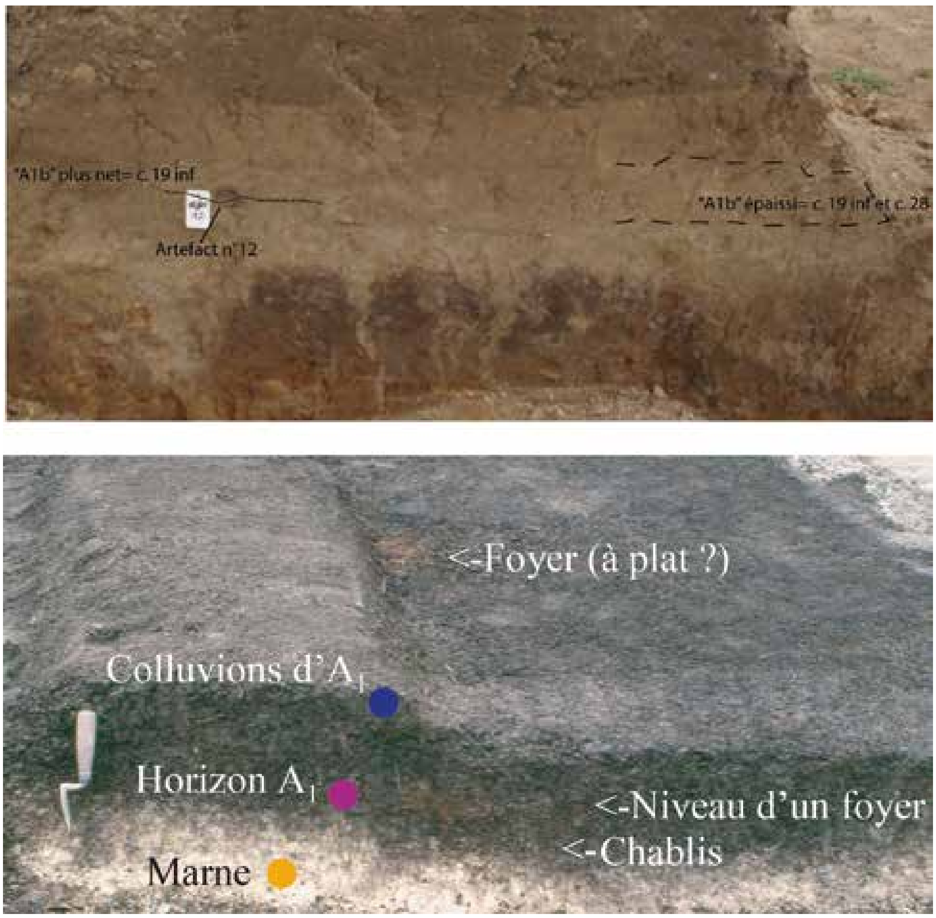

Figure 9. Exemples d'études pédologiques d'horizons de surface peu modifiés par les Néolithiques :

a. Surface avec rares artéfacts (étiquette) et charbons de bois, recoupée par le fossé Néolithique moyen II de Carvin « Gare d'Eau » (C. Monchablon, INRAP, échelle : env. 10 cm © K. Fechner). Elle est sus-jacente aux horizons « E », « II B21t da » et « B2t ».

b. Horizon forestier, confirmé par la malacologie, affecté par le feu, à Dampierre-le-Château « Liévau » (secteur ouest, F. Dugois/ K. Raynaud, INRAP, échelle env. 15 cm © K. Fechner).

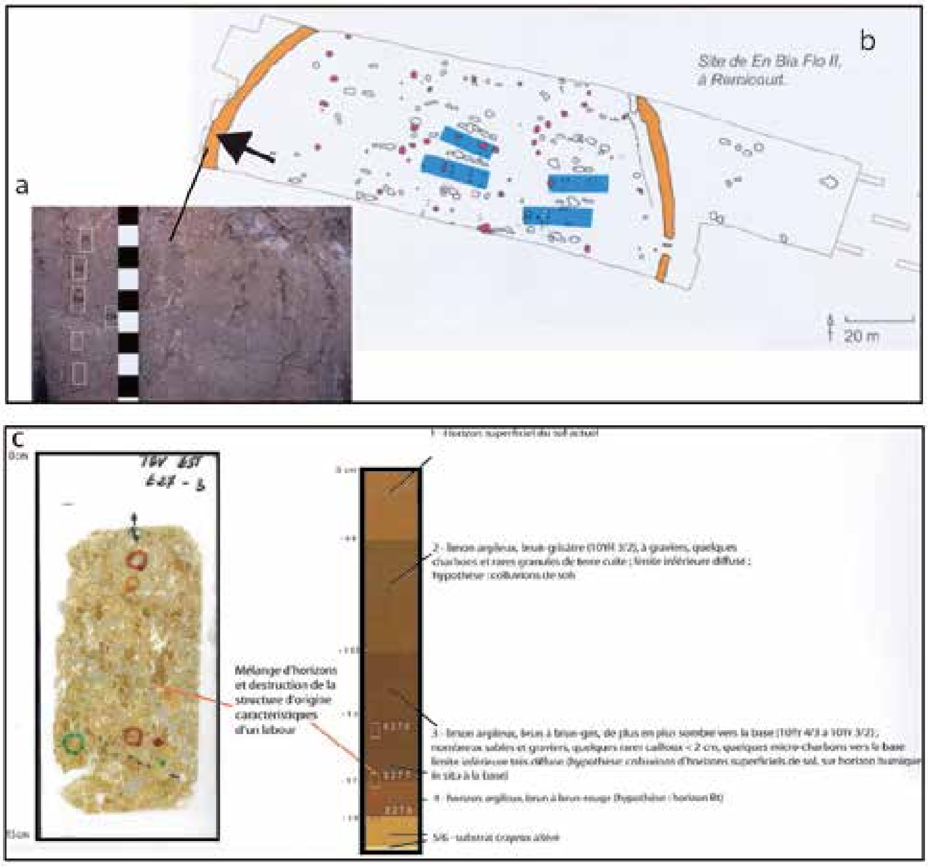

Figure 10. Exemples d'études pédologiques de couches de mise en culture néolithiques et du Bronze ancien :

a. colluvions sombres et homogènes fortement enrichies en éléments chimiques dans le fossé 30, aval, de Remicourt « En Bia Flo » II (D. Bosquet/ H. Fock, SPWallonie © K. Fechner).

b. Plan du site complété selon Fock et al. 2008 (flèche : provenance supposée du vide archéologique adjacent à l'amont du fossé (jardins ?) (© H. Fock/ K. Fechner).

c. Relevé du labour de Cuperly « Les Haches » (E. Frangin, INRAP ; relevé : D. Sordoillet) et vue d'ensemble de la lame mince (étudiée avec la coll. d'A. Gebhardt (© K. Fechner).

sol brun lessivé ou *luvisol* (Van Vliet et al., 1992; Van Vliet-Lanoë, 1990). La formation d'un horizon « E », appauvri en argile, a facilité l'effacement des caractéristiques du sommet de l'horizon B sombre antérieur. En migrant vers le bas, cette argile a formé l'horizon « Bt » enrichi en argile qui recouvre et dépasse en profondeur la base de l'ancien horizon sombre. Seule cette base restera mieux préservée grâce à l'accumulation d'argile au sein du sommet de l'horizon « Bt » qui, en empêchant la suite de l'altération, y maintiendra la couleur sombre et la richesse relative en matière organique, toujours visible dans les analyses actuellement.

Le *luvisol* rencontré par les néolithiques présente d'autres variations entre sites: il arrive ainsi, bien que rarement, que cette migration d'argile ait été interrompue par une phase d'érosion puis de sédimentation naturelle de la fin du Tardiglaciaire (recouverte par le site du Mésolithique ancien de Rebecq, B., Figure 8a ; pédo-région 1 du Tableau 1 ; Fechner et al., 2010, probable aussi à Augny, F., pédo-région 13, Weiler-la-Tour, L., pédo-région 11, et Remerschen, pédo-région 10: Fechner et al., 1997).

D'un autre côté, en milieu superficiellement décarbonaté (sur moins d'un mètre) et au plus faible excès des précipitations sur l'évapotranspiration (climat semi-océanique) on peut avoir des formations des *luvisols* qui sont au moins en partie post-mésolithiques (Nogent-sur-Seine, F., Figure 8b). Enfin, en milieu calcaire, on observe, en dessous des niveaux mésolithiques et/ou néolithiques, un sommet du sol encaissant qui est marqué, selon les cas, par un horizon humifère plus épais, lié à un sol calcaire de type rendzine, ou par un horizon humifère nettement plus fin, au sommet d'une argile de dissolution (Lhéry, Tramery, F., pédo-région 13).

3.2. PREMIERS IMPACTS HUMAINS SUR LA SURFACE DU NÉOLITHIQUE

Quelques cas montrent que ces horizons de surface peuvent parfois déjà être influencés par des activités néolithiques (Figure 9), caractérisées en particulier par un apport de charbons de bois (Carvin « Gare d'Eau », Figure 9a, pédo-région 5, Monchablon 2014, et Chevincourt, F., pédo-région 6 ; Fechner soumis) ou par leur association avec des restes de sol brûlé (défrichements par le feu : Fontvannes et Dampierre-le-Château, F., Figure 9b ; pédo-région 12 du Tableau 1 ?). Ces quatre cas datent du Néolithique moyen.

À la surface de ces différents sols hérités, un autre phénomène est parfois observé: des dépôts d'alluvions et de colluvions modifient, dès le Néolithique ou l'âge du Bronze ancien, la surface par de nouveaux apports, attribuables parfois à l'impact anthropique, local ou plus répété (Praud, dir. 2015 ; Fechner, 1996 ; Fechner et Langohr, 1994 ; Fechner et al., 2014).

3.3. TRACES PÉDOLOGIQUES DE LA MISE EN CULTURE DES SOLS

Avant les travaux archéopédologiques (p. ex. Fechner & Langohr, 1994 ; Fechner et al. 1997 ; Mikkelsen et Langohr, 1996 ; Fechner soumis), peu de choses étaient connues des positions et variations de la mise en culture du Néolithique et du Bronze ancien de la région d'étude. L'archéologie *stricto sensu* peine le plus souvent à trouver des arguments pour situer un champ ou un jardin qui soient positifs ; il s'agit généralement d'une interprétation basée sur la présence d'un vide archéologique sur le plan de fouilles. D'autres données proviennent surtout de l'analyse des artefacts et écofacts en position secondaire dans des rejets, comblant des structures en creux : graines, pollens, phytolithes, élément de houe ou d'araire, traces de défrichage par le feu, (...). L'approche pédologique s'attache, elle, à retrouver des traces *in situ* de la mise en culture, telles que remaniements caractéristiques des horizons de surface par un outil, recoupement du sol en place, indices d'érosion-sédimentation sur une surface à nu, insertion de croûtes de battance ou des écofacts, observés sur le terrain ou en lame mince. Elle tente ensuite de comprendre le mode de fonctionnement de chaque cas et par rapport aux autres : types de labour, fertilité initiale et fertilisation, outil de labour, taille de la surface et durée d'utilisation.

Malgré le nombre peu élevé d'horizons de mise en culture du Néolithique et du Bronze ancien, on observe à ce stade des différences nettes en matière de choix des sols, de topographie et d'hydrographie, selon les types de sols et pédo-régions. Brièvement discutés dans ce qui suit, ces différences seront à confirmer ou nuancer par des études ultérieures. Pour cette activité éminemment liée à la fertilité chimique et/ou physique du sol, il est davantage acceptable de prendre en compte un certain déterminisme naturel pour les choix préférentiels de lieux, alors que cela semble souvent plus difficile à accepter sans fortes critiques pour d'autres types d'activités mentionnés ici.

Les labours du Néolithique ancien étudiés en Moyenne Belgique, sur sols peu fertiles (pédo-régions 1 et 2 du Tableau 1 ; Langohr, 1990 ; 2001 ; dans ce volume) occupent des bas de versants et des fonds de vallées secs, alors que ceux sur limons fertiles de la Moyenne Moselle et de Seine-et-Marne préfèrent les sommets de versants et les plateaux. Enfin, les cas en milieu calcaire, plus tardifs, correspondent à des vallons et têtes de vallons secs marqués par une argile de dissolution. Une seconde différence se marque en matière de fertilité initiale et de fertilisation.

Pour les sols profondément décarbonatés des sites de Moyenne Belgique, cet appauvrissement rapide des sols par leur mise en culture a pu justifier le déplacement de villages une fois que les sols environnants disponibles, ou jugées comme aptes, étaient épuisés, expliquant le fait que l'on n'ait jamais plus d'une génération de bâtiments dans cette région (Langohr, 1990 ; 2001 ; dans ce volume; Whittle, 1996, 160). Ici, deux sites rubanés et un site mal daté témoignent de la nécessité et/ou la capacité d'enrichir le sol de manière artificielle (par du phosphore, des cendres végétales, du potassium et du calcium, entre autres sous la forme probable de cendres à Aubechies, par du potassium et du phosphore à Remicourt "En Bia Flo "II, par du phosphore à Remicourt "En Bia Flo I", *cf. infra*). Sur tous ces sites, l'horizon conservé possède la même couleur très sombre (cf. code de Munsell) qui rappelle celle de l'horizon « B sombre » (*cf. supra*), mais s'en distingue par la formation bien postérieure (Figure 10a) et la coloration et composition chimique dues aux ajouts par l'homme. À Aubechies, les lames minces et les accumulations de phosphore pourraient indiquer un piétinement et une fertilisation directe par le bétail (Mikkelsen et Langohr, 1996, de type vaine pâture ?). Le labour y est conservé sur une dizaine de mètres sur le bas de versant et dans le fond de vallon, et ce non loin des premières structures du site blicquéen, juste en amont. Cependant, certaines structures sur le site sur le plateau pourraient montrer la même morphologie et chimie (extension plus grande, autres zones cultivées ?). À Remicourt « En Bia Flo » II, les couches colluviées très sombres dans la partie moyenne du comblement du fossé d'enceinte rubané sont

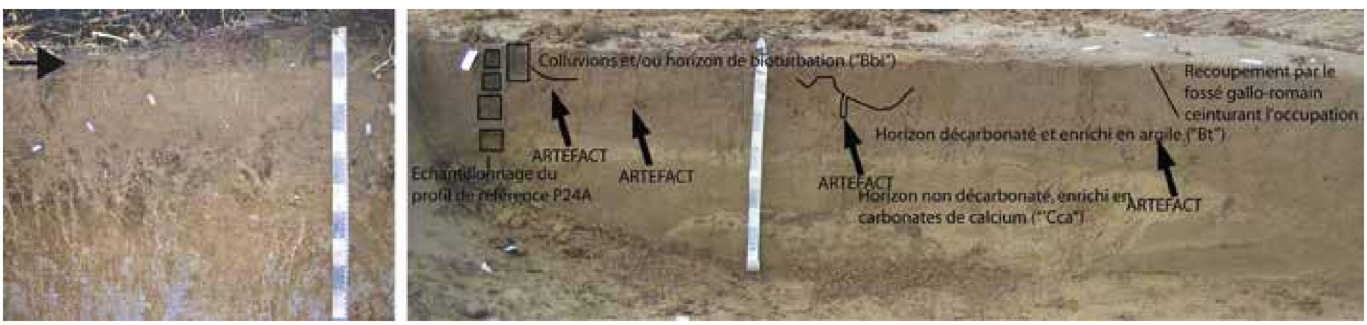

Figure 11. Exemples d'études pédologiques de « sols » d'occupation : a) profil P1 d'Aougny « Bois de la Vente » (flèche et étiquettes : éco- et artefacts sur et dans l'horizon « E » bien préservé, au-dessus d'un « II B21t da » et d'un « B2t »; Ph. Feray, INRAP © K. Fechner); b) profil G24 de Lieusaint « Centre Commercial » II (flèches : niveaux successifs de recharges séparés par des artéfacts et micro-artéfacts ; J. Durand, INRAP © K. Fechner).

vraisemblablement issues de l'érosion d'une zone cultivée assez large qui longe le fossé aval, dénuée de structures, en bas de versant (Figures 10a, 10b). Elles sont ainsi sans doute associées à l'occupation néolithique du site, plutôt qu'à son abandon. Les données des botaniques vont aussi dans le sens d'un champ ou de jardins sur le site. Remicourt « En Bia Flo » I, dans la vallée voisine, présente une couche non-datée, mais de couleur et de composition similaires, piégée dans une tête de vallon sèche sur le versant.

Au Néolithique ancien, en Moyenne Belgique, tout indique donc à ce stade un choix préférentiel de sols de fond de vallée ou de bas de versants (cf. déjà proposition de Gosselin 1986), voire peut-être de têtes de vallons. Les fonds de vallée en bordure d'habitat ont parfois des sols un peu moins indurés et pauvres en éléments nutritifs à l'origine. Ils sont en outre cultivés selon des méthodes évoquant du jardinage, avec des engraissements marqués, à la fois minéral et organique (Aubechies et Remicourt « En Bia Flo » II et peut-être I). L'appel local à certaines situations topographiques et à des méthodes d'enrichissement des sols à proximité de l'occupation adjacente est le reflet de l'inventivité de l'Homme, mais limite fortement les zones utilisables. Elle ne livrait donc sans doute pas de solution durale face au problème de la pauvreté initiale et de l'appauvrissement rapide par la mise en culture des sols dominants de Moyenne Belgique.

Dans la même pédo-région, le cas plus tardif (Bronze ancien probable) de Bruyelle est totalement différent de ces points de vue. Il est situé sur un plateau et dénué de traces de fertilisation autre que des charbons de bois et sans doute des cendres, donc une fertilisation minérale (abattis-brûlis ?, autres types d'ajouts délibérés ?[10]).

Durant le Néolithique ancien, en dehors de la large zone de limons profondément décarbonatés de Moyenne Belgique, on rencontre au contraire des sols suffisamment fertiles pour supporter des mises en culture successives sans appauvrir les sols au point de les abandonner (sud des Pays-Bas, ouest de l'Allemagne. En outre, en bordure de la Moyenne Belgique, les sites peu éloignes de zones alluviales, aux sols nettement plus fertiles, font exception à cette tendance à l'abandon précoce des sites. Le long de la Meuse, c'est ce que révèle le cas de Liège (pédo-région 6 du Tableau 1) dans le fond de vallée de la Meuse et sur le bas de versant occidental (*cf. supra :* §3.2). Peu éloigné, le site d'Alleur (bord de pédo-région 1) est implanté sur le plateau en bordure de ce même long versant occidental de la vallée, riche en sites rubanés. Tous deux présentent pour une fois deux occupations successives. Le premier est marqué par d'épais dépôts d'alluvions argileuses entre ces deux phases d'occupation rubanées (résultant d'une *landnam*?). Sur les sols superficiellement décarbonatés (Remerschen, L., pédo-région 10 du Tableau 1, Villenoy-Chauconin, F., pédo-région 14) ou calcaires (Ay-sur-Moselle, F., pédo-région 10), les cas de mise en culture *in situ* du Néolithique ancien étudiés sont à ce stade situés sur les hauts de versants et sommets de plateau. Leurs sols plus fertiles ne nécessitent pas d'ajouts pour rester cultivables. Des améliorations des sols sont néanmoins intervenus par le fait que les labours entament des niveaux et des fosses rubanées au sein et en bordure de l'habitat (Remerschen, Ay-sur-Moselle), dans ce qui s'apparente sans doute à de petits champs (min. 20 m de long). Une érosion-sédimentation y intervient en cours d'utilisation, ce qui livre des indications sur la durée et la taille des cultures et des hypothèses sur les outils utilisés. À Villenoy-Chauconin, l'étude confirme un phénomène de mise en culture avec traits micromorphologiques typiques, dont les nombreuses intercalations d'argile dues au remaniement par un outil de labours[11].

En Champagne (pédo-région 12), des présomptions existent pour la mise en culture (tardive ?) préférentielle des sols à argile de dissolution, en bas de versant; ils sont rencontrés à Cuperly (Figure 10b, pédo-région 12 du tableau 001), au Bronze ancien ou potentiellement un peu plus tard, ainsi que sur des sites protohistoriques plus tardifs, voisins. On n'a pas encore rencontré de labours préromain sur la craie[12]. Pour les indices ponctuels antérieurs rencontrés sous la forme de traces de défrichement par le feu à Dampierre-le-Château et à Fontvannes au Néolithique moyen-récent au Néolithique final (cf. §3.2), le lien avec des mises en cultures n'est pas établi[13].

Les outils utilisés au Néolithique et à l'âge du Bronze ancien n'ont pas laissé de traces au sol à l'inverse des sillons d'araire des époques qui suivent, sur les mêmes aires d'étude, cela favorisant, à ce stade, l'hypothèse d'une utilisation d'outils différents. En Champagne (pédo-région 12

10 L'organisation de cette surface cultivée pourrait pour une fois être attestée grâce au lien avec trois longs fossés rectilignes et parallèles, lien qui est probable sur base de l'étude pédologique et palynologique de leur comblement et rendue possible par les recoupements stratigraphiques (Bausier et al., 2018).

11 En son sommet on observe notamment un lit horizontal plus fin non-biréfringent, colluvial, plus bas on observe des pigmentations organiques, un fragment de revêtement, un revêtement en place poussiéreux, un autre succédant à un revêtement limpide, trois intercalations d'argile poussiéreuses typiques, des taches et lignes sombres de manganèse, des concentrations de bio-galeries sous forme de chambres alignées verticalement. Selon A. Gebhardt, on aurait sans doute les mêmes traces en cas de bêchage et de labours à la houe ou à l'araire (comm. pers.).

12 Une exception mal datée (protohistorique ?) pourrait être celle de Rumilly-les-Vaudes, sur grèze crayeuse alluvionnaire de basse terrasse.

13 Il doit être noté que ce lien est souvent difficile à prouver en contexte de versant crayeux car l'érosion-sédimentation massive due à la mise en culture postérieure, notamment moderne, de ce type de milieu a grandement altéré les pédo-séquences. À Fontvannes, les anciens horizons de surfaces sont ainsi remaniés et accumulés en fond de vallon.

du Tableau 1) et dans le Nord- Pas-de-Calais (pédo-région 5), on pourrait avoir plusieurs indices en faveur de mises en culture qui seraient surtout intervenues après les périodes traitées ici, à l'exception de points ponctuels dans le temps et l'espace (p. ex. Vanmoerkerke, 2009). La préservation plus fréquente d'anciennes surfaces néolithiques ou de l'âge du Bronze ancien, mais rappelant la surface naturelle héritée, dénuées de toute indice pédologique de mise en culture, semble également y favoriser l'idée de mises en culture plus tardives.

3.4. *SOLS* D'OCCUPATIONS DE NATURE VARIÉE

À presque toutes les périodes concernées par cette étude, nous avons rencontré des "sols" d'occupation, à savoir des horizons de surface formés entièrement par l'homme (Figure 11). Ils sont marqués par des concentrations de matériel très peu ou non déplacés (Durand et al., 2014; Feray, 2005; Fechner soumis). Au sein de notre zone d'étude, ils forment des horizons de surface plus ou moins humifères, plus ou moins épaissis et plus ou moins enrichis en argile ou en phosphore. Les résultats présentés ci-dessous portent, successivement, sur les cas les plus contrastés, puis sur l'attribution d'autres sites à ces « cas d'école ».

Le site d'Amilly, plus éloigné géographiquement (région Centre, F.), mais étudiée à titre de comparaison, est exemplaire car il révèle que l'on peut distinguer deux types de tels « sols » dans un seul site : des ateliers de débitage peu ou pas enrichis en phosphore et des aires d'activité plus enrichies, liés à l'habitat et entourées, elles, des fossés d'enceinte. Cette distinction se marque donc entre autres dans les données pédologiques et sert à poser les bases pour une partie des « sols » traités dans notre aire d'étude. Ici les sites-clé sont datés du Néolithique final (Aougny, pédo-région 13 du Tableau 1, et Sauchy-Lestrée, pédo-région 5, F.). Le premier est dénué de phosphore et de toute perte de sédiment par arasement et associé à une unique phase de la préparation d'outils en silex (Figure 11a). Le second présente au contraire une nette perte des horizons de surface, intervenue avant la formation d'une probable nouvelle litière et, enfin, avant le dépôt des artéfacts par les occupants. Cette succession exclut que l'érosion y soit postérieure à la mise en place du «sol» d'occupation. Dans plusieurs sites d'Ile-de-France (tous dans la pédo-région 14 du Tableau 1), dès les phases de diagnostics, on note la présence de silex taillés au sommet des limons, sur les sommets de versants; on y parle de concentration, de mobilier résiduel ou pris dans des colluvions, souvent sans que le phénomène de leur mise en place ne soit examiné attentivement. Or, après étude pédologique, les trois premiers de ces sites, du Néolithique ancien (Tremblay-en-France, F.) et du Néolithique moyen (Montevrain, Palaiseau, F.), renvoient sans doute à nouveau à une légère perte de sédiment déjà liée à la mise en place des artefacts. Elle se marque par l'absence de tout ou de l'essentiel de l'horizon « E » et la bonne préservation de tout ou partie de l'horizon « Bt ». À noter qu'il en va de même sur un site du Néolithique moyen lié à l'extraction de silex (Spiennes « Rue d'Harmignies », B.), à côté du puits d'extraction, donc sans doute arasé dans le cadre des activités d'occupation. Ici aussi, sous 5 centimètres de dépôts de pierres, on peut exclure un processus d'arasement post-dépositionnel. Dans deux des autres sites d'Ile-de-France, du Néolithique ancien (Lieusaint et Villenoy-Chauconin), les processus s'avèrent être très différents alors qu'ils étaient sensés répondre à un phénomène similaire au début de leur étude. À Lieusaint la reprise des études de lames minces[14] suivie d'une meilleure compréhension de l'ensemble des données a été motivée par les travaux récents de Marylise Onfray (p. ex. Onfray, 2017). On révèle un cas d'accumulation de fines couches anthropiques dans un habitat (dans le bâtiment ?) , vraisemblablement constituée avant tout de terre crue, entrecoupée de mises en places d'artéfacts posés à plat, conservées localement à la faveur d'une microdépression (Figure 11b). Ces traits contrastent notamment avec ceux de Villenoy-Chauconin mentionnés plus haut dans les sols labourés (§3.3) et initialement reprise dans les « sols » d'occupation.

Dans deux autres sites, on évoque aussi une accumulation de sédiments entrecoupée de mises en place d'artéfacts posés à plat (Lhéry, pédo-région 13, et Pont-sur-Seine, pédo-région 12, F.), sans que l'on n'y atteigne les épaisseurs de Lieusaint, ni celles des sites en région Centre (notre contribution à l'étude de Prasville « la Mare du Château », divers sites mentionnés par Ingrid Sénépart et al., 2018 ; Onfray, 2017). Il s'agit là des premières attestations de ce type au nord de la région Centre (et aussi anciennes), confirmant l'intuition de certains chercheurs (J. Wattez et T. Hamon, comm. pers.). Si l'étude pédologique permet de bien distinguer ces accumulations des types de formations de « sols » d'occupation mentionnés plus haut, certains de ces sites devront encore être étudiés de manière aussi approfondie que ceux de la région Centre. Comme on le voit, une fois que l'on approfondit l'étude des « sols » d'occupation, les interprétations des modes de fonctionnement peuvent diverger fortement, y compris dans des contextes pédologiques et pour des morphologies de terrain similaires.

14 Un nombre parfois important de fissures horizontales et verticales (structure prismatique à subangulaire) et de charbons de bois, dont certains en position horizontale et un recoupé par une fissure verticale, quelques éléments végétaux oblongs ou lenticulaires, petits fragments de matière organique, taux d'argile plus élevé (cf. aussi granulométrie), plusieurs remplissages de pores par de l'argile non biréfringente, précipitations de fer subhorizontales, chenaux localement omniprésents, reprenant ou prolongeant les fissures, revêtements argileux de pores qui sont très souvent limpides.

5. Synthèse: une perception originale du passé s'appuyant sur une démarche *multi-proxy*

La confrontation de l'ensemble de ces données, dépassant les types de structure, suscite de premières questions et hypothèses plus globales sur le mode de vie et l'environnement du Néolithique et du Bronze ancien. Les huit principaux résultats concernent les aspects suivants (Fechner soumis) qui devront être développés dans un article ultérieur :

a. Plusieurs traits caractéristiques du Néolithique ancien rubané ont été précisés par l'étude pédologique : en font partie les bâtiments (cf. Broes et al. 2018 ; Fechner soumis, pour leur affectation différentiée et les nettes différences par rapport au Néolithique moyen, final et l'âge du Bronze) et les fortifications, tous deux connus pour leurs plans souvent répétitifs, voire superposables (p. ex. Fock et al., 2008), sans parler d'autres aspects liés au matériel (décors de la céramique, ...). Il est démontré avec l'aide des études pédologiques que l'utilisation des certains types de fosses est souvent similaire dans différents sites, dont certaines à un endroit particulier dans l'habitat ou par rapport aux maisons (préparation de matériaux divers, récolte d'eau, fosse d'extraction, mare, décantation d'argile). On y fait davantage appel à des coffrages en bois (celliers, puisards, fosse de tannage ?, ...) que jusque-là suspecté. La même chose vaut pour le soubassement d'un cas de four aménagé spécifiquement pour cuire, probablement, des terres cuites ou céramiques (Fechner et al., 2003 ; Fechner soumis).

b. Toujours au Néolithique ancien, on observe des différences régionales marquées en terme de mode et de lieu de mise de culture. Les trois cas étudiés sur sols plus fertiles (sur limon plus argileux et calcaires et sur limons superficiellement décarbonatés) pourraient rappeler des champs plus que des jardins et sont situés sur des plateaux et des sommets de versants, enfin à plusieurs reprises entre des bâtiments en bordure du village. Ils ne présentent pas de nette fertilisation par l'homme. À l'inverse, les deux ou trois cas sur sols pauvres, sur les limons profondément décarbonatés de Moyenne Belgique, sont fortement enrichis à la fois par des engrais organiques et minéraux. On y assiste à une méthode qui rappelle plus du jardinage. Au pied des habitats, ils sont, eux, situés en bas de versant et fond de vallée, aux sols d'origine un peu moins pauvres.

c. Ces particularités agro-pédologiques sont lourdes de conséquences pour la durée et la fin des occupations rubanées en Moyenne Belgique. Si la production agricole pouvait sans doute s'appuyer sur une exploitation spécifique de zones défrichées dans des fonds de vallon et vallées plus fertiles ou de zones fortement anthropisées (jardinage), cela limitait néanmoins les endroits disponibles, rendant d'autant plus crédible la théorie des «shifting villages » (villages changeant de place une fois les terrains appropriés épuisés) de Roger Langohr (1990 ; 2001), reprise par Whittle (1996) et présentée en détail par Dr. R. Langohr dans cet ouvrage. L'abandon de sites, en lien probable avec les ressources limitées, pourrait aussi être révélé par le rebouchage final et massif de deux des fossés qui entourent des habitats rubanés. Tant à Voroux-Goreux qu'à Remicourt « En Bia Flo » II, les fortifications semblent avoir été rebouchées de manière à clôturer leur utilisation, plutôt que de les laisser se reboucher tout seul, posant à la fois la question de la raison de leur élévation et celle des causes et du mode de leur abandon[15].

d. Les *Schlitzgruben* alignées en ligne droite ont été analysées de manière répétée et existent dans certaines régions du Mésolithique à l'âge du Bronze. La plupart ont les caractéristiques pédologiques et/ou micromorphologiques de fosses soit de calage (poteaux), soit de piégeage (vide parfois entouré d'un cuvelage de piquets, traces rares d'excréments) et font au moins parfois partie d'alignements de fosses. Un cas au plan d'ensemble des fosses grossièrement ovalaire a aussi pu être étudié et analysé en détail. À l'instar d'exemples d'autres époques et contrées, il pourrait être un lieu de collecte des animaux sauvages à l'extrémité d'un des alignements de poteaux précités. Sur base des recherches exemplaires menées en Champagne-Ardenne, on peut considérer que ces réseaux de fosses sont le témoin non seulement de toute une partie de l'affectation des paysages anciens qui nous échappe d'habitude, mais aussi de certaines époques peu représentées dans les autres types de vestiges.

e. Des *Schlitzgruben* isolées dans l'entrée d'enceintes reflètent, elles, avant tout un acte de fondation entourant des habitats du Néolithique ancien en Moyenne Belgique et du Néolithique moyen dans le Nord de la France. L'ensemble des données pourrait

15 De plus, le fait de fortifier plusieurs de ces sites est considéré comme spécifique à cette limite occidentale du monde rubané tardif par certains auteurs (p. ex. Bogucki, 2000).

refléter l'existence de zones d'entrée et de sortie à la vocation plus complexe (autant utilitaire que symbolique ou religieuse). Cela, alors que le reste de ces fossés et sites ont livré des occupations plus classiques pour un habitat. Un cas de comparaison dans le Bade -Wurtemberg, toujours du Néolithique moyen est particulièrement parlant, étant donné que l'interruption avec *Schlitzgrube,* de plan très comparable mais aux conditions de préservation meilleure, a conservé nombre d'offrandes d'animaux sauvages et de tombes (Behrends, 1991), alors que le reste du site forme un habitat fortifié classique. Si les sites fortifiés munis de ces *Schlitzgruben* supposées « votives » forment des cas bien distincts des *Schlitzgruben* rencontrées ailleurs, ils posent néanmoins la question de évolutions et contacts entre différents mondes et modes de pensées du Néolithique en relation avec les animaux sauvages et ce type de fosses.

f. Les cartographies de phosphore, toute en prenant en compte des facteurs taphonomiques, révèlent un contraste entre des fortifications du Néolithique moyen à plus ou moins forte occupation interne. Les études pédologiques de fossés et d'enclos fossoyés et de leur espace intérieur révèlent que certains cas sont nettement plus anthropisés alors que d'autres ressortent par une étonnante absence de pollution. On distingue en particulier le cas de Carvin, riche en indices de fortes pollution interne, de celui de Boitsfort. Néanmoins, comme révélé aussi par les fouilles anciennes de ce dernier site, le fossé lui-même y est nettement plus marqué par les traces de l'homme ce que confirment les tests de phosphore. Pour un enclos palissadé du néolithique final, la légère pollution constatée est nettement plus compatible avec des activités agricoles (jardins, …) qu'avec un enclos avec bétail.

g. Deux fossés à très courte durée d'utilisation entourent sans doute des lieux de rassemblements ponctuels au Néolithique moyen et au Bronze ancien en Picardie. La rapidité et le mode de comblement du fossé du Bronze ancien-moyen de Louvencourt, et, sans doute, du fossé Néolithique moyen ou final de la Chaussée-Tirancourt, rappellent à cet égard le cas laténien d'Aalter "Woestijne", un fossé remblayé rapidement et de manière spécifique à l'âge du Fer (Langohr et Fechner, 1993 ; Fechner, 2018). Il s'agit de rares cas qui attestent d'une utilisation courte et qui peuvent rappeler les cas étudiés en détail par Whittle et al. (2011), Jeunesse (2010) ou les collègues danois (enceintes de type *Sarup*, cf. Danish Prehistory 2016) celle d'un lieu de rassemblement ponctuel, le plus souvent funéraire et/ou religieux, et pouvant être situé sur les trajets de transhumance (Kerig et Knoche, 2015; Knoche et Schyle, 2015).

h. Des 'sols' d'occupation peuvent être regroupés en minimum quatre ensembles qui reflètent des modes d'accumulations et d'occupation différents: brève utilisation pour une activité ponctuelle sans érosion ni pollution, utilisation du lieu avec pollution et activités et outils lithiques liées à l'habitat, utilisation avec érosion ou arasement liés à des activités spécifiques (lieu de passage, puits de mines, …), enfin accumulation de terre argileuse dans le cadre de constructions et aménagements en terre crue. Ce dernier cas d'école est attesté pour la première fois au nord de la région Centre, vraisemblablement sur trois sites, tous dans le bassin versant de la Seine.

Ces différents exemples, liées à divers sujets archéologiques, permettent d'illustrer à nouveau la plus-value apportée par un approche multi-proxy et son caractère indispensable en cas de fouille, cette dernière étant toujours un acte destructeur et définitif. Les sujets évoqués (fossés, palissades, enclos, fosses, sols naturels et anthropiques, …) sont surtout liés à des environnements de versants et de plateaux. À défaut de conservation des matières organiques, voire souvent des ossements, ces sujets et environnements semblent particulièrement bénéficier de l'approche pédologique pour augmenter la résolution de la connaissance du passé.

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THE EVOLUTION AND MEDIEVAL RE-USE OF A PREHISTORIC BARROW AT WIELSBEKE (WEST FLANDERS, BELGIUM)

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ABSTRACT

During archaeological research in the sandy loamy region of north-western Belgium in 2015, a prehistorical burial mound was uncovered. Based on detailed macro and meso soilscape analyses, the archaeological excavation data, and a soil micromorphological study, we were able to reconstruct the life cycle of this barrow. After its initial erection in the Bronze Age, the barrow was restored during the Iron Age. A cremation burial was added to the burial mound in the late Iron Age. Roman pottery finds from the ditch filling illustrate that the barrow was still present in the landscape at the time of founding of a late Iron Age to Roman Age settlement in the direct vicinity of the barrow. Finally, in the High Middle Ages, a new and larger mound was erected superimposing the original barrow.

KEYWORDS

Prehistory, Iron Age, Middle Ages, burial mound, soil micromorphology

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1. Introduction

In East- and West-Flanders, prehistoric barrows have all but disappeared in today's landscape. The circular ditch that surrounded these monuments is often the only relic left in the soil. Mainly due to intensive agriculture and erosion, the hill itself and often also the original burial has been topped off (Reu et al., 2013; Bourgeois et al., 1998). Even when all that is left is the infill of the surrounding ditch, very valuable information can still be deduced when archaeological research is combined with archaeopedological fieldwork and soil micromorphology (Ampe et al., 1996). In 2015, two excavations on the flanks of the river Lys revealed four circular barrows and a long-barrow (Figure 1). The structures where erected in the period ranging from the Early Bronze Age until the Iron Age (Beke et al., 2017; Vanhoutte et al., 2018; Mikkelsen et al., 2018).

Nowadays, not much is preserved of the historical natural landscape of Wielsbeke: concrete roads are flanked by residential areas and industrial complexes and the river Lys is channelled. Based on the research of one of these excavated barrows, we built up a chronological hypothesis to how this monument and its surrounding landscape evolved through time.

2. The soils of the site and the barrow

Within the study area, the soils are composed exclusively of light loamy sand (P) textures. In the immediate vicinity, soils are described as having a loamy sand (S) texture. The drainage class ranges from dry to moderately wet (b, c, d). To the east of the excavation, where today there is a canal and where a small stream has formed the soils, they are mapped as moderately wet. The soils are characterised by a degraded Bt horizon (www.DOV.be).

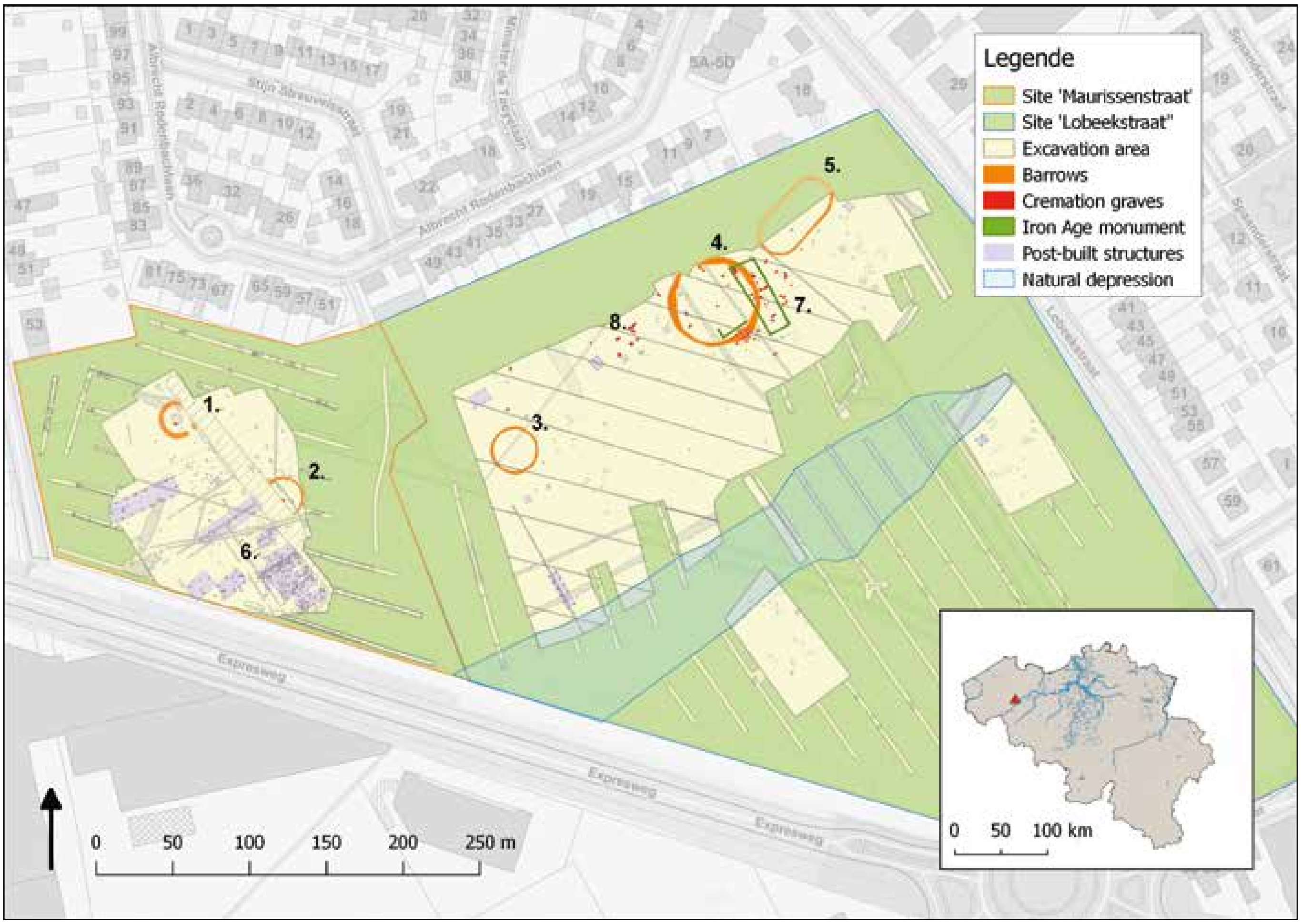

Figure 1. Excavation plan: prehistoric barrows at the site 'Maurissenstraat' (1&2); Bronze Age barrows at the site 'Lobeekstraat' (3-4); long-barrow (5); Late Iron Age and Roman settlement (6); Late Iron Age and Roman funeral structures (7-8).

2.1. THE REFERENCE PROFILE P1

The reference soil profile (P1) of the excavation can be divided into 6 horizons. H1 is the A-horizon that was created when a football field was laid out. This horizon therefore has a rather high humus content and a loose granular structure, probably related to intensive fertilising. H2 is the original Ap horizon, testifying that the soil has a history as arable land. Like H2, H3 is a homogeneous horizon with a slightly browner colour. This horizon is most likely a buried surface horizon that was also, at least partially, worked by man. H4 is a leaching horizon, almost entirely depleted from clay and humus and H5 is the illuvial horizon (Bt), in which the clay and humus have accumulated. H6 is the parent material, which consists of clayey and sandy, more or less, horizontal layers (Figure 2).

Initially, probably in the late glacial period, H6 was deposited in a fluvial environment. H3 to H5 were also deposited during this period and perhaps at least a part of H2. Possible part of the sediment is of eolian origin. In the Holocene period, soil development began with the leaching of clay and humus and the formation of an A-E-Bt soil (soil with a texture B-horizon). Later, the soil was cultivated and undoubtedly also fertilised. In a levelling phase, the soil at the location of P1 may have been raised slightly, and elsewhere the soils may have been eroded slightly. In the final phase, the football field was constructed, and the upper 7-8 cm of the soil developed further below the grass field to become a distinct humiferous A-horizon.

2.2. SOIL BARROW PROFILE A

On the circular ditch, interpreted as part of a Bronze Age structure, 3 soil profiles offering a cross section of the circular ditch were studied. Profile B is located in the northern-, A in the southern- and D in the western direction (Figure 3). The soils of profile A and B are discussed in more detail below.

Profile A is divided into 9 soil horizons of which the first 5 (H1 tot H5) are part of the circular ditch. The horizons H10-12 make up the natural in situ soil. The horizons H6 and H8-9 are only present in profile B. The horizons H10 to H12 are similar to horizons found in the reference soil profile. H10b is a pale horizon, strongly depleted of clay and iron. H10 is the illuvial horizon where the clay and iron from H10b has deposited. H11 and H12 are the deeper clayey and sandy soil horizons (Figure 4).

At first it is striking how little influence the ditch seems to have had on the in situ soil. On a meso scale,

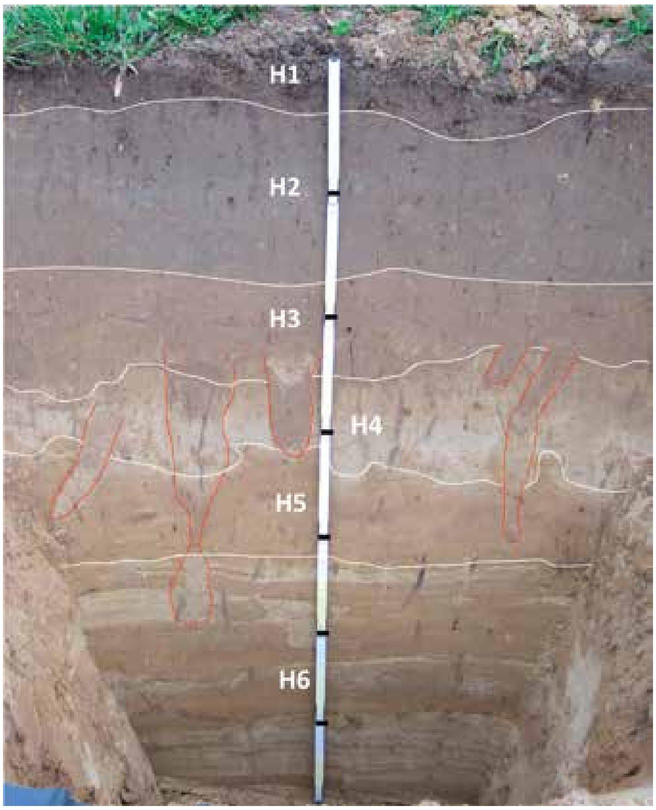

Figure 2. Photo of reference soil profile P1. Indicated are the soil horizons and the major bio galleries (red lines).

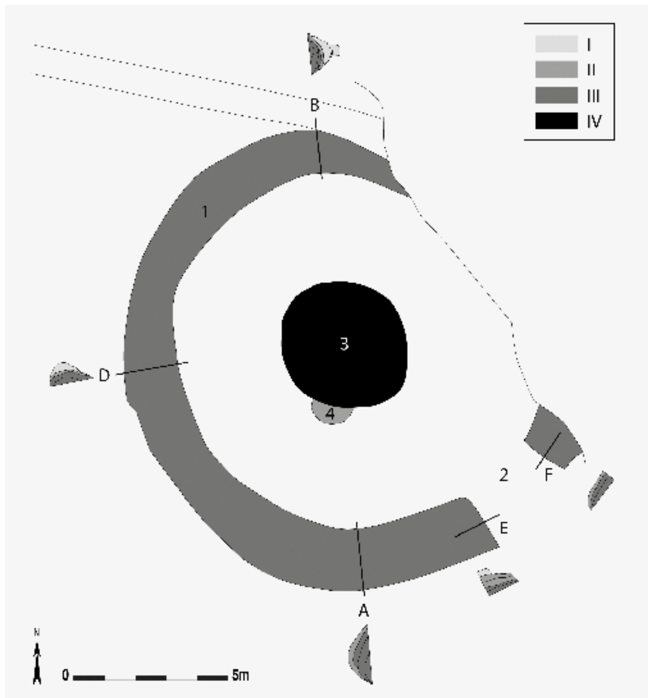

Figure 3. Barrow n°1 with the circular ditch (1); intentional interruption (2); Late Iron Age cremation (4); and the central pit dating to the medieval period (3). Legend, I: Foundation phase; II: Iron Age restauration phase; III: Anthropogenic filling; IV: High Middle Ages.

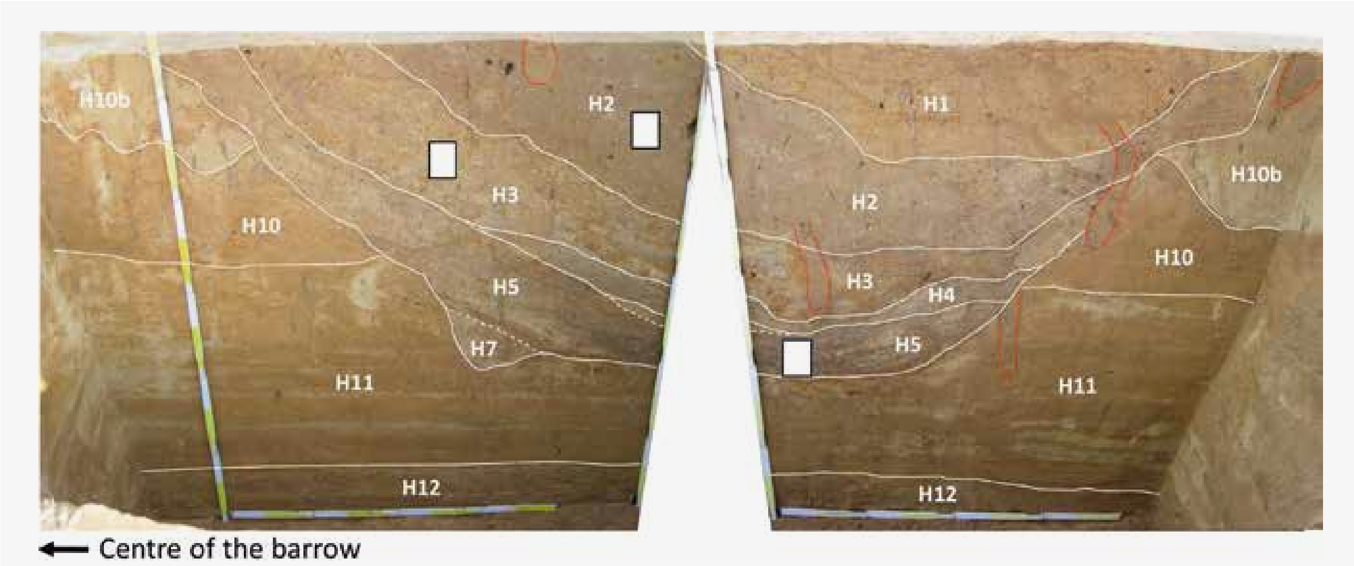

Figure 4. Cross-section A of the surrounding ditch: foundation phase (H7) Iron Age restoration phase (H5), anthropogenic filling of the ditch (H1-H4). The white boxes mark the samples for micromorphology.

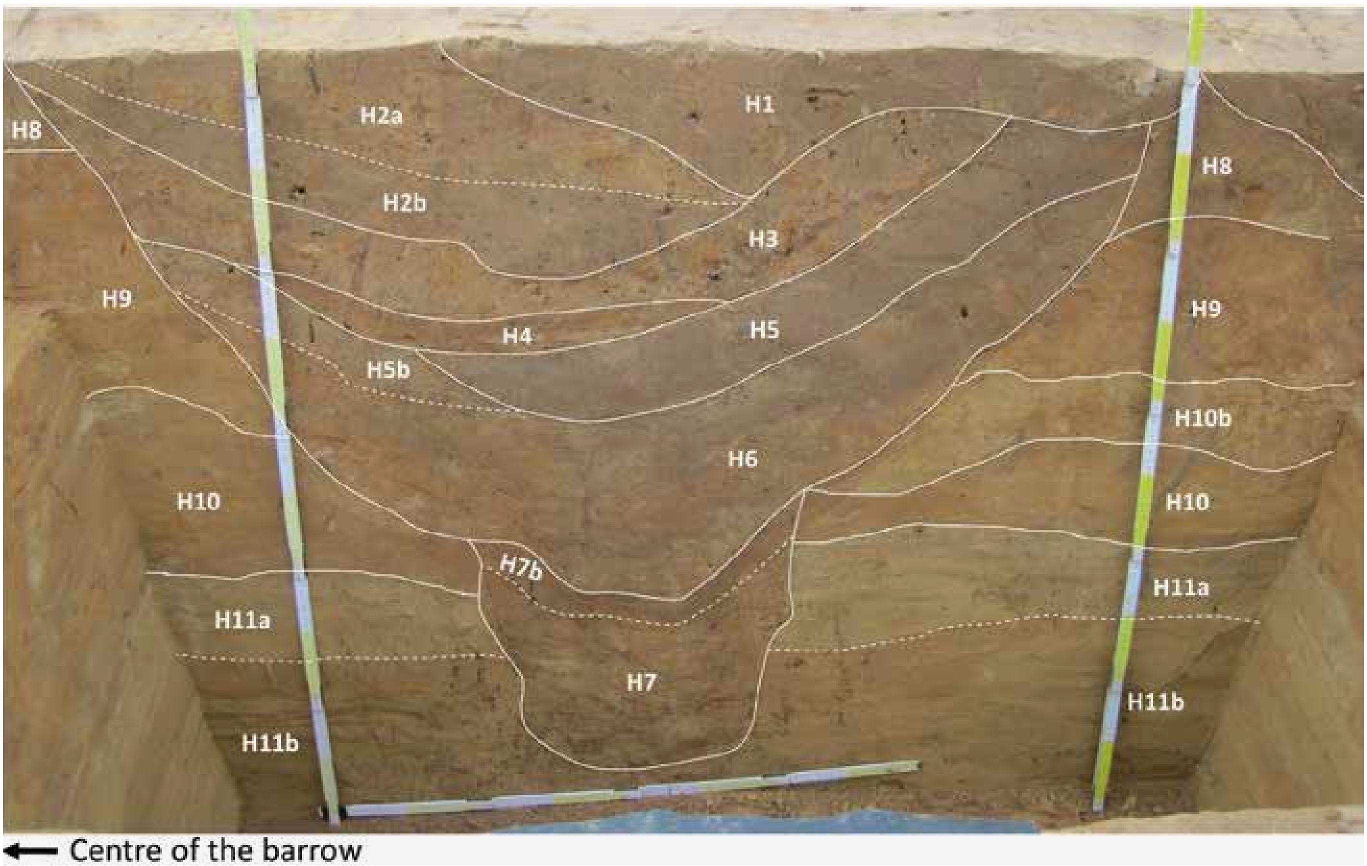

Figure 5. Profile B of the circular ditch: foundation phase and first use (H7); erosion phase (H6); Iron Age restoration phase (H5-H5b); anthropogenic filling of the ditch (H1-H4); intact soil (H8) and B-horizon (H9).

there are no visible traces of oxidoreduction reflecting stagnating water in the in situ soil or at the bottom of the ditch. Possible hypotheses are:

1) the soil is well drained with a relatively deep water table, which means that rainwater quickly seeps out of the ditch, leaving the ditch dry for the most part of the year,
2) the ditch is quickly filled with sediments, either intentionally or as a result of erosion of the surrounding soils and/or anthropogenic soil structures (e.g. the burial mound),
3) a combination of the above suggested explanations.

H2 could reflect a phase of erosion of an earthen hill or construction situated at the centre of the ditch. As the accumulated sediment of H2 is rich in humu s, it may indicate that the accumulated material originally was at or near the surface, or that the deposition rate happened rather slow, allowing vegetation to grow and accumulate organic debris in the ditch. The relatively uniform nature of the horizon suggests a good bioturbation of the soil material.

H3, a rather heterogeneous horizon, composed of clay rich brown areas, greyish brown humiferous areas, and paler humus and clay depleted areas. Traces of stratification are visible, possible reflecting more intensive periods of barrow erosion. The stratification is parallel to the bottom of the horizon. H3 is asymmetrical with more material accumulated on the inside of the ditch than on the outside. The heterogeneity of this horizon suggests that the horizon was formed quickly, and was maybe an anthropogenic infill.

2.3. SOIL B ARROW PROFILE B

Profile B, studied opposite to profile A, consists of 11 horizons. The horizons H1 to H7 outlines the area covered by the circular ditch, and the in situ soil is labelled from H8 to H11. The deeper soil horizons recognised in this profile are the pale light-beige horizon H11a, followed by the brown clay-rich horizon H11b. H9 resembles a brown B-horizon and H8 an old surface horizon, the upper part of which may have been eroded (Figure 5).

The circular ditch consists of a deep narrow part (H7 and H7b) and a wider upper part (H1-6). In lacking organic matter, the clay content in the soil is in general insufficient to keep the walls of the ditch stable, so the lower narrow part (H7) probably sealed of rather fast after the ditch was constructed. In H7 different stratification lines were observed, both horizontal and oblique. At the top of the horizon, there is a brown homogeneous zone without stratification (H7b). This horizon possibly reflects a period of stabilisation with accumulation of humus (leaves, etc. that fall into the ditch) in combination with bioturbation. Apart from manganese-oxide stains, there are no signs of oxido-reduction.

H6, with a more heterogeneous matrix and less humus accumulation, probably reflects a relative quick deposition phase of the ditch. H5, with a homogeneous matrix and a higher content of organic matter, may represent a period of vegetation growth and stability. It is noteworthy that H5 is only present on the outside of the ditch. Possibly, the inside was removed during maintenance works of the ditch and structure. After this suggested maintenance period, horizons H1-4 were deposited.

In this profile, it seems that most of the original in situ soil has been preserved, including the brown B-horizon (H9) and the original surface horizon (H8). If this hypothesis is correct, it implies that the soil has never experienced erosion, as the original soil appears well preserved.

The ditch of Profile A reaches approximately 70 cm below the level of the excavation and the ditch of profile B reaches about 90 cm deep. If we assume that the ditch originally was constructed to the same depth measured from the surface, it implies that the soils around profile A are missing about 20 cm of the original soilscape compared to the soils of profile B. Local erosion or levelling in the immediate surroundings of profile A and not around B could explain this difference.

2.4. THE SOIL MICROMORPHOLOGICAL STUDY OF PROFILE A

From profile A three thin sections from horizon H2, H3 and H5 were prepared (Figure 4). The soil micromorphological study was carried out by C. Nicosia (Nicosia, 2018). His observations and conclusions are synthesised below.

H5 revealed an alternating sequence of laminae composed of fine sand and silts grading to silty clay (Figure 6). This laminated aspect of the horizon indicates deposition in water, with various episodes of sedimentation with higher energy (most likely in-wash of sand during heavier rainfall events) and episodes with lower energy (standing waters with slow sediment settling). Wet conditions are also confirmed by the presence of iron and manganese nodules, indicating oxidation-reduction processes related to repeated cycles of water saturation and subsequent drying.

As a post-depositional process, we observe traces of clay illuviation. The latter indicates the action of soil-forming processes after the deposition of the sediments, in an undefined moment after the filling of the ditch. Anthropic materials are very scarce as only a few wood charcoal fragments have been observed. Phytoliths are frequent and are transported together with sediments from the surrounding area (Nicosia, 2018).

Horizon H3 differs greatly from the thin section of H5. H3 is composed of non-stratified silty fine sands with a

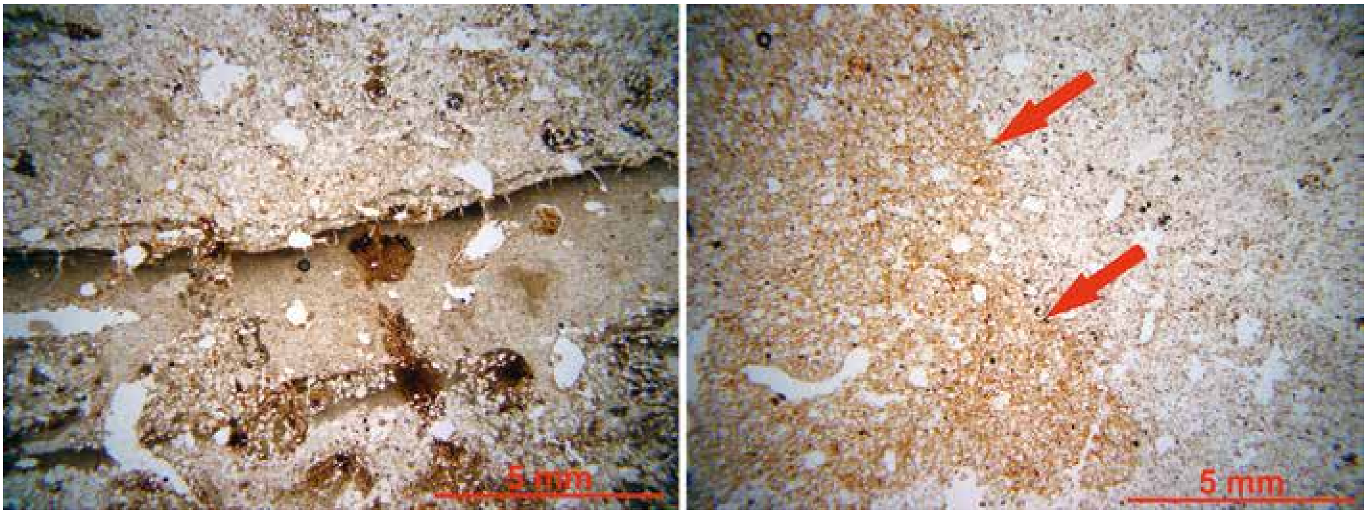

Figure 6. Left: Horizon H5 with alternating sequence of laminae, composed of fine sand and of silts grading to silty clay.

Right: horizon H3. Limit between a pedo-relic (arrows) and the surrounding sands (PPL). The pedo-relics are reworked soil fragments dug up from elsewhere and thrown in the ditch as backfill.

Figure 7. Barrow n°1: the surrounding ditch (1); intentional interruption (2); Late Iron Age cremation (4); the central pit dating in the medieval period (3); the more recent structures are delineated in black.

rather open arrangement, indicating a disaggregated and loose consistency. The lack of sedimentary structures (i.e. laminations, stratifications, grading) allows us to exclude that this layer of the ditch fill was deposited by water. Rather, the presence of pedorelics, such as fragments of soil dug up from elsewhere and redeposited here, suggests that H3 is in fact backfill. Sediments, and the soils formed on them, were therefore quarried from the surroundings and dumped back into the ditch.

The lack of indicators of oxidation-reduction processes, except for very scarce iron nodules in much lesser quantity than in H5, and of wet environmental conditions, such as the remains of algae, help confirm that H3 did not form in water. Anthropic inclusions are very scarce in H3 as well with only a few finely fragmented charcoal fragments observed.

From horizon H2 a third thin section was studied. This horizon is rather similar to H3, as it is composed of disaggregated silty fine sands devoid of any sedimentary structure. Therefore, it can be excluded that these sediments were deposited in or by water. It is interesting to observe that in this layer there are reworked iron nodules, meaning the nodules are in a secondary position. These appear to have been dug up from deeper horizons of the surrounding soils, similarly to the pedo-relics of H3. This characteristic suggests, once again, that this part of the ditch was sealed by backfill put in place by man. There are no indicators of colluvial processes which might indicate that H3 and H2 derive from the material from earthen structures inside the area surrounded by the ditch. Anthropic inclusions are very scarce and are limited to only a few fragments of wood charcoal.

3. Discussion

3.1. THE CONSTRUCTION OF THE PREHISTORIC BARROW

To create this Bronze Age barrow, a circular ditch with a diameter of 14,5 m was dug (Figure 7). At the southwestern side, an intentional interruption gave entrance to the centre of the circle. This mound was erected on a slightly sloping terrain (Figure 8). Most likely, the earth from the ditch was used to construct a hill at the centre of the circular ditch.

The five soil layers of the ditch (profile A and B: H1-H5) are continuous over its entire length. Only at the northern side, where the ditch is deeper, two older layers are preserved beneath (profile B: H7 and H7b) (Figure 5). These represent the soil present when the barrow was founded and the first use phase of the barrow and are absent at the southern side of the ditch (Figure 4). Furthermore, the horizons H8-9, associated with the soil that existed when the barrow was erected, are absent in the southern part and present on the northern side (Figure 5: H8, H9), which suggests that the site was levelled at a later stage.

The oldest layers did not contain any dateable material, therefore, it is not possible to date the foundation phase of this barrow. The four other barrows excavated in the direct vicinity of this burial mound (Figure 1) were dated using AMS ^{14}C and can be dated in the early (n°2) and middle Bronze Age (n°3-5). Therefore, it seems reasonable to assume a Bronze Age date for the fifth barrow as well.

The lower horizon H7 (Figure 5) was deposited relatively quickly. After the construction, the burial mound was largely overgrown, resulting in a strong reduction of the sedimentation rate. The organic rich composition of the upper ditch filling (H7b) confirms this hypothesis. H6 is witness to an active erosion phase. Agricultural activities, potentially preceded by deforestation, are often the direct cause of erosion. Presumably, the burial mound was constructed on a very gentle slope, where the top of the slope was levelled due to agricultural induced erosion-sedimentation also known as colluvium. This erosion phase had a larger effect on the southern side of the barrow, that initially was situated higher in the landscape than the northern part of the barrow.

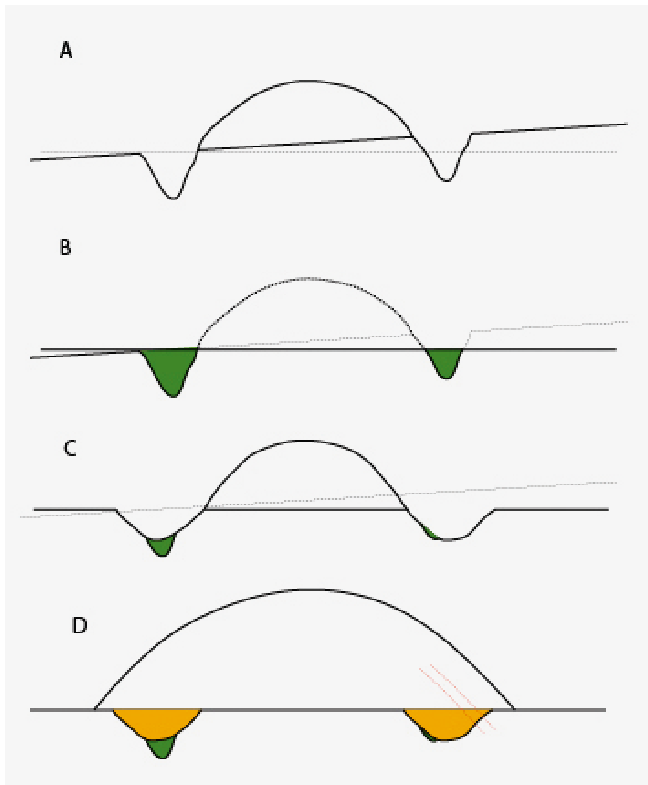

Figure 8. Schematic reconstruction of the barrow: Bronze Age foundation phase (A); erosion phase (B); Iron Age restoration phase (C); medieval re-built (D).

3.2. THE RESTORATION OF THE BARROW IN THE IRON AGE

In the Iron Age, the eroded barrow and circular ditch were restored. The new ditch was 1.4-2.0 m wide and had a depth ranging between 0.5 and 0.7 m over its entire length. This constant depth indicates that the originally sloping terrain was probably already levelled by this time. The entire ditch and its interruption were re-dug at the exact same location as the Bronze Age barrow, indicating that it was a restoration of the Bronze Age monument, rather than the creation of a new barrow. The pattern of soil sequences on the south side (Figure 4) indicates that the extracted soil was used to build the central mound.

To reconstruct the surrounding vegetation, soil samples from this restoration phase were analysed botanically. Unfortunately, neither pollen nor macro residues were found, but it was possible to select a sample for 14C dating (Van Beurden et al., 2017). AMS 14C dating of a charcoal fragment (cf. Prunus spinosa) from this restoration phase (RICH-23621, 2σ) yielded a date between c. 750-390 cal BC. This large age interval results from the so-called 'Hallstatt plateau' of the calibration curve.

In yet a later phase, during the late Iron Age, a cremation burial was added to the barrow. For this, a pit was dug, slightly asymmetrically, within the burial mound. Besides abundant charcoal, this pit only yielded some burnt pottery and a few grams of cremated bone, belonging to an individual older than 5 years. AMS 14C dating of a charcoal fragment (cf. Pomoideae) from this cremation grave (RICH-23622, 2σ) yielded a date between c. 380-190 cal BC.

3.3. ROMAN SETTLEMENT

The remains of a settlement consisting of at least 14 houses were found at less than 50 m from the barrow, dating from the late Iron Age to the Roman period. Pottery related to this occupation was found in horizon H5, indicating that the ditch was still functional, and the barrow was left untouched. A burial ground with at least 85 graves, contemporaneous with this settlement, was organised around the largest Bronze Age barrow (Figure 1, barrow n°4).

3.4. MEDIEVAL PERIOD

The youngest sediments of the barrow ditch (H3, H2 and H1) consist of a mixture of sediments (humus-rich greyish-, brown clayey-, and sandy pale sediments). The large heterogeneity of these upper 3 horizons suggests that the sediment was moved several times. Micromorphologically, they show inclusions in the soil matrix that indicate that the ditch was consciously filled with material that was dug elsewhere.

It is still not clear when the eventual infilling of the ditch took place. The Roman pottery in layer H5 indicates that this must have happened during or after this occupation phase. Sequences of thin migrated clay layers were noticed at the south side of the ditch (Figure 4 and 9). These are related to a larger structure that superimposed over the Iron Age burial mound. Based on the location of these layers at the outermost part of the ditch, this new mound must have been larger than its predecessors. Centrally in this new mound, a round pit of 2m diameter was

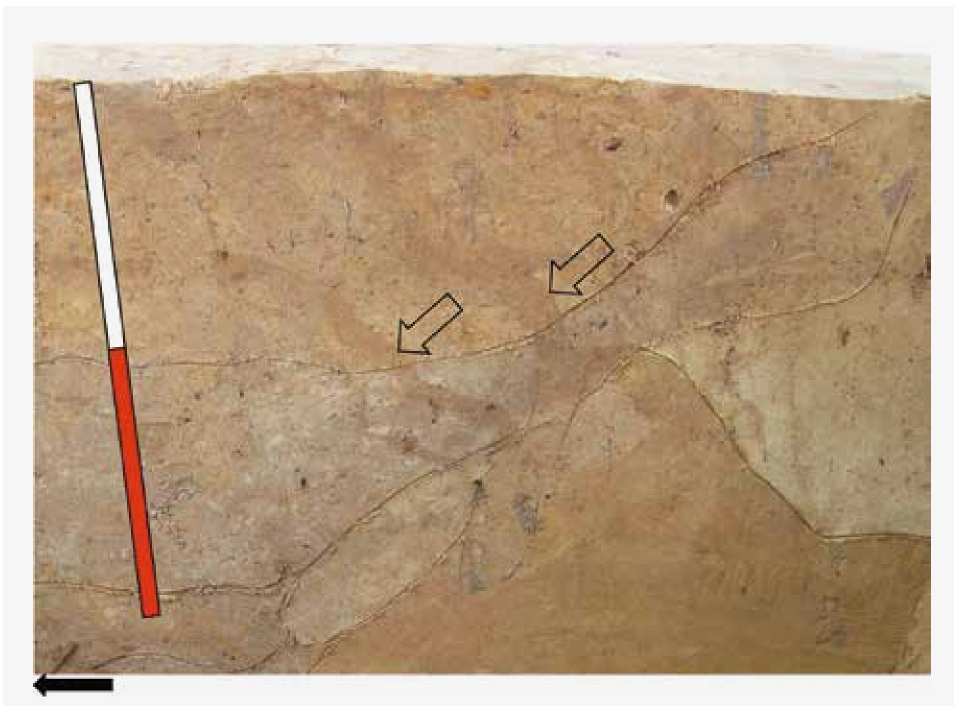

Figure 9. Photo of the clay migration bands (thin hollow arrows), which are younger than the sediments that covered and filled up the Iron Age burial mound and circular ditch. These gentle sloping migration bands suggest a soil body located above, having the same slope angle as the migration bands (black arrow: centre of the barrow).

dug, destroying a large part of the late Iron Age cremation. In this pit, pottery dating to the High Middle Ages was found together with strongly decomposed brownish organic matter. The latter could be from decomposed bone material.

The reason why this medieval mound was created remains unclear. The map of Ferraris (1770-1778) provides a first hypothesis. The hamlet where this site is located is marked as 'Grae Molenhoeck', which means mill corner. Historical data (Santy, 2008) confirms that in the Late Medieval /Early Modern Period at least three mills where located some 100 m in a northern direction. It is possible that a predecessor of these mills was situated on this site.

Another hypothesis is that the mount was re-used as a gallow hill. Several excavations in the Netherlands have shown that prehistorical barrows were re-used in medieval periods as execution sites or sites for displaying the bodies of executed individuals. The location of these gallows is important, because they are not only used as an execution area but also as deterrents (Meurkens, 2010). Therefore, visibility is (as in the Bronze and Iron Age) important. The round pit in the middle of this hill could be interpreted as a bone pit where the remains of the deceased were buried. Phosphate samples were taken and may confirm that the decomposed organic matter in the pit is the remnants of bone. These analyses still need to be performed.

3.5. THE CHRONOLOGY OF THE *BURIAL MOUND*

During the archaeopedological fieldwork, we realised that this prehistorical burial mound has a complex history. Detailed field observations in combination with a soil micromorphological study and a thorough archaeological excavation were combined in order to build up the chronological sequence of events that lead from the initial structure to the present-day situation. The following hypothesis are made as to how the prehistorical burial mound was founded and how the structure changed over time:

1) The structure was erected during the Bronze Age. The field evidences include a circular ditch of up to 100 cm depth below the excavation surface. The diameter of the circular ditch is 14.5 m and includes an opening towards the southeast
   a. we have no information what the structure looked like within the circular ditch, but it was not a pit or a depression. Most likely, the earth from the ditch was used to construct a barrow at the centre of the circular ditch;
   b. probably instantly after the ditch was constructed, sediments started to accumulate at the bottom of the ditch. The erosion phase would last until the barrow was covered with vegetation, as a vegetation cover will offer (some) protection from sheet and rill erosion;
   c. small scale maintenance during the Bronze Age period of the structure is not excluded, but this was not recorded in the ditch filling.
2) By the Iron Age, the ditch was probably almost filled with sediment. At this moment, the barrow was renovated, which included the re-opening of the ditch. The new ditch was wider and less deep (about 65 cm below the excavation surface) compared to the original ditch.
   a. after the ditch was re-opened sediments again started to accumulate at the bottom of the ditch forming H6; this indicates that erosion-sedimentation was possible in the immediate surroundings of the ditch:
      i. either because the vegetation cover was deliberately removed from the structure inside of the ditch or from the soils outside of the ditch, or
      ii. the earth excavated when the ditch was re-opened was used to restore the structure, allowing soil erosion to occur until the barrow was again protected by vegetation.
   b. H5 indicates a phase of relative stability with slow input of sediment into the ditch. The micromorphological study suggest that H5 was deposited by water and that oxido-reduction, at least for some periods, must have prevailed in the ditch, probably during the winter and early spring.
3) In the Late Iron Age a cremation burial was added to the structure, fragments of pottery and bone testify that a person of 5 years or older was cremated and buried.
4) Towards the end of the Iron Age period and during the beginning of the Roman period, a settlement was founded about 50 m from the barrow. Pottery fragments related to this settlement were excavated from H5. Evidently, we can conclude that the ditch and probably the entire structure was still visible in the landscape in this period.
5) Somewhere between the period of the Roman settlement and the High Middle Ages, the ditch was deliberately filled with material from elsewhere and a new larger hill was constructed.
   a. both the field studies of the horizons H1-3 and the micromorphological study suggest a fast filling of the ditch with heterogeneous material and containing pedofeatures that must have come from elsewhere. There are no traces of colluvium observed in the thin sections, so possibly the ditch was filled in a very short period (few days to few weeks?).
   b. clay migration bands superimpose the infilled ditch sediments, with a completely different

orientation than the sediments of the ditch. Based on the oblique orientation of these migration bands, it is suggested that the orientation to a certain extend reflects the form of the newly erected structure.

i. this implies that the new barrow or hill must have covered the entire prehistoric monument, including the ditch and beyond.

6) During the High Middle Ages, a round pit with a diameter of 2 m was dug out centrally in the new structure. The age of this pit was based on findings of pottery in the pit.

7) Somewhere between the High Middle Age and modern time, the entire structure was levelled, most probably to facilitate an optimal agricultural production of the field.

a. the historical map from the 18th century (Ferraris) shows no signs of a mound at or in the vicinity of this site. This indicate that the mound was probably gone by that time.

4. Conclusions

During the excavation of a Bronze Age barrow, the archaeological research and the ceramics testified to a more complex history than initially expected. By including detailed soil observations and soil micromorphology, more information was gained, which allowed the establishment of a comprehensive chronology of the structure and its immediate surroundings.

In today's landscape of Flanders, prehistoric barrows have almost disappeared. Yet, in this study we have been able to unravel a structure that was kept in place for centuries, maybe a half millennium, before it was transformed and possibly given a new function. Although the only remains of the initial barrow were the infill of its surrounding ditch, very valuable information could still be deduced, which gave numerous insights into the sedimentary history of the monument, both natural and anthropogenic.

The detailed study of the infill revealed a Bronze Age barrow which remained visible at least until the High Middle Ages. During its life cycle, the rather small barrow was restored and remodelled, but remained a distinct part of the landscape.

At a first glance, this appeared to be yet another routine archaeological excavation. But, this project and some other recent studies (Beke et al., 2018; Deconynck et al., 2018) show that an interdisciplinary approach of these burial mounds delivers a valuable addition. Adequate sampling for micromorphology is therefore strongly recommended for future excavations of these kinds of prehistoric structures.

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CURBING THE TIDE

The discovery of a Roman terp along the Heistlaan in Ramskapelle (Knokke-Heist)

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ABSTRACT
Archaeologists have long struggled trying to understand the nature of the Roman-period occupation of the coastal plain of Flanders. From the start of the 21st century, following academic and development-led projects, knowledge on the nature of the Roman occupation in the coastal plain has gradually been expanding. To assess the possible destruction of archaeological remains in the area along the A11-highway connection between Damme, Knokke-Heist, and Bruges, a different methodology was implemented. This resulted in the discovery of a 2nd to 3rd century AD site along the Heistlaan in Ramskapelle (Knokke-Heist). Based on geo-archaeological and sedimentological observations, coupled with micromorphological data, the site is interpreted as an artificial dwelling mound or terp. This discovery is a significant step in understanding the impact of human activities on the landscape in the coastal plain. The results help reinterpret older excavation data and aid future research projects.

KEYWORDS
Roman archaeology, coastal plain of Flanders, terp, soil science, micromorphology

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1. Introduction

For decades, understanding of the Roman occupation in the Holocene coastal plain of the Civitas Menapiorum (the most northern district of the Gallia Belgica Province) has lagged behind the knowledge of the higher-lying Pleistocene sandy area bordering the coastal plain. This resulted from a lack of insight into the link between human occupation and complex landscape evolution. Deposits of tidal flat environments and peat beds form the core of the coastal plain. The dynamic character of these sedimentary environments caused frequent changes in the landscape. Hence, it is not always obvious to pinpoint archaeological findings within the stratigraphic context of a site. Based on -the currently abandoned- models of transgression and regression, academic studies struggled for decades to interpret the occurrence of Roman period finds that were seemingly deprived of any clear context in the coastal area. These finds were often interpreted as the results of non-permanent occupation or off-site activity (Thoen, 1978, 1987; Pieters, 1996; Ervynck et al., 1999 and 2000). However, a scarcity or obscurity of data, does not necessarily mean that the coastal plains were a Roman no man's land. On the contrary: classical sources and isolated finds indicate a thriving economy, centred on salt production (Thoen, 1986; De Clercq, 2011,). Building on the increasing (geo)archaeological evidence available in the region (Baeteman, 2007; Baeteman et al., 2015; Baeteman, 2016) and a comparative analysis of excavated features in the adjacent Dutch side of the Menapian coastal plain, three possible forms of Roman habitation locations in the coastal plain can be put forward: 1) on outcropping Pleistocene sand ridges or on Pleistocene sand covered with a thin peat bed; 2) on artificially raised platforms; 3) on drained peat bogs (De Clercq, 2009, 215-217).

The construction of the A11, a 12 km long highway connection between Bruges, Knokke-Heist, and Damme, presented the perfect opportunity to test these hypotheses in the field in one micro-region of the Menapian civitas, located north of Bruges. Previous watching-briefs of infrastructural work in the area pointed to the presence of Roman-period salt-making (Hillewaert et al., 1987; Hollevoet, 1998 and 1989). The 19th century find of a Roman sea-going ship at Bruges (Vlierman, 2011, 49-50) implies a navigable sea-way crossing the area from Bruges towards the sea.

From 2008 till 2014 Raakvlak, Archaeology, Monuments and Landscapes of Bruges and Hinterland, was tasked with the archaeological survey prior to the construction of the A11 highway connection. Archaeologists and soil-scientists joined forces to pioneer a new approach, better adapted to the complex stratigraphy of the coastal plain. In 2013, this project resulted in the discovery of a small Roman settlement on top of a buried sandy ridge. The discovery of the settlement, consisting of a house and a well, along the Zonnebloemweg in Dudzele (Bruges) proved to be the first possible form of habitation (Hollevoet et al., 2019, 59). Additionally, a salt-production site is located on the flanks of this ridge.

In 2014 the second possible form of habitation in the coastal plain of Flanders was detected. On a field along the Heistlaan in Ramskapelle (Knokke-Heist) an artificially raised dwelling mound or 'terp' dating from the 2nd and 3rd century AD was discovered (Verwerft et al., 2019). The term 'terp' comes from Friesland and describes an artificial living platform, providing a dry living space at high water levels (Hendriks, 1996). Located on top of the terp, traces of a small-scale settlement were found consisting of five sod houses with sunken floors. The finds date the site between 175 and 250 AD. The site yielded the largest collection of Roman pottery so far encountered in the whole of the Bruges area. Some very rare metal and glass objects, as well as the archaeozoological remains, seem to point to a high, or at least to a quite deviating, status of the site and its inhabitants.

This paper focuses on the geo-archaeological and sedimentological field observations that led to the discovery of this Roman-period terp. It also presents the micromorphological data supporting the research and proposes guidelines for future fieldwork.

2. The A11-project: pioneering a geo-archaeological approach

This particular part of the eastern coastal plain north of Bruges is characterized by two distinct lithological sequences or soil types according to the pedological map: 1) a sequence consisting of Pleistocene sand overlain by peat and tidal-flat sediments and 2) sand-filled tidal channels, hereafter called gullies (for an in-depth overview of the Holocene geology of the Belgian coastal plain see Baeteman, 2018.). To assess the archaeological impact of the construction of the A11 highway connection, a strategy better adapted to this particular geological situation was implemented.

The first step is mapping the location of the sand-filled tidal channels in the so-called 'geulenkaart' or gully-map. The map is based on the study of Quaternary geological data, the land register, and the digital elevation model (Hillewaert et al., 2018, 5-7). As the map depicts the contrast between the two distinct lithological sequences, it serves as a tool to guide archaeological research (Lambrecht et al., 2017, 4-5). At the location of the gullies, where the original deposits have been deeply eroded, possible prehistoric to Roman sites have disappeared. As the archaeological surface is situated right underneath

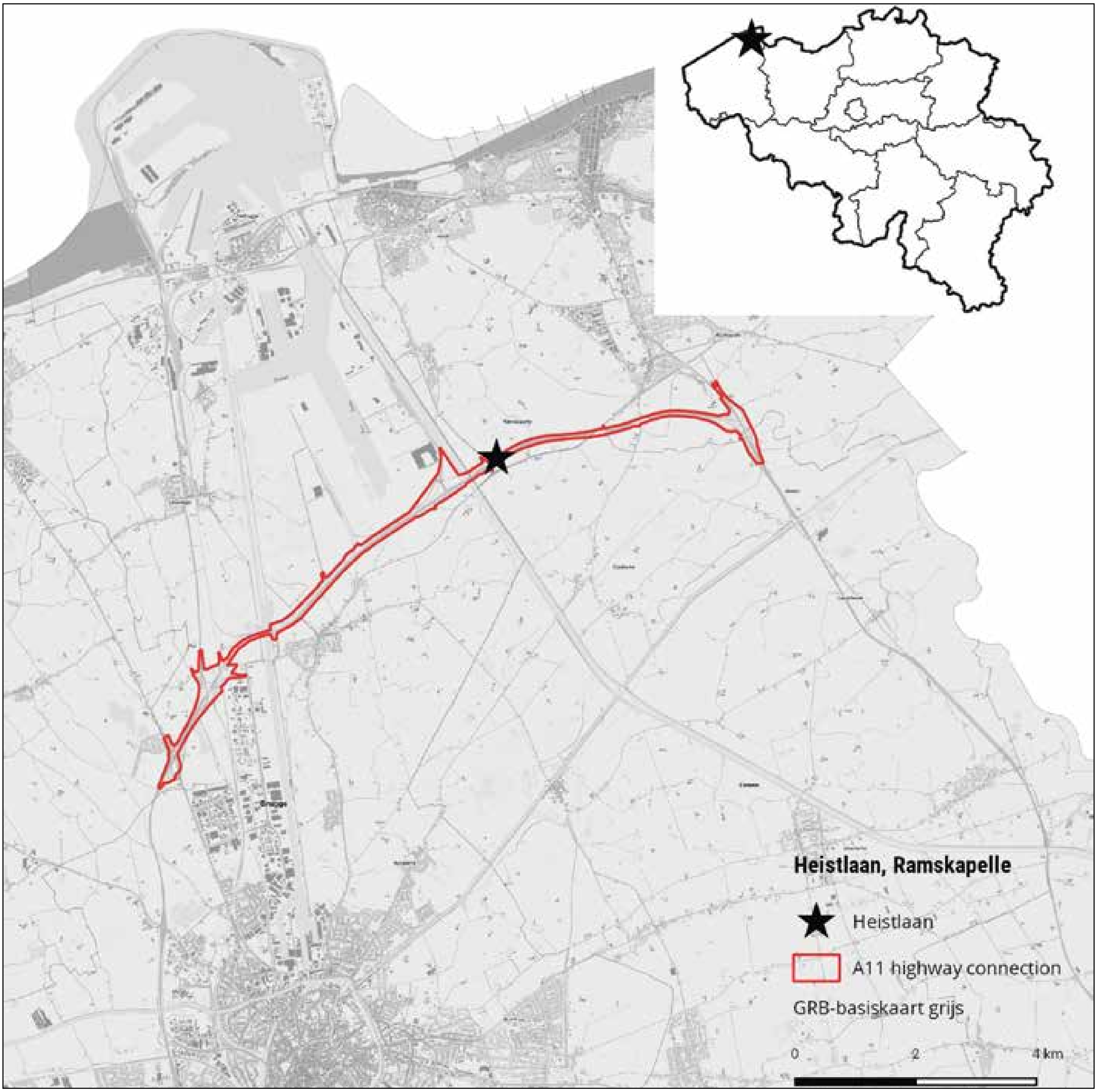


Figure 1. The location of the A11-highway connection and the site Heistlaan (star) indicated on the GRB-map (AGIV).

the ploughing soil, a combination of fieldwalking and trial trenches is the optimal method for detecting sites.

In the zones in between gullies, where the original stratigraphy is preserved, there are multiple archaeological surfaces, each potentially containing sites from the prehistory till the Middle Ages. The recent discovery of a late-Neolithic arrowhead on top of a peat layer in Koolkerke, just north of Bruges made this amply clear (Verwerft et al., 2018). In these zones a manual auger survey is needed to assess the basic landscape morphology and state of preservation, followed by an intensive, archaeological auger

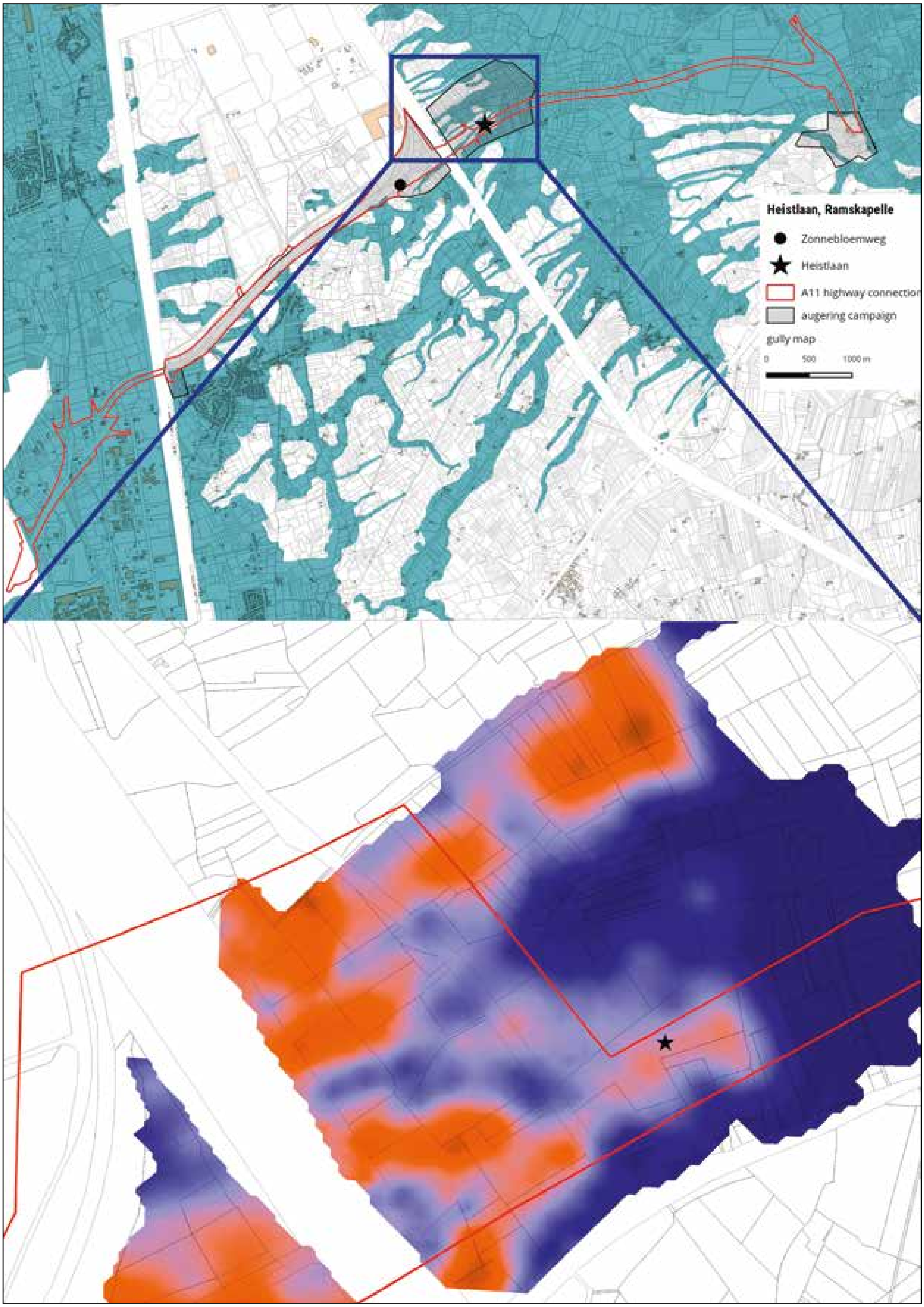


Figure 2. The location of the A11 indicated on the gully map and an interpretive map of the borehole survey (blue: gully, brown: conserved peat, orange: extracted peat).

survey if a well-preserved palaeo-landscape is discovered. This method has been introduced and refined in Flanders by Prof. dr. Philippe Crombé to detect prehistoric sites (Verhagen et al., 2011; De Clercq et al., 2011). In 2015, at the start of the next big project in the coastal plain, the Stevin power line, stepped trenches were introduced to evaluate different archaeological surfaces in one trench (Cruz et al., 2013, 60-61). Following positive test cases in the Belgian coastal plain (De Smedt et al., 2009; Delefortrie, 2012), it is clear that a geophysical prospection aimed at mapping buried landforms forms an (cost-)effective method to guide an auger survey.

3. The discovery and excavation of a Roman site along the Heistlaan in Ramskapelle

During the auger survey of the A11-project 712 boreholes covering an area of 212 hectares were carried out. Around the Zonnebloemweg in Dudzele, the research revealed a strongly pronounced palaeo-landscape with sandy ridges and hollows filled with peat. In prehistoric times, this Pleistocene landscape presented itself as a suitable location for an encampment. A subsequent, intensive auger survey and four small-scale excavations yielded the first fully recorded prehistoric site in the coastal plain (Verwerft et al., 2016; Noens et al., 2018). The open-area excavation also revealed a small Roman settlement on top of the sandy ridge.

Along the Heistlaan in Ramskapelle, the auger survey showed buried soils varying between silted up gullies and peat covering Pleistocene sand. The terrain borders a more than 1.5 km wide complex of silted up gullies. Several smaller gullies branch out in a southwestern direction. Extensive peat extraction and sparse patches of a well-conserved peat layer characterise the areas in between these gullies. As the original stratigraphy has almost completely disappeared, trial trenching is the logical next step in the research campaign.

The trial trench evaluation of the terrain yielded an unexpected, positive result. The archaeologists discovered enigmatic Roman traces buried under a 10 to 40 cm thick topsoil: ditches, pits, waste layers, and a possible artificially raised mound. The team gathered a large amount of pottery dating from the 2nd and 3rd century AD. An excavation was needed to better understand the nature of this settlement and subsequently improve our understanding of this complex landscape.

According to the Belgian Soil Map the terrain is located in 'peat extracted areas' (OU2). From an agricultural perspective, this type of soil is considered of a lesser

Figure 3. An aerial view of the excavation along the Heistlaan in Ramskapelle (Knokke-Heist).

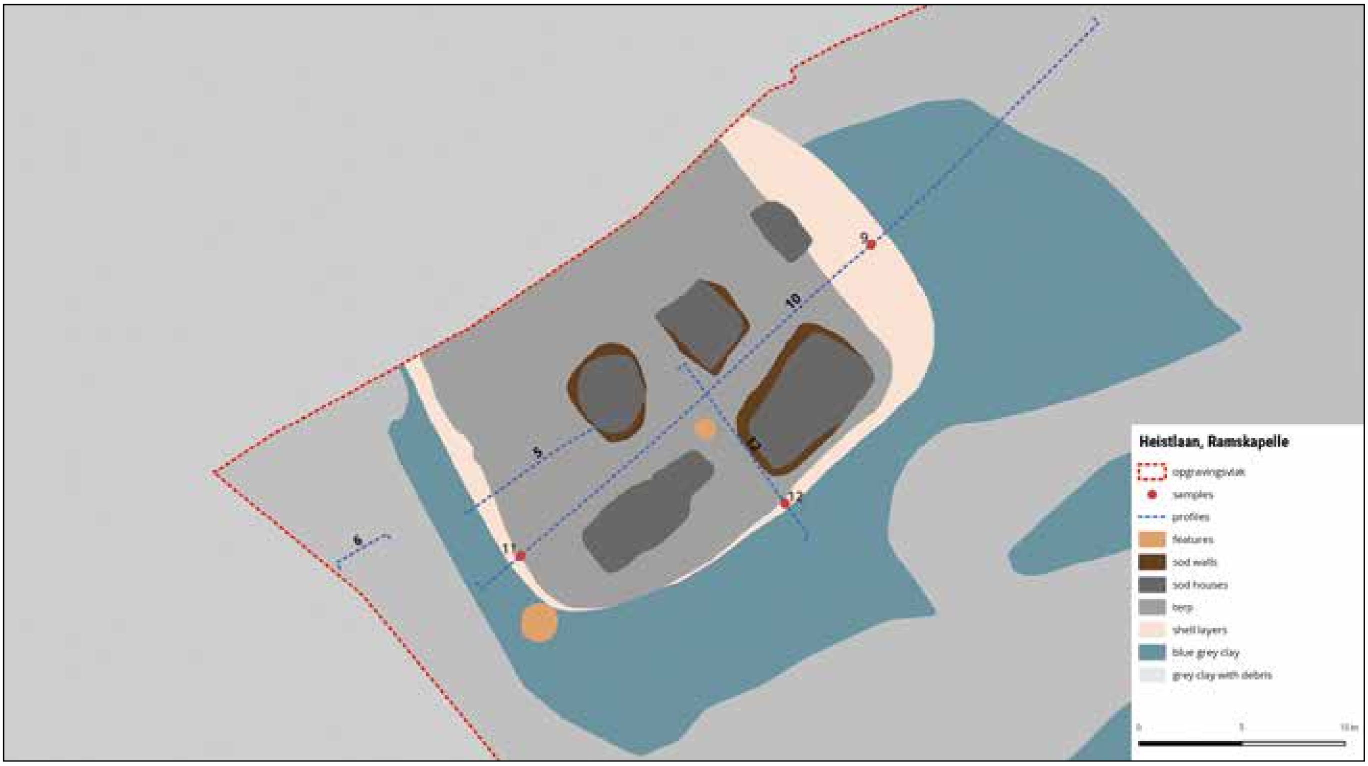


Figure 4. The location of the profiles and micromorphological samples discussed in this paper indicated on the excavation plan.

quality. But, from an archaeological viewpoint such a terrain is of significant value: here older traces are potentially conserved, safeguarded from the erosion by gullies. The Belgian Soil Map depicts stretches of 'covered creek ridges' (D5) north and south of the terrain. These reflect the smaller gullies branching out of the big gully in a south-western direction. The elevation of the terrain varies from +230 to +263 cm TAW (*Tweede Algemene Waterpassing*). During the investigations, the terrain is used as a pasture.

During the summer of 2014, an area of 2 203 m² was excavated. The excavation resulted in the discovery of 26 Roman features and no less than 14 328 artefacts. To better understand the archaeological site and its relation with the surrounding landscape, the team registered 14 soil profiles. The most important profiles are discussed in detail in the following chapter.

4. The geo-archaeological observations

4.2. PROFILE 6: THE SURROUNDING LANDSCAPE

Profile 6 gives an overview from the Pleistocene subsoil to the present-day surface. It serves as a witness of the landscape prior to, during, and after the Roman occupation of the site. The profile is marked by three distinct units. The lowest unit consists of Pleistocene light grey cover sands (H11). There are no traces of soil development in this substrate. Following the sea-level rise (although at a reduced rate), the groundwater table rises. The site became humid and -compared with data in other regions- peat growth probably started around 6000-5500 cal BP (Baeteman, 2018).

A 220 cm thick peat layer between -153 cm TAW and +75 cm TAW overlies the Pleistocene sand. This marks the second unit of deposition. Originally, the peat layer was much thicker. Due to drainage, the peat layers in the coastal plains have compacted. The drainage could have been caused by the scouring of tidal channels with the return of the tidal system in the late Holocene (Baeteman, 2005). Another possibility is human intervention: the peat bog could be drained for better accessibility.

Situated on top of the peat, is alternating cm and mm-layered sand/silt and clay with peat detritus originating from the erosion of peat (some cm or mm wide), deposited within a tidal bedding (H7-H4). In a tidal bedding, silt and sand are deposited at flood- and ebb-current, while mud with peat detritus is deposited at turning tide and no current (see Baeteman et al., 2015 for examples). The absence of cross-stratification -pointing to a high-energy environment- and bioturbations from bottom-dwelling animals suggest a deposition in a shallow gully. The filling of a shallow gully can happen relatively fast, within a few months. On top lays the transition from the shallow

Figure 5. Profile 6. In the two pictures on the right, the upper part of the profile was damaged by the excavator.

gully to a mudflat (H3). The transition from mudflat to salt marsh is situated at the next boundary (between H3 and H2). The topsoil (H1) is developed in these salt marsh sediments.

4.3. PROFILE 5: THE ROMAN TRANSFORMATION OF THE LANDSCAPE

This profile is studied in a southwest to northeast oriented trench. Both the side and the plane of the trench have been registered. Within the profile are three distinct parts. They are discussed here form the southwest to the northeast.

Based on three augerings in the surface of the trench, this profile is situated above a 100 cm thick layer of peat and 85 cm of sand and clay. The top of the peat layer varies between +85 and +115 cm TAW.

4.4. PROFILE 5: PART A TO B

The first horizon (H1) is formed by light grey sediment with patches of iron oxides. The sediment, formed in a shallow gully, shows a distinct stratification of alternating layers of light gray, silty to fine sandy sediments and darker, more clayey sediments. Very strikingly, the stratification is not continuous. In the horizontal plane, this discordant stratification is clearly visible. This indicates that the originally horizontal lamination is no longer *in situ*. The length of the divergent stratigraphy and the discordant pattern indicate displaced blocks of sediment. The sides of the block vary between 20 and 40 cm. The clay blocks were stacked, creating a 250 cm wide and 91 cm high wall, encompassing a surface of 367 m². Horizons 2 to 7 are found on the inside of this wall, forming an artificial platform or terp. The top of the terp varies between +241 and +260 cm TAW.

Horizon 2 (H2) consists of greyish clay, lacking stratification. This absence of stratification can be explained by a lack of stratification in the parent material. Horizon 3 (H3) has a clayey texture, rich in humus. The layer has been carefully placed on horizons 1 and 2. The horizon was exposed for a relativly short period, possibly a couple of weeks. Abundant precipitation caused a sorting of the soil: light grey and beige, silty sediments run parallel to the mound.

4.5. PROFILE 5: PART B TO C

The next horizon (H4) connects to the previously placed blocks, thus creating a terp. The outlines of the displaced blocks are clearly visible: the stratification is no longer *in situ*. Horizon 5 (H5) is less clayey, with a less pronounced stratification. Its deposition, during a period of abundant precipitation, is comparable to horizon 3 (H3). This causes a sedimentary stratification parallel to the wall. In some horizons (H1 and H4), the blocks are placed one upon the other in alternating directions. This creates a very recognizable checkerboard pattern. In other horizons (H3), all blocks are placed at an angle of 45°.

4.6. PROFILE 5: PART C TO D

Horizon 6 (H6) is a relatively wide, clayey layer, completing the sequence of clayey fill layers. The layer is, again, characterised by a distinct pattern of discordant stratification, proving that this material is displaced to create a terp. The innermost horizon (H7) differs from the previously deposited layers. It consists of silt with little clay. A possible explanation for this distinction is a careful selection of material with a coarser texture. This leads to a better permeability of the soil, avoiding flooding of the mound after heavy showers. The irregular border between horizons 6 and 7 points to the fact that they were placed shortly after one another.

4.7. SUMMARY OF THE GEO-ARCHAEOLOGICAL OBSERVATIONS

The Roman settlement along the Heistlaan in Ramskapelle is situated at a favourable position in the Holocene landscape: at the edge of a large complex of tidal channels connecting the Pleistocene coastal hinterland to the sea and hence, connecting it to the rest of the Roman Empire. The large complex of gullies runs along Heist over Koolkerke towards the Roman harbour at Fort Lapin in Bruges. From these large channels, several smaller gullies branch out in a south-western direction.

The soil at the site was studied during the augering campaign, the trial trenching, and the excavation. Within the study area, the Pleistocene cover sand surface is preserved. A 220 cm thick peat bed overlays the Pleistocene sand. Originally, this layer was much thicker, but it has since then compacted. Only scattered patches of this layer are fully conserved: the augering campaign reveals intensive peat extraction in the area between the gullies. The sediments on top of the layer of peat were deposited within a shallow gully.

Profile 5 yields the most remarkable observations. The profile is marked by a discordant stratigraphy, visible in the horizontal plane. The original horizontal stratigraphy formed in a shallow gully is no longer *in situ*. The shape and dimension of the discordant stratification are a clear indication of the displacement of the blocks. These blocks have been dug out elsewhere and placed on the site. The oldest layers form a wall. Subsequent layers of displaced blocks are placed against this wall, creating an artificial dwelling mound or terp. Some of these layers have been exposed for some time: the building of the mound probably took several weeks or longer. The inner layer differs from the outer layers. This layer is made up of a coarser material with little clay: this provides a better permeability of the soil, enabling effective water management.

The landscape in the period of Roman occupation at this location most probably consisted of peat at the surface and small areas already affected by tides. This period is characterised by the renewed tidal extension with the formation of tidal channels, which progressively penetrate the plain. Before the construction of the terp, the peat bog was intentionally drained and added to through intensive peat extraction in the surrounding areas, the peat bog has been de-watered and consequently compacted. This caused a lowering of the landscape. The lowering, in turn, provided an accommodation space for the deposition of tidal sediments. At this location, interlaminated sand and mud with peat detritus formed in a shallow gully. The thickness of the deposit and the small amount of tidal bundles (representing a fortnight), with almost no reactivation surfaces, suggest that the gully silted up in a period of a few months. These deposits have to have been excavated somewhere else to build the terp. An almost similar situation was found at Raversijde (Oostende) (Baeteman et al., 2015). Here, laminated gully deposits were used to build a dike or a causeway.

These observations indicate a well-planned and

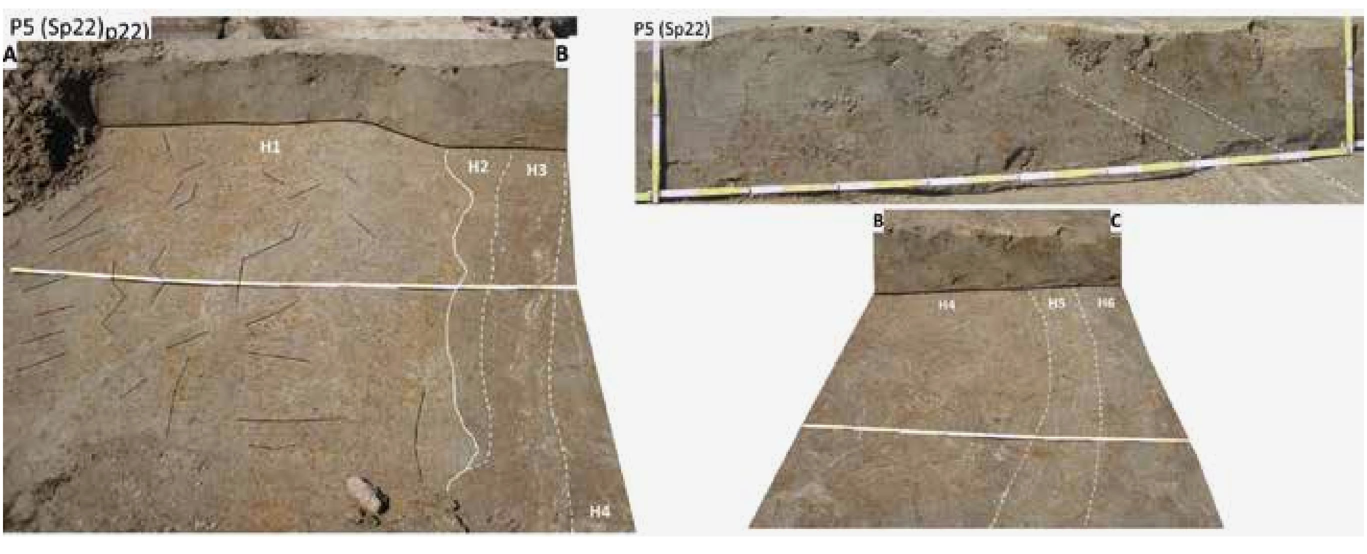


Figure 6. Profile 5.

well-organised construction. On top of the tidal sediments a 367 m² large and 91 cm high terp was created, between +241 and +260 cm TAW. According to a conservative estimation, over 330 m³ of soil has been displaced. As silt and clay weigh about 1.7 metric tons per m³, about 567 tons of soil must have been moved. Assuming the soil contained 10 % water, this adds another 33 tons, bringing the total weight of the transported soil to roughly 600 tons. The terp can only be constructed from ripe soil, meaning only the top 20 cm of the surrounding soils could have been used. This implies that an area of 1 650 m² was stripped from its topsoil. On top of that, the textural difference between the clayey, sturdy outer rim and the coarser, permeable inner side point to the careful selection of the material.

Also observed, are layers of clay containing large amounts of mollusc shell fragments. These layers, 2 to 8 m wide, were recognised all around the terp. These are very probably reinforcing layers, deposited after the building of the terp, rather than waste layers. Based on several overcuts by structures, these layers have effectively enlarged the living space on top of the terp. An alternative or additional explanation is the added visibility of the white shells, making the terp a landmark in an otherwise flat landscape.

The terp creates a patch of land permanently above the water level. After the silting up of the large complex of gullies, the reclamation of the coastal plains and the compacting of the peat, the site was in a low position in the landscape. Because of the lower position, the terrain has never again been suited for settling and was only used as pasture. This has safeguarded the archaeological remains for centuries.

5. The micromorphological data

During the excavation, the team collected undisturbed soil samples for micromorphological research. The location of the samples was carefully chosen to answer questions regarding the landscape prior to the construction of the mound, the transition from natural to anthropogenic layers, and the post-site deposits. Three sequences were selected for thin sections.

The micromorphological research is executed by Sara Pescio (Pescio, 2019) of the Quaternaria di Pescio Sara Micromorphological Services. The samples were transported as in situ oriented blocks. After drying, all pores were filled and all soil particles fixed by using a polyester or epoxy resin. After hardening, the samples were cut, thinned, and polished until the standard thickness of 30 µm (micron) was reached. Thin sections were studied under the petrographic or polarizing microscope and described using the terminology and concepts introduced by Georges Stoops (2003). The most important findings are discussed here per sample, from bottom to top.

Figure 7. A drone shot of the discordant stratigraphy in profile 5.

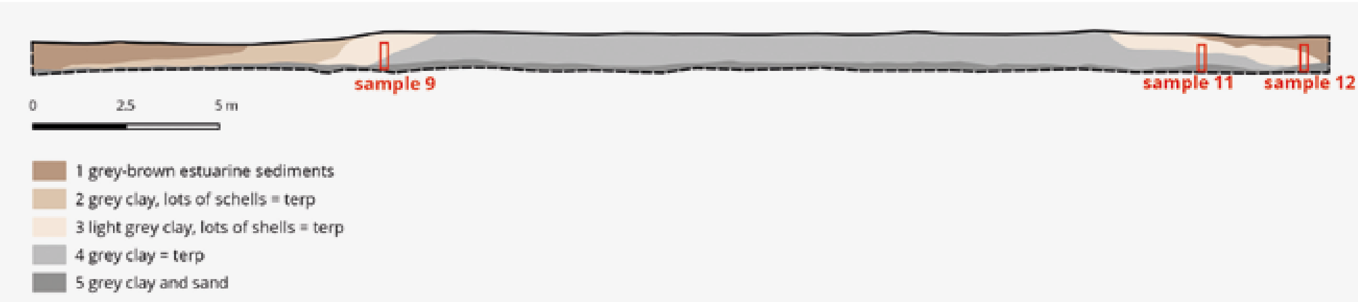


Figure 8. An abstracted location of the samples discussed in the micromorphological study indicated on profile 10.

5.1. SAMPLE 9

The first sequence to be discussed is sample 9 from profile 10. This sample was collected at the north-eastern edge of the mound. The main focus of this sequence is the transition from *in situ* estuarine sediments to the anthropogenic layers of the mound. From this sequence, four thin sections were analysed.

The bottom half of this sample contains two superimposed layers. The features present in the bottom layer point to sediments deposited in a tidal environment. The presence of sponge spicules and diatoms indicate wet conditions and water stagnation. The upper layer consists of alternating laminae of peat and of sandy silt minerogenic sediments. The presence of diatoms remains and Chrysophycea stomatocysts, abundant horizontally-aligned plant fragments, and the laminated aspect of the sediments testify that this unit originated from marshy or palustrine conditions, but was transported by currents and deposited in a shallow gully characterised by tidal bedding. The section contains no anthropogenic elements.

The upper layer contains the same elements (algal remains and iron features) as the bottom half, but the laminated aspect has disappeared. This leads to the conclusion that this material has been displaced. The sediments were deposited *in situ* in a marshy environment, later they eroded and were transported and eventually displaced in the Roman period to this location. The upper part of this sample contains a widespread amount of mollusc shell fragments.

5.2. SAMPLE 12

The second sequence is situated on the south-eastern edge of the mound. Three sections within this sequence were investigated. The sequence covers the transitions between the mound, the layer with shell fragments, and the post-site clay deposits.

The bottom part of this sample is composed of displaced sediments. In contrast to the previous sections, this layer contains a large amount of anthropogenic elements. Within the sections, fragments of charcoal, bone and eggshell could be recognised. The section contains sparse fragments of mollusc shells. Iron nodules point to wet conditions and hydromorphic processes. The top part of this layer shows more evident traces of bioturbation. Charcoal and bone fragments are the result of an anthropogenic presence. Mollusc shell fragments are more abundant than in the lower zone of the sequence.

The upmost part of the sample is characterised by a decrease of hydromorphic traces and indicators of human presence. The section is situated on the transition from the terp to clay sediments, deposited after the abandonment of the site.

5.3. SAMPLE 11

The third sequence is located at the south-western edge of the terp. Two sections within this sequence were investigated. The sequence encompasses the transition from tidal sediments to anthropogenic layers.

The bottom half of this sample is made up of sandy silt. The presence of diatoms, Chrysophycea stomatocysts, sponge spicules, and the lamination of the sediments point towards sedimentation processes in a shallow gully. Iron nodules suggest hydromorphic processes. No anthropogenic elements were recognised. Within the upper half of the sample, fragments of reworked material are visible, suggesting displaced material. Which is another indication of the human origin of this layer.

5.4. SUMMARY OF THE MICROMORPHOLOGICAL DATA

The micromorphological research contributes significantly to our understanding of the formation of the terp. Before the construction of the terp, the site was made up of sediments deposited in a shallow gully. Micromorphological data deliver clear proof of the anthropogenic origin of the layers described as 'terp'. These layers consist of displaced material, with characteristics strongly resembling the underlying, natural (in situ) sediments. The building blocks of the terp were probably excavated close by.

Within the layers of the terp, there is a clear distinction between the core and the edge. At the core, there are no inclusions of anthropogenic origin, while these are

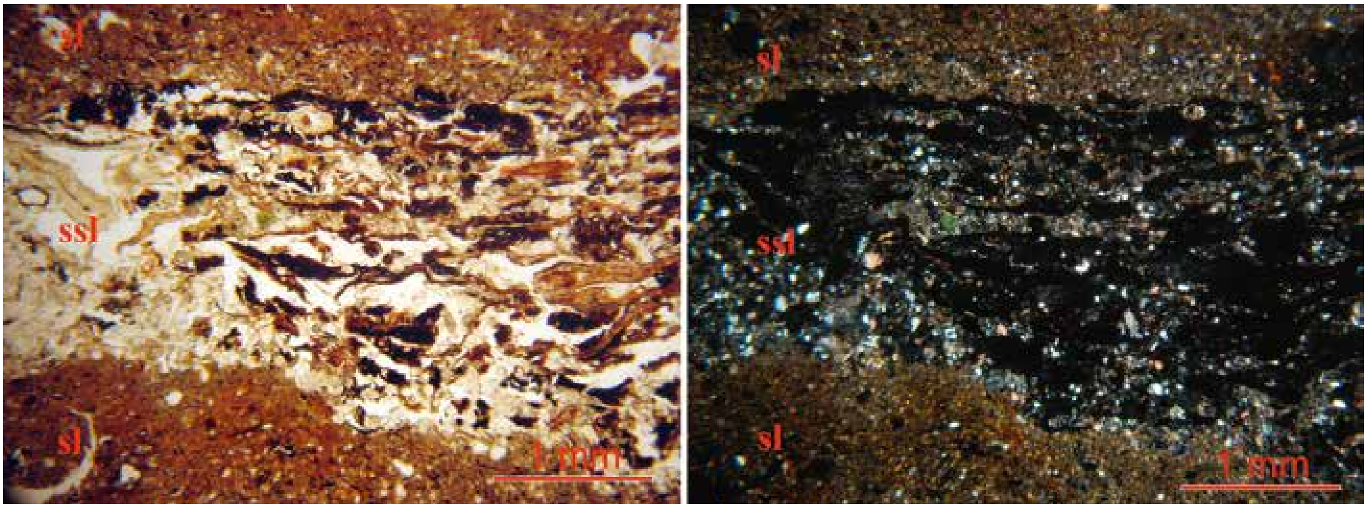


Figure 9. The alternation of silt loam (sl) and sandy silt loam-textured micro-layers (ssl) including abundant plant residues. The laminated aspect of sediments and the horizontal alignment of the organic remains suggest a palustrine/marshy environment with alternation of higher and lower energy periods. Thin section 39664. PPL and XPL (Pescio, 2019, 10).

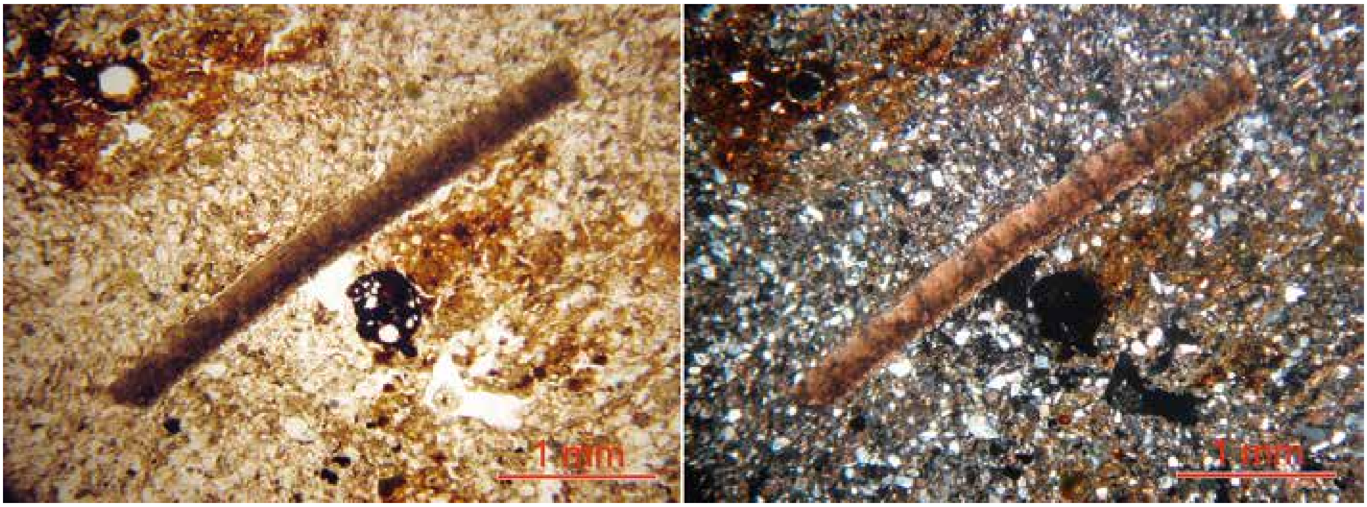


Figure 10. Anthropic indicators: an eggshell fragment. Thin section 39667. PPL and XPL (Pescio, 2019, 12).

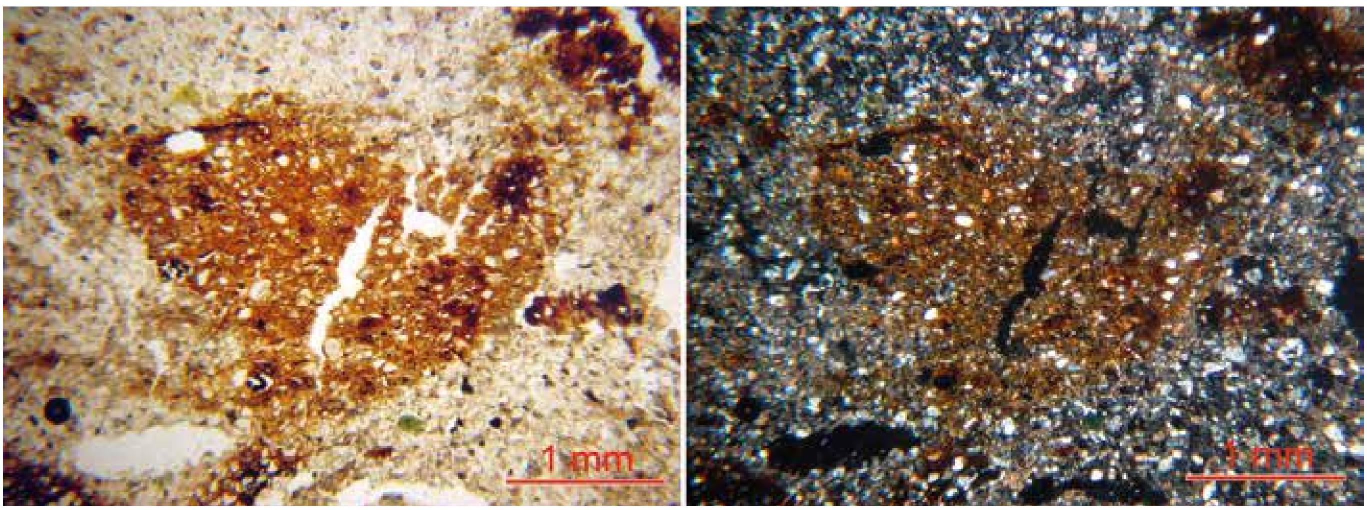


Figure 11. Fragments of allochthonous reworked materials (from the lower layer?). Thin section 39670. PPL and XPL (Pescio, 2019, 16).

numerous at the edges. This entails that the terp was not inhabited during its construction. With the exception of the presence of anthropogenic inclusions, the outer layers do not differ from the inner layers. Additionally, shell fragments are present, but they do not dominate the material. This reinforces the idea that the outer layers of the terp are not waste layers, but have been placed here during the occupancy of the terp to enlarge the living space and to strengthen the terp.

Supplementing field observations with micromorphological data allowed for a detailed reconstruction of the evolution of the terp. The results of the micromorphology are used to test hypothesises and to contribute to new insights. To enable this research, all key profiles must be specifically sampled for thin sections.

6. Discussion

Since the start of the 21st century, knowledge on the nature of the Roman occupation of the coastal plains has been expanding. Excavations around Ostend and in Zeeland (The Netherlands) provide evidence for the Roman transformation of the landscape, to accommodate habitation and economic activities. The two sites that are most similar to the terp in Ramskapelle are Serooskerke-Wattelsweg and Stene. But, also in other, more northern areas along the Roman coast and beyond, comparable features have been documented (Van Londen, 2006; Meier, 2006). While no pre-Roman terps have been encountered in the Flemish coastal area yet, an exclusive Roman cultural and chronological attribution should not be made. Indeed, Plinius (Nat. Hist. 16,2) describes extensively how the Chauci, a Germanic tribe living in the Elbe, Ems and Weser estuaries, lived on platforms near the sea ‘raised with their own hands above the highest of tide known’. Aside from elevated sand ridges or dried-out peat bogs, artificially raised dwelling mounds seem a logical human adaptation to a complex and dynamic landscape.

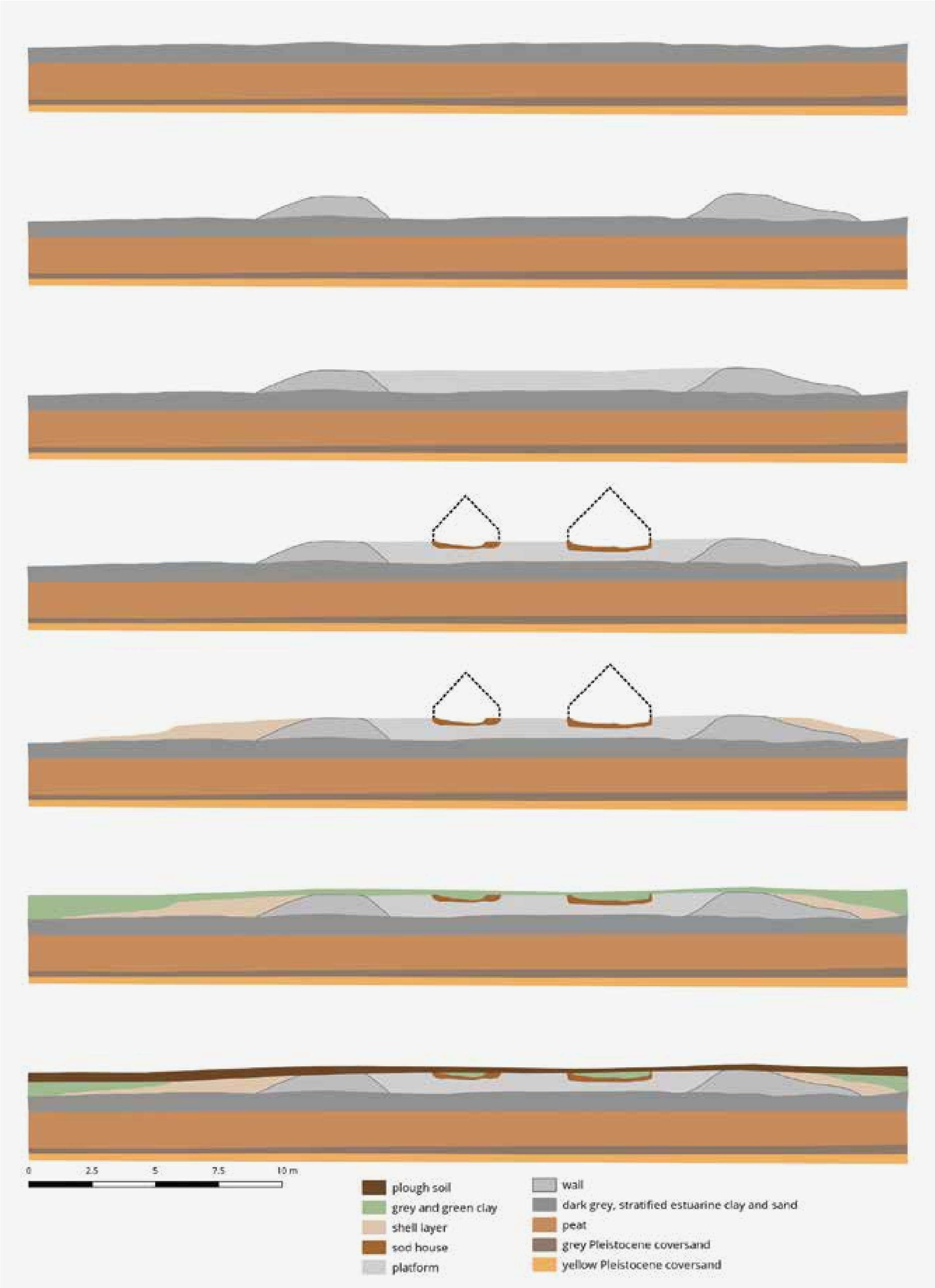
Along the Wattelsweg in Serooskerke (Zeeland, the Netherlands) (Dijkstra, 2011, 65), the landscape starts changing in the 3rd century AD as the influence of the sea increases. To protect themselves against the rising water level, the inhabitants constructed a terp and a dike. The excavated part of the dike is 85 m long and 80 cm high. The dike is made up of blocks of clay and peat, excavated nearby. The dike joins the south-western corner of the terp. The exact measurements of the terp are unknown. It is larger than 7.5 by 7.5 m, but not larger than 7.5 by 9 m. The minimal height is 80 cm. On top of the platform, some possible traces of sod-houses could be observed (De Clercq, 2011, 204).

The second known Roman terp is the site situated at Stene (Ostend) (Demey et al., 2013). This was the first excavated Roman terp in Flanders. The site consists of a dike and a mound. The mound is at least 17 by 8 m and 97 cm high. The terp has been adjusted several times: at the slopes, alternating layers of sods and waste layers are visible. On top of the mound, the archaeologists found traces of buildings, although their exact nature could not be ascertained. Pottery dates the site between the late 1st and early 2nd century AD.

Based on our experience during the A11-project and other projects, and with the experience of others working in this complex landscape, we would like to propose three simple guidelines to assist future research in the coastal plains of Flanders:

1. During a desktop study concerning a project in the coastal plain: use a gully map. While proprietary data can enable the creation of alternative gully maps, the map presented here is freely available upon request to the author.
2. Use the information from the gully map to differentiate the archaeological research. At the location of the gullies, where the original deposits have been eroded, a combination of fieldwalking and trial trenching is preferred for detecting sites. In the zones between gullies, where the original stratigraphy is preserved, the first step is a geophysical prospection aimed at mapping buried landforms. Following the results of this prospection, a manual auger survey is used to examine key landscape features. At promising locations, this survey is supplemented with a close-grid auger survey aimed at tracing down archaeological remains. If this study reveals superimposed well-conserved archaeological surfaces, stepped trenches are the most efficient way to evaluate each one of them.
3. When encountering Roman features or scattered finds in the coastal plain: carry out long soil profiles, stretching several meters and register both the sides and the plane of the trenches. Alternate these long profiles with deep pits, to register each subsequent period of deposition. Supplement this with manual boreholes to fill in any gaps in the evolution of the landscape.

Figure 12. An abstracted representation of the evolution of the Roman terp along the Heistlaan in Ramskapelle.


0
2.5
5
7.5
10 m
plough soil
grey and green clay
shell layer
sod house
platform
wall
dark grey, stratified estuarine clay and sand
peat
grey Pleistocene coversand
yellow Pleistocene coversand

7. Conclusions

The discovery of the terp along the Heistlaan in Ramskapelle constitutes a significant step in understanding the nature of the Roman occupation in the coastal plain of Flanders. Not only is it the largest Roman terp discovered to date, it is also the most complete. With an area of 367 m² and a height of 91 cm the construction was a considerable endeavour, involving the handling of around 600 metric tons of displaced material, stemming from an extraction area of 1 650 m², close to the site. This indicates the investment of a considerable amount of man- and animal effort and the presence of a social force and framework to mobilise this power. As with the construction of embankments, this could point to (local) Roman authorities or a local power-holder involved in supra-local networks.

Furthermore, soil characteristics, sedimentological observations, and micromorphological data indicate a well-organised and well-planned structure and hence, point to a well-known and probably widespread building-concept, as well as to good knowledge of the landscape and its opportunities. The extracted sediments were indeed carefully selected: clayey, sturdy material for the outer rim, forming a firm base and coarser, silty material for the inner structure, providing a better permeability and avoiding the flooding of the terp. During the occupation of the mound, the surface used for living was enlarged with white layers of estuarine sediments and containing mollusc shell fragments, making the raised platform a landmark in an otherwise flat landscape.

These findings not only confirm that artificially raised platforms indeed occur in the northern part of the civitas Menapiorum, they lead us to suspect that these dwelling mounds or terps were indeed much more widespread than suspected so far and should provoke the reinterpretation of older excavation data (De Clercq 2009, 208; Vanhoutte et al., 2003; Vanhoutte et al., 2006). This form of habitation seems to have been popular in a more or less uniform fashion for centuries, well into the Middle Ages (Tys, 2004).

Figure 13. An artistic reconstruction of the Roman terp along the Heistlaan in Ramskapelle (Yannick De Smet, http://yannick.de-smet.me/).

Acknowledgments

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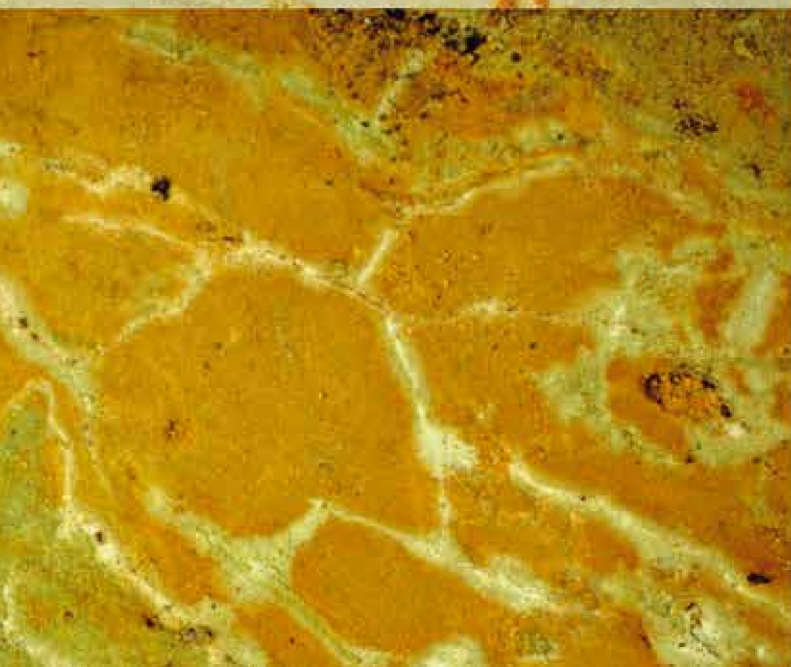


4

Past climates and environments

SOILS AS RECORDS OF PAST AND PRESENT
FROM SOIL SURVEYS TO ARCHAEOLOGICAL SITES:
RESEARCH STRATEGIES FOR INTERPRETING SOIL CHARACTERISTICS

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SOILS OR SEDIMENTS?

The role of Roger Langohr's process-oriented approach in understanding carbonate-related palaeosols of the stratigraphic record

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ABSTRACT
This paper is a summary of palaeopedologically-oriented research on and the interpretation of subaerial exposure-related features in cyclically organised shallow marine carbonates. We point out that the structure of soil profiles in such environments cannot be interpreted simply in terms of pedogenesis. Apparent soil-thickness is not necessarily proportional with soil-maturity and clays and secondary carbonates are not always direct indicators of climate, either.

KEYWORDS
carbonate palaeosols, soil-maturity, climate signal, Late Triassic, Hungary

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1. Prelude

My friendship with Roger Langohr was promoted by Judit Deák and dates back to the early '90s of the past century. Being a bauxite geologist, I arrived on the Soil Science scene from the field of ferrallitic weathering. I wanted to use the Cretaceous bauxites I was studying to understand Cretaceous climates. However, soon I realised that beyond the generalisation of the Cretaceous Greenhouse, undoubtedly favourable for bauxite formation, there are other factors controlling soil development, with *time* being the most important of them all. So I became interested in soil science and wanted to learn more about non-bauxitic palaeosols, possibly contemporaneous with my bauxites. At this time, Greg Retallack published his book about palaeosols (Retallack, 1990). Not knowing about Roger Langohr's Soil Science School, I decided to go to the US and spent nine months with Greg Retallack in Oregon. I learned a great deal, both in the field and in the laboratory, however, I also had fierce disputes, even quarrels with Greg because I did not share his rather rigid attitude towards palaeosol-classification. He would mechanically apply the categories of the US Soil Taxonomy (obviously constructed for recent soils) and would do so not only concerning suborder, but sometimes even on a subgroup level. However - despite these quarrels - as a result of Greg's experience and enthusiasm and the beauty of those colourful Central Oregonian palaeosols, I happened to fall in love with palaeopedology forever.

When I returned from the States, I became involved in a Tertiary palaeosol project in Nigeria's Kerri Kerri basin. There, I had to face the complexities of pedogenesis in an alluvial environment, where, unlike in the US, soils developed on strongly pre-weathered ferrallitic materials and the whole sequence was first subject to shallow-burial diagenesis, then uplifted and eventually re-exposed. In other words, a superimposition of too many processes. At that point, I almost gave up working with palaeosols.

That was the point in time when I got into contact with Roger Langohr's Soil Science Group.

Despite all the previous frustrations, I launched a curriculum on Palaeopedogy in Budapest in 1993. To fill the gaps in my knowledge, I began to regularly invite foreign scientists and included their lectures and short courses in this new curriculum. In addition to Paul V. Wright from Reading (UK) and Jacques Thorez from Liège (Belgium), there was Prof. Georges Stoops from Ghent (Belgium) who gave an unforgettable course on Soil Micromorphology, and, thanks to Judit (my former MSc student), suddenly and unexpectedly Roger Langohr also turned up. They were working on a project on European loess-related palaeosols for which they visited Hungarian loess sections. I happily volunteered to assist and got acquainted with Roger in the field. That was a true revelation. Roger's attitude towards palaeosols was exactly what I was missing throughout my stay in the US. His approach was truly process-oriented and his way of thinking was exactly that of a geologist. He had a clear concept of time and knew how temporal changes of the environment could or could not be reflected in changes in soil properties. He always stuck to the facts and knew precisely how physics and chemistry (including colloid chemistry) controlled those processes, the results of which can be seen in the soil. As he always said: "*the soil is a book and with the right approach, we might be able to read it and thus understand the story written in it*".

Equipped with Roger's ideas and understanding the advantages of the process-oriented approach, I began to examine a well-studied, but still ambivalent group of palaeosols: those intercalated in cyclic carbonate depositional sequences.

2. Introduction

The study of palaeosols associated with cyclically organised, shallow-marine carbonates dates back to the 19th century. For a long time, they were considered indicators of sub-aerial exposure at the base of individual cyclothems (= Fischer's Lofer-cycles). This exposure was suggested to be the result of astronomically controlled, eustatic sea level oscillations (e.g. Schwarzacher, 1954; Fischer, 1964; and others). Only in the 1980s, their potential to assess the duration of subaerial episodes was realised (e.g. Goldhammer and Elmore, 1984). Through an analogy with modern soils, the degree of development (a soil-maturity index) of pedogenically modified surfaces seemed to be promising. Soil thickness was used first as a measure of maturity, however, several detailed studies revealed that there were other features that could be taken into account when trying to establish a rank exposure index for carbonate palaeosols (Smosna and Warschauer, 1981; Goldhammer and Elmore, 1984; Goldhammer et al., 1990; Strasser, 1991 and others). D'Argenio and Ferreri (1991) found a straightforward relationship between cyclothem packaging, the maturity of palaeosols, and the degree of development of other exposure-related features. The climate signal, potentially recorded by the mineralogy of palaeosols, has also been used by sedimentologists to support climate reconstructions. There was general consent about predominantly argillaceous palaeosols being signs of a humid climate (precipitation>>evaporation), whereas predominantly calcareous ones ('calcretes' for the geologist) pointing to aridity/semi aridity (precipitation<<evaporation) throughout their exposure period (e.g. Wright 1994). More and more detailed studies, however, revealed

that the analogy with modern soils had to be applied with extreme caution. These palaeosols, occurring in cyclically organised shallow-marine carbonate sequences, proved to be much more like sediments than just plain old soils and the climate signal, supposedly preserved by their mineralogy, turned out to be less straightforward than previously expected (Muhs et al., 1990; Foos, 1991). As to the time signal, recalling the irregularities of the sea-level curve, Wright (1996) suggested that even when, theoretically, accepting that each cyclothem represents ~20 kyrs (the Milanković-frequency), the duration of the effective exposure of the sediment surface at cycle-bases could not be more than ~1000 yrs or less. Additionally, he put forward the idea of apparent palaeosol development sometimes being the result of the amalgamation of several successive soil-forming events and suggested that some of these cycle-bound palaeosols could be polygenetic, sometimes even recording climatic change during their development.

3. A case study

3.1. STUDY AREA

Back in the late '90s, two cyclically organised Late Triassic (Rhaetian) carbonate platform sequences of the Gerecse Hills (Transdanubia, Hungary) were selected for a detailed study (Mindszenty and Deák F.J., 1999; Deák, F.J. et al. 2002).

The Kecskekő profile, exposed in a still active quarry close to the village of Lábatlan, was ~41 meters thick and comprised 19 cyclothems and related palaeosols (Fig.1). Vöröshíd, next to the village of Tardosbánya, was ~30 meters thick comprising 16 cyclothems and related palaeosols. The top of both profiles was truncated by submarine bioerosion and the contact surfaces overlain with a hiatus, by Lower Jurassic (Liassic) pelagic sediments. The latest Rhaetian and the earliest Liassic are missing from the succession (Fülöp, 1975; Haas, 2001). No palaeosols could be detected on this contact surface. According to Vörös and Galácz (1998) and Győri (2014), the contact can be qualified as a typical drowning unconformity. However, Győri (2014) presented isotopic geochemical evidence strongly supporting the idea that final drowning might have been preceded by a short subaerial episode.

3.2. AIMS OF THE STUDY

The aim of this research was a high-resolution micropetrographic investigation to:

- contribute to the understanding of the controls of apparent soil maturity in the carbonate depositional environment;
- see whether in the studied palaeosol sequence the climate-signal is separable from the time signal;
- see whether the distribution of soil types in the vertical profile could be interpreted in terms of climate change within the time period presented by the studied sections.

3.3. METHODS

The methods used were:

- detailed field descriptions of the recognised cyclothems and the related palaeosol horizons;
- cm-scale sampling and detailed micropetrographic analysis of 140 thin sections taken from the palaeosol horizons and the enclosing carbonates;
- establishment of palaeosol types;
- qualitative XRD and DTA to check the mineralogy of the clay- and carbonate fractions associated with the exposure surfaces.

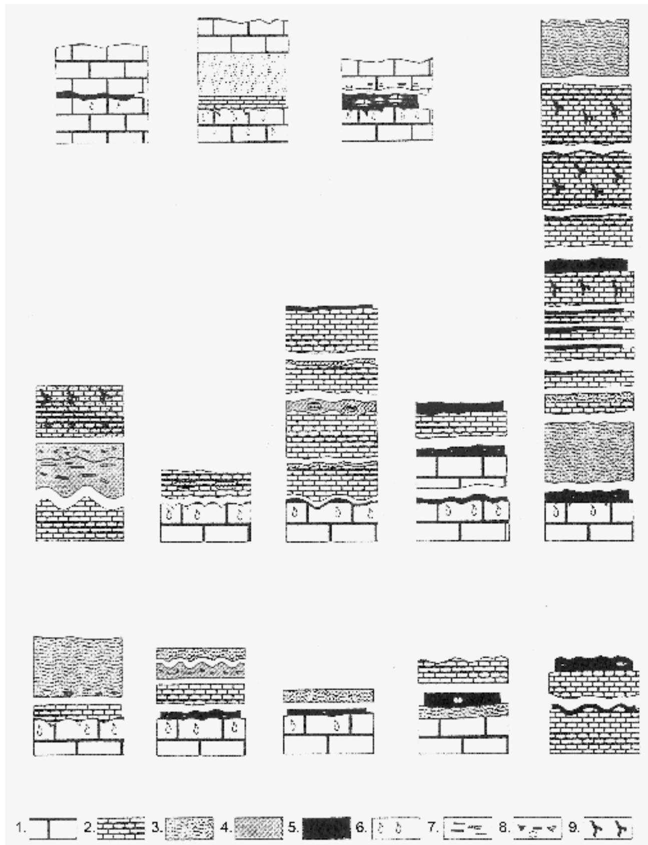

Figure 1. Schematic representation of carbonate-palaeosol profiles recording several exposure events (marked by interruption of the columns) of the Late Triassic Kecskekő (Gerecse Hills, Transdanubia, Hungary), after Mindszenty and Deák 1999.

Legend: 1) subtidal (marine) limestone, 2) mud pond deposit, 3) partially 'calcretised/dolocretised' microbial mat, 4) calcrete/dolocrete, 5) clay 6) microkarst, 7) laminated calcrete/dolocrete, 8) limestone, calcrete, dolocrete fragments, black pebbles 9) rhizolith.

3.4. RESULTS AND DISCUSSION

Soil maturity

The conventional approach based on destratification, clay accumulation, soil colour, and soil-thickness proved to be inadequate to assess the degree of development of the studied palaeosols.

Clay thickness could not be correlated with microkarst features in the substrate, supposedly formed simultaneously with pedogenesis. All clay horizons were rich in silt size detrital minerals (quartz and mica), even though other evidence suggested that there was no substantial erosion to provide for such a voluminous dissolution residue. Therefore, in full accordance with Wright (1994), it was possible to confirm that the clay content is not pedogenic, but airborne. Instead of representing the intensity/duration of pedogenesis, it is rather the measure of dust-deposition that perhaps indirectly provides some hints on the duration of the exposure, as during a longer time span more dust can be deposited.

Soil colour proved to be the most ambivalent. Definite and widespread signs of hydromorphy, apparently arising from early diagenetic overprint during incipient burial, were widely observed in the studied sections. This resulted in the transformation of ferric to ferrous iron and the formation of finely disseminated pyrite, suggesting microbial decomposition of former organic matter in brackish or marine porewaters. Most palaeosols in the sequence are therefore greenish to greyish in colour. However, some of them somehow managed to preserve their original(?) reddish tint, though they apparently were affected by the same burial diagenetic history as the green ones. The only way to solve the problem of this apparent contradiction was to apply the famous 'process-oriented' approach learned from Roger.

We know that soil colour depends on the oxidation state of Fe in the soil. The presence of ferric iron, normally associated with good drainage, results in red soils. However, when reddish coloured Fe^{3+}-oxides are present in a mineralogically unstable form (like e.g. ferrihydrite) they will – as a result of the hydrological change associated with the rise of sea-level – readily react with reducing porewaters and because of the $Fe^{3+} \rightarrow Fe^{2+}$ conversion, the soil colour will change to grey or green.

Good drainage combined with long-enough exposure may result in the mineralogical stabilisation of Fe-oxides during the subaerial period, and in this case, as the result of prolonged exposure, a red colour may survive even in shallow burial.

Poor drainage results in hydromorphy and hydromorphic soils that are relatively rich in organic matter and poor in Fe^{3+}, their colour is originally grey or green and this colour of course survives during shallow burial.

Whether palaeosols are well-drained red or hydromorphic grey/green in a cyclic carbonate sequence depends on how far below the platform top the relative sea level drops and how fast it rises again. The reason for this is that the eventual redoximorphic overprint of an originally red (well-drained) palaeosol under conditions of a rising sea level is ultimately controlled by the degree of mineralogical stability of Fe-oxides in the soil, which is controlled by the duration of exposure. Unstable Fe-minerals react with hydrological change, while those already stabilised by the time of re-submergence preserve their original structure and colour during early and also during a later shallow burial diagenesis.

Soil thickness as an indicator of maturity is also ambivalent and, therefore, received special attention. By definition, soil thickness includes the topsoil and the underlying pedogenic altered, homogenised, or horizonated substrate. In a carbonate depositional environment this includes all karst features formed simultaneously with pedogenesis. Due to the repeated and profuse phreatic-lens related micro-karst pervading the whole sequence, it is difficult, if not impossible, to distinguish between micro-karst features that belong exclusively to one or the other of the superimposed palaeosol levels.

Micropetrography revealed that the thickest exposure horizons are not the most mature ones. Rather, they consist of a series of moderately to very weakly developed palaeosols formed on the surface of muddy supratidal pond-type sediments and they represent stacked ephemeral exposure surfaces. This way, instead of representing a single long-lasting soil-forming episode, the thickest exposure horizons record a long-lasting period during which the groundwater table was more-or-less coincident with the sediment surface. Furthermore, due to the oscillations of the groundwater table, a system of alternating supratidal pond-type sedimentation and pedogenic alterations could be maintained for a long time. This particular set of conditions resulted in the (observed) almost continuous inter/supratidal aggradation. Similar successions of weakly developed palaeosols that occur in Devonian alluvial environments are called 'cumulates' by Wright and Marriott (1996). They are close equivalents to Roger Langohr's 'soil-sedimentary complex', introduced for Quaternary palaeosols. They form when the sedimentary increments added to a soil profile are thinner than the horizons of the developing profile would be. In this way, the sediment becomes digested by pedogenesis and the profile gradually migrates upward.

3.5. SOIL TYPES AND THE CLIMATE SIGNAL

Based on mineralogy, macro-, and micropetrography, the following major groups of palaeosols could be distinguished in the investigated sequences.

Simple clayey

Generally, greenish/grey clay that overlays eroded subtidal carbonate facies, characterised by minor microkarst and covered by subtidal facies. The clay lacks both pedofeatures and/or limestone fragments. Laterally it may pass into stylolites (pressure solution features related to burial diagenesis).

Interpretation: single exposure of short duration. Supposed origin of clay: airborne dust settled on the exposed surface; no particular climatic significance.

Simple, calcareous

A thin layer of supratidal pond-type sediment covers the subtidal substrate. It is overlain by vaguely laminated calcrete, with or without thin clay intercalations and sometimes well-developed root molds. The subtidal substrate is affected by minor to moderate microkarst, often with pendant cement.

Interpretation: moderate length of exposure, brought about by a single oscillation of the sea level, but not accompanied by significant dust-transport. Climate: probably semi-arid, evaporation>precipitation.

Simple, mixed (clay + calcrete)

Brecciated, clayey with cm-size hard carbonate clasts, black pebbles, root molds and a thin calcrete cap on top. It is accompanied by moderately to well-developed microkarst, often with distinct cm-scale karst topography.

Interpretation: relatively long exposure (possibly comprising more than one high frequency sea level oscillation), accompanied by considerable air-born dust deposition, promoted by abundant rainfall; prolonged humidity. Climate signal: ambiguous (humid rather than arid).

Composite, mixed (clay < sediment < calcrete)

Thin clay blanket followed by laminated, brecciated, or massive calcrete with intraformational erosion surfaces. Karstification of the substrate variegated. ('Composite' is used in the sense of Wright (1992) i.e. *'merging superimposed soil profiles'*).

Interpretation: Long exposure, possibly comprising several high frequency sea level oscillations, or interruption of the ephemeral low-supratidal pedogenesis by autocyclic events (e.g. storm-tides). Climate signal: ambiguous.

Cumulate mixed (clay < sediment > calcrete)

Predominantly calcareous with micritisation/melanisation, intraclasts, calcrete clasts, root molds, wispy clay-seams and microkarst ('cumulate' is used in the sense of Wright and Marriott, 1996). It rests on moderately karstified subtidal lithologies, first blanketed by a thin clay film. On the top, there is a thin clay-film beneath the covering subtidal sediments. It is interesting that calcretes and karst features are not mutually exclusive in this type of profiles, either in space or in time.

Interpretation: slowly aggrading soil-sediment complex brought about by the stacking of repeated ephemeral episodes of supratidal to high-intertidal sedimentation and pedogenic alteration, suggesting long-lasting development in close-to-sea level position. They are thought to be the result of a delicate balance between steady platform-subsidence and (several) high frequency sea level oscillations superimposed on a likewise steady, lower-order fall of sea level. The obviously changing clay content may be the result of episodically changing dust-supply. Alternation of more calcretised and more intact, clayey sublayers may reflect either high frequency climate-oscillations

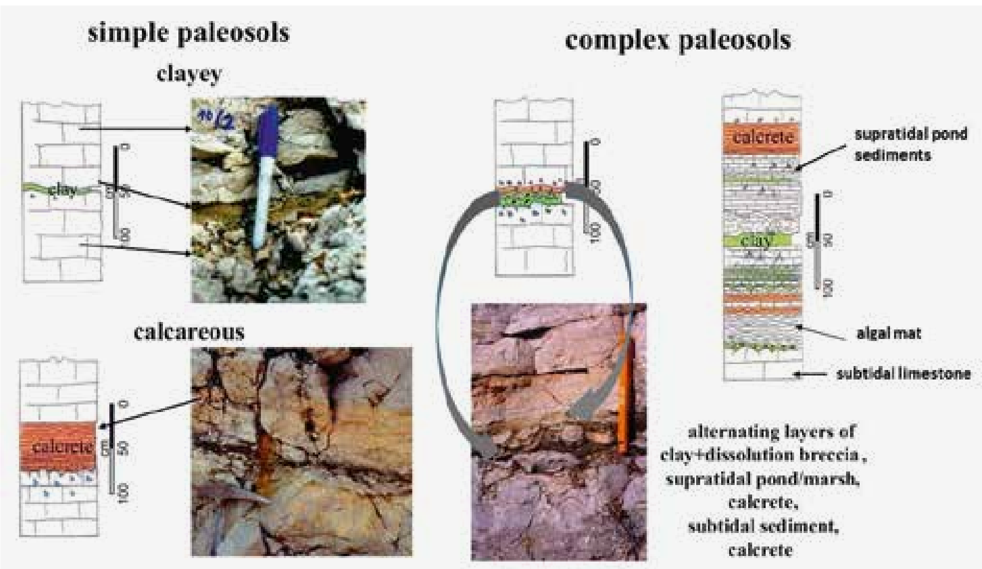

Figure 2. Selected examples of carbonate-related palaeosol-types recognised in the Gerecse Hills Triassic (Transdanubian Range, Hungary).

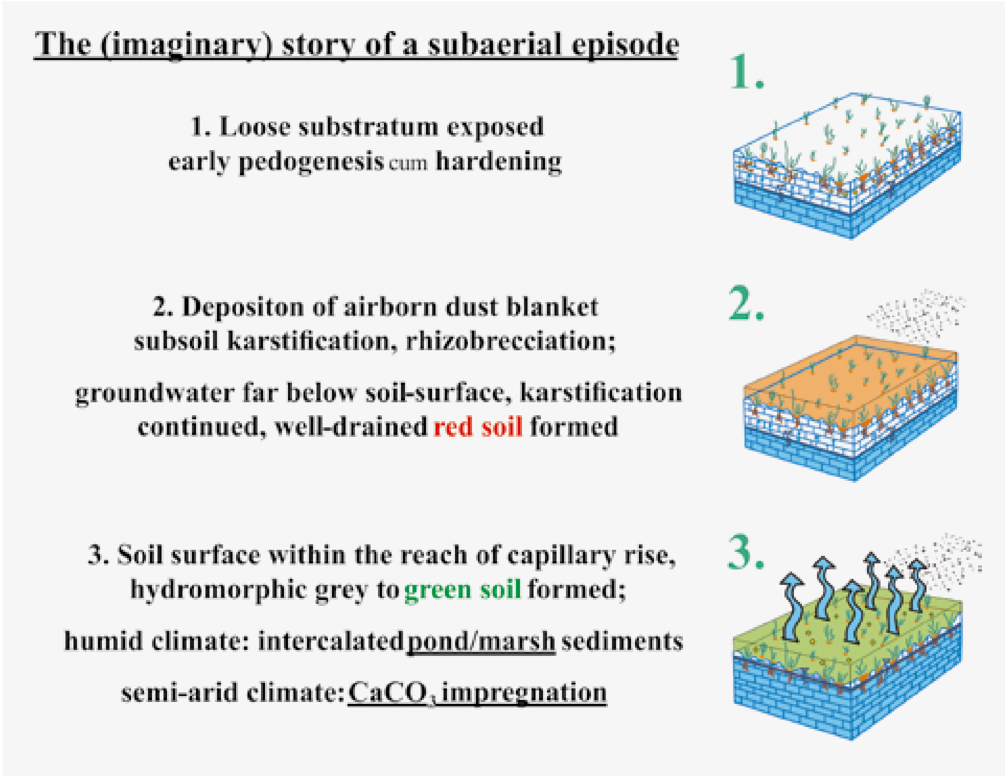

Figure 3. Illustration showing the imaginary story of a subaerial episode in the peri-tidal carbonate depositional environment.

between the humid and arid extremes during the suspected long interval, or it could record the changes of the soil-moisture regime (a combined effect of climate and a changing sea level). Climate signal: ambiguous.

Steady co-occurrence in these cycle-bound palaeosols of calcretes and clays *cum* karst, considered antithetic in terms of climate, obviously require an unorthodox explanation.

It is suggested here, that the calcrete-clay-calcrete succession, accompanied by micro-karst, observed in most of the studied palaeosols is not the result of climate change (arid-humid-arid) during the subaerial episode (as proposed by Vanstone, 1996). Instead, it may simply be the result of the change of the soil moisture-regime caused by the oscillation of the groundwater table concomitant with sea level change. When the water table is high enough for groundwater to reach the surface by capillary action and the climate is at least seasonally arid (= amphipercolative system of Yaalon, 1983), evaporation may easily provide elements for the formation of laminar calcretes, particularly when that groundwater is slightly saline (as it is in a coastal position when the sea level is high). On the other hand, when the groundwater table is far down (i.e. at times of a sea level low stand), moderate karstification may, indeed, occur in the fresh-water vadose-zone.

4. Conclusions

In a shallow-water carbonate-platform environment

1. the apparent thickness of palaeosols is not necessarily time-proportional;

2. the clay content is not proportional to soil maturity and cannot be taken as a direct indication of a humid climate. Most of the clay is not pedogenic in origin, but probably wind-born;

3. the secondary carbonate enrichment is not necessarily a sign of high aridity. It may just be an indication of a slight seasonal surplus of evaporation in a soil/sedimentary environment, where any porosity is filled with saline groundwater;

4. the structure of the soil profiles cannot be interpreted simply in terms of pedogenesis. Most of the palaeosols of the intertidal to low-supratidal carbonate environments, particularly the composite and cumulate ones, include a great deal of sedimentary aggradation, and are equivalents of R. Langohr's soil-sedimentary complex.

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PALAEOSOILS AS INDICATORS OF LOCAL PALAEOENVIRONMENTAL CHANGES

Mosaics from the Hungarian loess studies

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ABSTRACT
The loess palaeosoils are known for their palaeoclimatic significance and have also been used for regional stratigraphic correlations. In this paper, three important loess section sites were studied in the frame of an interdisciplinary approach. The soil-sedimentary sequences presented here cover the timespan between the MIS9 and MIS3. Basaharc is one of the key loess sections of the European loess belt. New sections allow for the description of so far unknown facies of the famous Basaharc Double (BD) and Basarharc Lower (BA) palaeosoils. Moreover, they indicate so far unknown sudden environmental changes during the development of the Upper Mende (MF) palaeosoil. The seven analysed sections of Verőce brickyard allowed the characterisation of the Last Interglacial palaeosoil in various landscape positions. The detailed investigations of the loess-palaeosoil series at Hévízgyörk suggest hiatuses which may have been hidden by a well-developed palaeosoil complex formed over multiple interglacial periods during the Late Middle Pleistocene. This research allows us to complement former knowledge by applying newly available research methods, to obtain new chronological data, and to highlight that soil characteristics of loess palaeosoils are not only influenced by climatic parameters, but also by geomorphological settings.

KEYWORDS
loess-palaeosoil sequences, climate changes, paleoenvironmental reconstruction, Hungary, Basaharc, Hévízgyörk, Verőce

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1. Introduction

In Hungary, the palaeosoils developed on loesses were mainly used for the correlation of distant profiles and for chronostratigraphic reasons, despite the fact that they also contain information about sedimentation rates, pedogenesis and erosion, and therefore about changes of the palaeoenvironment and palaeotopography (Horváth and Bradák 2014). Some of the recent studies of the Loess Research Group at the Department of Physical Geography at Eötvös Loránd University focus on the question how the palaeotopographical position influences palaeosoil formation and how this is visible in different outcrops. The purpose of this paper is to present some results concerning these questions.

Two of the selected sites, Basaharc and Verőce, are located in N-NW part of Hungary (Fig. 1a,b) along the River Danube. Hévízgyörk is located in the Gödöllő Hills, Central Hungary, to the East of Budapest on a terrace of the River Galga. Based on the presence of the Bag Tephra layer found at Basaharc and Hévízgyörk in the lowermost parts of the loess-palaeosoil sequences overlying fluvial sediments, the terrace of the Galga and the Danube rivers are considered to be coeval (Bradák et al., 2014, Horváth 2001; Horváth et al., 2019).

In the outcrops of the abandoned brickyard of Basaharc and Verőce, different palaeogeomorphological positions were revealed. This is in contrast with the case of Hévízgyörk, where only a wide section of the loess-palaeosoil sequence was explored. Former interdisciplinary studies point to the importance of erosion processes during or after the formation of the soil (Bradák et al., 2014; Csonka et al., 2019).

2. Methods

In addition to detailed documentation and the sampling of profiles, low field volumetric magnetic susceptibility (κlf) was determined during the field campaign. Frequency depended susceptibility (χfd) and the anisotropy of low field magnetic susceptibility (AMS) were measured in the laboratory. Samples were taken for granulometry, for bulk stable isotope, for geochemical research in 2 cm intervals, for palaeomagnetic (only from some outcrops) research, and for secondary carbonates analysis in 10 cm intervals.

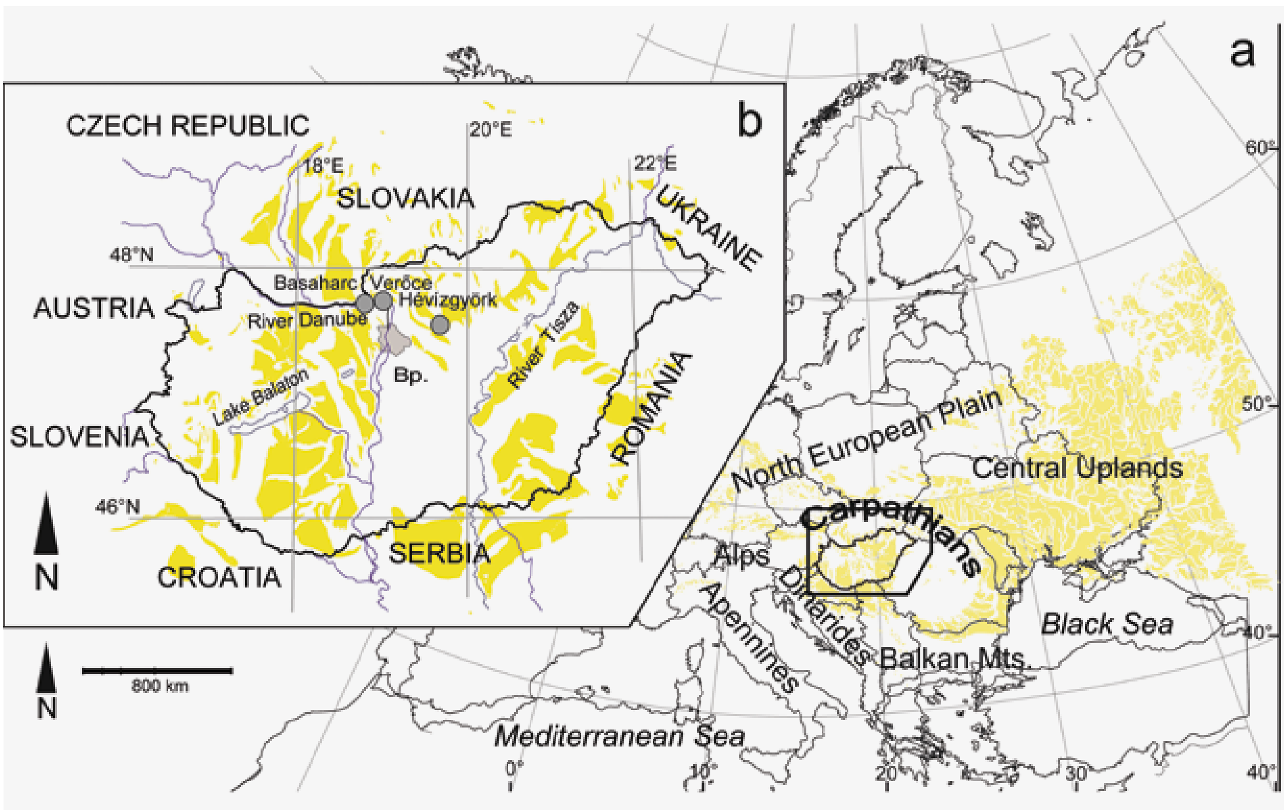

Figure 1. Distribution of loess sediments in Europe (a) and in Hungary with the location of the profile (b) (based on Haase et al., 2007 and Csonka et al. 2019).

The luminescence samples and the oriented samples for soil meso- and micromorphology were taken from selected horizons. ^{14}C-ages were measured from mollusc shells and charcoal. A detailed description of the applied methods is presented in previously published research papers (Bradák 2009; Bradák et al., 2014; Bradák and Kovács 2014; Barta 2014; Barta et al., 2018; Csonka et al., 2019; Novothny et al., 2010). Stable isotope investigations were carried out on the secondary carbonates, specifically on hypocoatings. For a more detailed characterisation of the palaeosoils, the Harden test was carried out, and the soil development index (SDI) and micromorphological soil development index (MISODI) were calculated (Bradák et al., 2014; Csonka et al., 2019).

3. Results and discussion

3.1. BASAHARC

One of the outcrops of the 20 m thick loess-palaeosoil series, covering a terrace surface of the River Danube, is at Basaharc in a former brickyard (Fig. 2). Three palaeosoils were identified from the classical sections situated in different parts of the brickyard. The Basaharc Double palaeosoil complex (BD1-2) and Basaharc Lower palaeosoil (BA) are important stratigraphic units in the Hungarian loess stratigraphy named after this site (Pécsi, 1965). Based on the luminescence ages and the presence of the 350 ka old Bag Tephra layer in the lowermost loess, the palaeosoils can be correlated with the marine isotope stages as follows: the uppermost, Mende Upper (MF1-2), palaeosoil complex developed during MIS5, the Basaharc Double palaeosoil developed during MIS7, and the Basaharc Lower palaeosoil developed during MIS9 (Frechen et al., 1997; Novothny et al., 2002; Novothny et al., 2009; Novothny et al., 2010; Thiel et al., 2014; Horváth et al., 2014). The reinvestigation of the classic profiles using the new methods proposed by our research group started two decades ago.

In the last couple of years, in the western part of the quarry, a new continuous profile was excavated and investigated using multi-proxy methods (Horváth et al., 2019). The ongoing studies clearly show the diverse development of coeval palaeosoils indicating different palaeoenvironments. The palaeosoils here are in a higher topographical position than the classic profiles. Even so, the MF1-2 palaeosoil is very weakly developed in this wall. It was identified using luminescence ages and appeared to have slightly higher values on the low field volumetric magnetic susceptibility (κlf) curve (Horváth et al., 2019). The presumption is that the pedogenesis could not keep up with the aggradation of the surface by the dust accumulation during MIS5, although the outcrop seems to be on a local hilltop position.

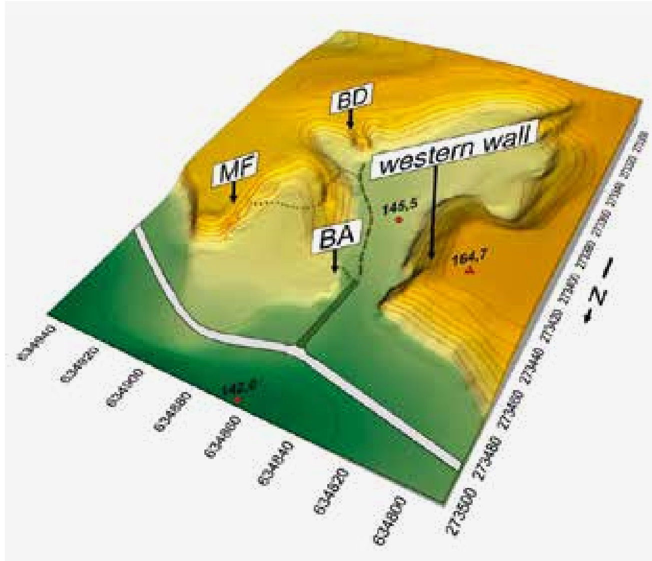

Figure 2. Digital elevation model of the Basaharc brickyard. Elevation (m a.s.l.), arrows show the positions of the loess-palaeosol sections; palaeosoils: MF – Mende Upper1-2, BD – Basaharc Double 1-2, BA – Basaharc Lower (based on Horváth et al., 2019).

Changes of the local palaeoenvironment were visible in two other parts of the abandoned brickyard as well. At the entrance of the quarry, below the BA palaeosoil, a hydromorphic environment can be observed based on the strong accumulation of Mn and Fe along the cracks and in the matrix in 4-5 m width. Most likely, there was a small fluvial channel which resulted in stagnated water appearing in the loess before the soil formation started. In the backyard of the quarry, a bigger sized fluvial channel is recognizable based on the layered soil material and the slightly layered loess with andesite blocks of 15-50 cm diameter. Below this reworked material a thick and strongly developed palaeosoil is located. Based on its topographical position, it is presumably the Basaharc Lower (BA) palaeosoil, which developed here in an environment with more water supply, possibly in a palaeovalley position. The layered material could be the result of a gully erosion, connected to the Palaeo-Danube after the development of the BA palaeosoil between MIS8 and MIS3. In the BA palaeosoil, a lighter horizon with low magnetic susceptibility (κlf) value suggests the presence of a period when the soil formation was subordinate relative to the sediment accumulation (Horváth et al., 2019).

3.2. VERŐCE

The abandoned brickyard of Verőce is situated on the foothills of the Börzsöny Mountains (the Visegrád Gorge) on the left bank of the River Danube. The seven investigated sections reveal a large panoply of palaeoenvironmental information. Firstly, the soil and sedimentary *characteristics* are witness to both interglacial and glacial climatic conditions. Additionally, the analysed sediments reveal that various depositional environments existed along the studied area and throughout time.

The fluvial-alluvial sediments of the Danube were covered by eolian and proluvial material. Based on the relative and numerical dating results, the sediment accumulation of this area started at the beginning of MIS6 or even at the end of MIS7 (Bradák et al., 2014; Barta et al., 2018). Four palaeosoils were identified in the sections, showing the climatic oscillations of the Late Pleistocene (Fig. 3).

A characteristic palaeosoil (P4) formed in MIS5e was identified from different sections (A, C, D, E) and three of its facies were characterised (Bradák et al., 2014).

Two loess outcrops at Verőce (profiles D and E) developed in a palaeovalley position, most likely in a former oxbow lake or a tributary valley connected to the Palaeo-Danube. Alluvial sediments in profile D are overlain by loess with an age of 132±7ka. The transition between them is gradual. The P4 palaeosoil is developed on this loess deposit.

The thickest loess-palaeosoil section has a higher elevation, in a so-called local hilltop position (profile C). Here, the P4 palaeosoil, attributed to the last Interglacial, is overlain by two succeeding palaeosoils formed during subsequent phases of MIS5. The luminescence age of the loess underlying the P4 palaeosoil is higher than that in profile D (202±11ka), which suggests the earlier onset of the dust accumulation on hilltops or high landscape positions and erosion in the alluvial position.

The P4 palaeosoil in profile D is well-developed and more than 2 m thick. It can be divided into a lower red, a middle brown, and an upper black horizon. The upper part of the brown horizon is characterised by slickenside phenomena and blocky soil structure. The black horizon was characterised by carbonate veins. The soil development index (SDI) is very high compared to those of the other P4 palaeosoils, most likely because of the great thickness due to the continuous pedogenesis during sediment accumulation. This palaeosoil formed during the MIS5e interglacial period under hydromorphic conditions (Bradák et al., 2014). The stable isotope investigations revealed signs of the effects of hydromorphic phenomena, implying significant evapotranspiration under dense vegetation cover (Barta et al., 2018).

The P4 palaeosoil in profile C is characterised by well-developed and separated, differentiated pedological horizons, the same as in profile D, but with a smaller thickness. Its SDI is lower than the SDI of P4 in the valley bottom position (in profile D). The stable isotope patterns

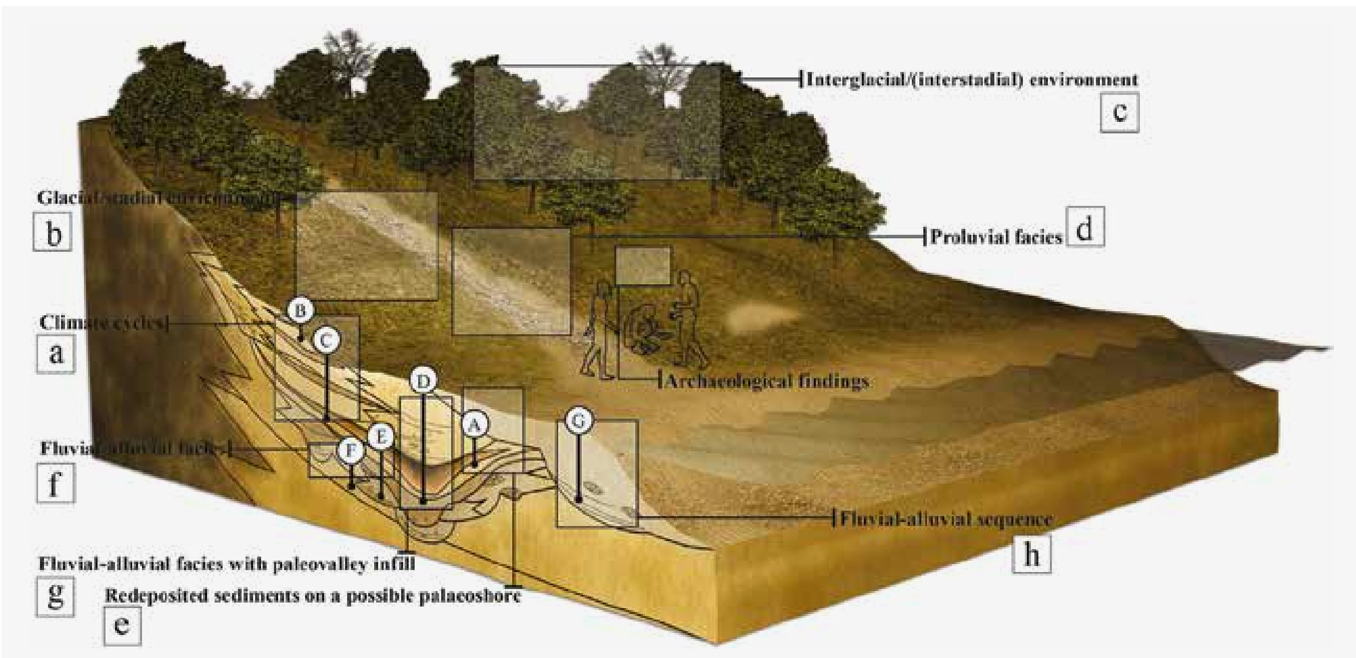

Figure 3. Summarised and idealised image of the palaeoenvironments that appeared around the Verőce brickyard during the Late Pleistocene period (based on Bradák et al., 2014).
A-G: studied profiles; a-c: reconstructed palaeoclimatic contexts; d-h: reconstructed depositional settings.

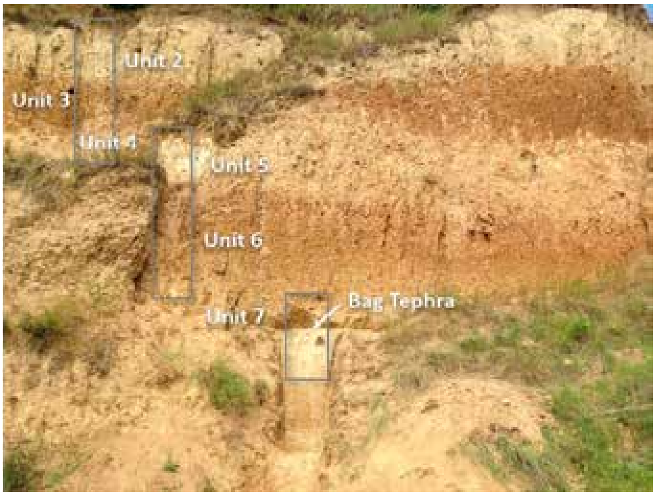

Figure 4. Loess-palaeosol sequence at Hévízgyörk (based on Csonka et al. 2019).

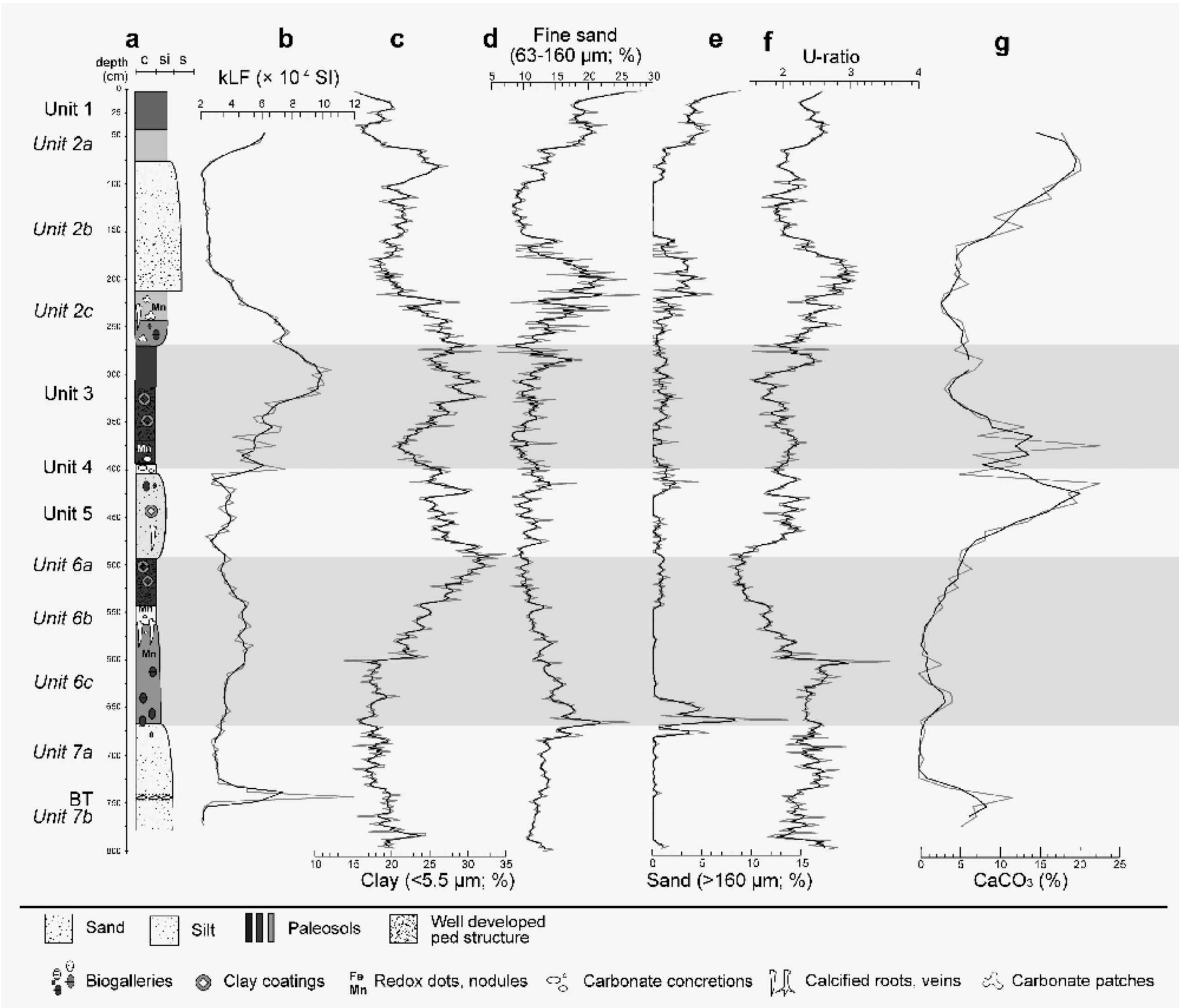

Figure 5. The results of the multi-proxy analysis of Hévízgyörk profile: a. studied section and its subdivision by Units; b. κLF curve/variations along the studied section; c. the clay content curve; d. fine sand; e) sand distribution; f. the U-ratio (44–16 μm/16–5 μm); g. bulk $CaCO_3$ distribution (Csonka et al. 2019).
The black curves represent the smoothed version (three member moving average) of the original dataset (grey line).

of hypocoatings from this palaeosoil can be used as palaeoclimate indicator because it developed primarily under climatic influence and therefore, it can be correlated with other profiles in hilltop position as well.

The thinnest P4 palaeosoil is in profile A. Although the pedogenetic horizons of the P4 palaeosoil were difficult to detect in the field, further analyses showed that several of its soil characteristics, such as the SDI value, are similar to the ones documented for the P4 palaeosoil situated on the hilltop position (profile C) (Bradák et al., 2014; Barta et al., 2018). In addition, its uppermost part is mixed with new sediments and covered by fine layered material, suggesting reworking. Sedimentation by run-off processes could be also observed. These signs of overland flow have been interpreted as indicators of higher precipitation in this palaeoslope position.

3.3. HÉVÍZGYÖRK

The section of the abandoned brickyard of Hévízgyörk contains only two fossil soils without a visible hiatus (Unit 3 and 6, Fig. 4). But, based on the presence of Bag Tephra (an important marker layer) and the so far documented palaeosoil sequence documented in the Hungarian loess stratigraphy, it was very likely that there had to be at least one missing palaeosoil.

High resolution multi-proxy studies were carried out in the last couple of years by our research group in order to discover these missing units. In the lower part of the upper palaeosoil (Unit 3) a strong secondary carbonate accumulation appeared along vertical cracks which suggested the polygenetic development of this palaeosoil. This hypothesis was confirmed by the results of further investigations. The low field volumetric magnetic susceptibility (κlf) curve indicated a strong pedogenesis with at least two periods in the upper palaeosoil. In addition, these soils are characterised by a higher clay and $CaCO_3$ content than the other units (Fig. 5). The simultaneous presence of the clay coating and secondary carbonate accumulations and the absence of the humiferous surface horizon are most probably related to the combined effect of eolian and/or water triggered erosion processes and of the passage from a leaching to a non-leaching environment during the long evolution of this sequence. Furthermore, it is possible that a lower loess sedimentation rate occurred during the cold phases in this landscape position. Preliminary luminescence results confirmed an important hiatus between the upper part (84±5ka) and the lower part (>243ka) of this palaeosoil (Unit 3), therefore, the two parts formed in different interglacial periods (Csonka et al., 2019; Novothny et al., 2019). Based on the luminescence age of the uppermost loess unit (35±4ka) another hiatus is detectable above this palaeosoil.

4. Conclusions

The development of the palaeosoils was strongly influenced by the climate, but the local palaeoenvironment had a great influence on it as well. The sites presented here provide a great opportunity to investigate coeval palaeosoils in different geomorphological positions and therefore recognise the distinct balance among pedogenesis-erosion-sediment accumulation. At Verőce, the local top, the palaeovalley and the palaeoslope landscape positions were clearly characterised by different soil features of the same P4 palaeosoil. At Basaharc, various environments and geomorphological processes were described as well. It was possible to detect unconformities in the Hévízgyörk profile by using a multiproxy analysis.

The palaeosoils developed in a higher landscape position (such as local plateaus or intervalley ridges) are suitable for the determination of the intensity (the strength) of the interglacial and interstadial periods, and can be used as a basis for the interregional correlation. Other geomorphological positions (slopes and valley bottoms) were more sensitive to the local changes, therefore they carry information about the development of their local environment.

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A DISTINCT PEDOGENETIC PATH UNDER A MEDITERRANEAN CLIMATE

The case of soils on Areny sandstone formation (Tremp basin, NE Iberian Peninsula)

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ABSTRACT
The Areny Formation is an Upper Cretaceous sandstone outcropping in the South Pre-Pyrenean area. It is composed of well-sorted quartz sand and gravel, cemented by calcite. It outcrops at a wide range of altitudes (400 to 1700 m). Soils developed on this formation in the Tremp basin (NE Iberian Peninsula) have xeric/ustic and mesic soil climate regimes. They display several soil characteristics corresponding to advanced stages of pedogenesis such as decarbonation, clay formation, and illuviation and rubefaction, ranging from Cambisols and Luvisols to Lixisols. These pedofeatures are absent in adjacent soil units of similar age, developed on finer materials, such as marls and calcareous conglomerates, where the dominant soil formation processes are carbonate translocation and weak cementation. These neighbouring soils are mainly Calcisols, some of them with a petrocalcic horizon. Six profiles formed on the Areny sandstone were selected for an in-depth study of their soil formation processes. A multi-scale approach, from geomorphological to micromorphological analyses, was employed. The soils have a neutral to slightly acidic reaction in the Bt horizons, with loamy sand textures and a clay content of 10 % that appears completely as illuviated clay in the thin section; reddish hues (2.5YR) and high chromas, the absence of calcite in the upper horizons or in the whole profile, and the presence of iron pans in some locations. Amorphous iron is found in low amounts compared to Fe in silicates and as finely crystalline forms. The latter increases with depth in the decarbonated profiles. The high weathering degree of the oldest profiles is shown by kaolinite being the dominant clay, which was probably inherited from the pre-Quaternary period. The clay fraction also contains remarkable amounts of mixed layers chlorite/smectite, chlorite/vermiculite or illite/smectite, which may be considered products of present-day pedogenesis. The geomorphological analyses allowed us to determine the ages of the surface formations of four of the profiles (50 to more than 350 ky), which indicated much faster soil formation rates than those reported in similar Mediterranean environments. Thus, the proposed stages of soil evolution in these sediments imply a fast decarbonation, followed by clay formation, and illuviation. These processes have strong implications in establishing the soil-landscape relationships in the area.

KEYWORDS
carbonate, decalcification, rubefaction, clay illuviation, clay formation, Catalonia

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1. Introduction

Soils under Mediterranean environments do not undergo specific soil formation processes different from other climates, although it is recognized that they do have a particular set of common soil formation factors in several parts of the world such as the Mediterranean climate (warm and dry summer), the presence of carbonate rocks, steep slopes and – in the Mediterranean – the supply of Saharan dust and a long-lasting anthropic influence (Yaalon, 1997). The resulting processes are moderate weathering, 2:1 clay illuviation, hematite-induced reddening, and carbonate redistribution (Yaalon, 1997; Bech et al., 1997; Fedoroff and Courty, 2013). Even so, the present or palaeo-character of these processes is not completely understood. According to Fedoroff (1997), clay illuviation is only active in the northern, wetter margins of the Mediterranean basin and should be considered a palaeofeature in the rest of the region. Indeed, the alternation of wetter/drier climates during the Quaternary has been claimed as a driver of decarbonation, clay illuviation, and reddening/recarbonation in several Mediterranean chronosequences (e.g. Sauer et al., 2010; Poch et al., 2013; Fedoroff, 1997; Darwish and Zurayk, 1997).

One of the tasks of pedogenetic analysis is the establishment of the relationship between soil age and formation degrees, which is normally defined regionally, taking into account climatic variables (Sauer et al., 2006). These relationships do not always apply because of external inputs (such as dust) or outputs (mainly erosion) (Scarciglia et al., 2015); additionally, soil evolution is not uniform, but subjected to internal thresholds and feedback mechanisms (Sauer et al., 2006), as it occurs with clay illuviation and rubefaction taking place after decalcification.

The Tremp basin is located in the Pre-Pyrenean area, north-east of the Iberian Peninsula, on a sliding mantle formed by calcareous Cretaceous and Tertiary materials, resulting from the uplift of the Pyrenees. The climate is Mediterranean semi-arid. The surface formations of known age are the Segre river terraces and several levels of travertine mounds equivalent to those of large alluvial fans covering the basin, which were formed during the Middle and Upper Pleistocene. Detailed soil surveys of this area revealed the presence of strongly expressed contrasting processes (calcium carbonate accumulation/cementation and clay illuviation/reddening) on adjacent surfaces of similar ages (Porta et al., 2013), but that were developed on different parent materials. In particular, soils formed on Areny sandstones (Upper Cretaceous sandstone, made of quartz sand cemented by calcium carbonate) are redder and more acidic than surrounding soils and may show clay illuviation, while petrocalcic horizons are found on adjacent pediment surfaces at the same level. Bech et al. (1985) noted different degrees of decarbonation, reddening, and clay illuviation on neighbouring soils in the area and attributed this to the different parent materials of the soils.

The objective of this research is to determine the role of the parent material (Areny sandstone) on soil formation processes (clay illuviation and reddening) in order to establish the present or palaeo character of these soil-forming processes, following a multi-scale approach; and to discuss the correlation of the degree of expression of these processes with age and with neighbouring soils on geomorphic positions of a similar age undergoing very different pedogenetic processes.

2. Material and methods

2.1. PHYSICAL ENVIRONMENT

The Pyrenees are a mountain range of the Alpine folding, which is over 1500 km in length. It is the result of the continental drift of the Iberian Plate during the Mesozoic and its final collision with the European Plate during the Cenozoic. This uplift caused the formation of several landslide mantles that make up the Pre-Pyrenees, South of the Axial Zone, formed by rocks of the Mesozoic and Paleogene, which determine several mountain ranges of east-west orientation. The Tremp Basin (Conca de Tremp) is one of the intra-mountain basins between them, south of the main axis of the Pyrenees, where it is possible to find sediments and structures of previous palaeoenvironments. Its width is approximately 50 km, with altitudes ranging between 400 m in the centre and nearly 1700 m at the margins.

The climate is mountainous Mediterranean, with an annual precipitation between 580 and 750 mm that follows an altitudinal gradient and a bimodal distribution along the year (spring and autumn), with a severe summer drought. The mean annual temperatures are between 12.8 °C at the valley bottom and 8.4 °C at the highest altitudes, which have common snow events every winter. Soil moisture and temperature regimes in the region are Xeric/Ustic (below and above ca. 1000 m) and Mesic respectively (SSS, 2014).

The soils are mainly formed on highly calcareous materials of different nature, from sandstones to clays and travertines. Calcium carbonate redistribution is very common, from calcic to petrocalcic horizons developed on old alluvial fans (Machette stages II to IV; Machette, 1985; Porta et al., 2013). At the valley bottom, soils with gypsum accumulations and vertic features are present, probably inherited from the colluvium of the Garumnian (Upper Maastrichtian) marls (Porta et al., 2011). The presence of travertines is also noteworthy since they are very important in the centre of the basin, due to springs originating from the underlying confined aquifer (Linares et al., 2010).

It is composed from a series of relict tufa mounds older than 350 ky BP and a lower tufa unit associated with current groundwater aquifer outlets (Basturs Lakes), which have been active since 106 ky BP during both cold and mild Marine Isotopic Stages (MIS) (Pellicer et al., 2014).

The main land use in the basin is forestry. Agriculture is concentrated on valley bottoms around the main villages and on the plains close to rivers. Besides cereals and alfalfa, both rainfed and irrigated, traditional almond and olive trees can also be found. There has been a recent increase of vineyards, included within the Costers del Segre Appellation d'Origine wines. The occupation of the land dates back to at least the end of the Middle Pleistocene, as illustrated by the Nerets Archaeological site on the soils of the Areny sandstones, where lithic artefacts can be found along the whole slope due to the erosion of the original red soils (Rodríguez and Rosell, 1993). The first large-scale transformation of the landscape was due to the Roman rule that brought a new territorial organization and a complex administrative framework (Iber – Roman period, 650 BC - 450 AD). This occurred along the old optimum climate and permitted the expansion of crops throughout the territory.

2.2. THE ARENY FORMATION

The Areny sandstones in the Conca de Tremp mark the transition from marine (marls of the Upper Maastrichtian, locally named Garumnian) to continental environments (Cretaceous–Tertiary) (Oms et al., 2016). As such, they are calcarenites, formed by deltaic quartz sand derived from the weathering of the igneous rocks of the axial Pyrenees and cemented by carbonates. The average thickness of the Areny formation is about 500 m and it outcrops at the margins of the basin (Figure 1).

Regarding its composition, the quartz content in the calcarenite samples decreases regularly from 40.5 % at the bottom to 17.5 % at the top (Nagtegaal, 1972). The quartz grains are rounded and well-sorted. Among the carbonate grains, well-rounded calcareous algal fragments (rhodophyceans) and larger Foraminifera (Orbitoides, Siderolites) are particularly abundant. Other grains include pelecypod and echinoderm fragments, *Radiolitella pulchellus* (Vidal) rudists (hippuritids), pelecypod debris, and corals (Mey et al., 1968; Nagtegaal, 1972; Villalba-Breva et al., 2015). This formation underwent an early complex diagenetic process, consisting of a first stage of marine and meteoric cementation (development of ferruginous rims and

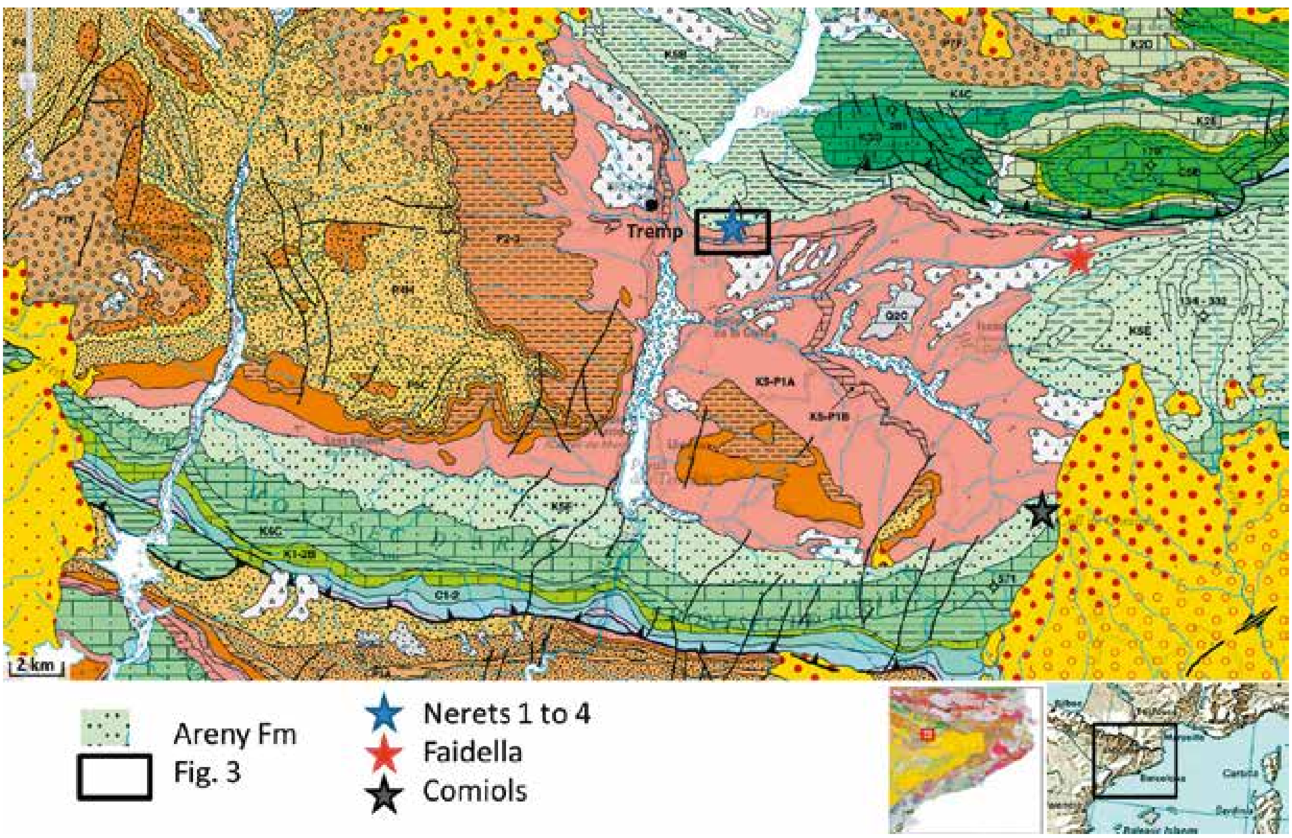

Figure 1. Geological map of the Tremp basin and profile location.
Source and complete legend: ICGC http://www.icc.cat/vissir3/llegendes/mgc250m.pdf.

Table 1 Main site characteristics of the studied profiles

Profile	Altitude (m asl)	Slope and aspect	Landform	Parent material	Vegetation
Faidella	1170	15 %, NW	Middle slope	Calcareous (Areny Formation) sandstone	Afforestation. *Pinus sylvestris, Quercus ilex sp. Ballota; Erica scoparia, Juniperus communis, Genista scorpius, Artostaphylos uva-ursi, Genista hispanica, Lavandula angustifolia, Globularia vulgaris, Calluna vulgaris.*
Comiols	1099	10 %, W	Upper slope		
Nerets 1	584	10% N	Upper alluvial fan	Pedosediment from the Areny sandstone	*Quercus ilex, Thymus vulgaris, Rosmarinus officinalis.*
Nerets 2	577	15% N	Upper alluvial fan		
Nerets 3	545	3% S	Lower alluvial fan		*Quercus rotundifolia, Rosmarinus officinalis.*
Nerets 4	515	2% S	Lower alluvial fan		*Quercus faginea, Genista scorpius, Rubia peregrina.*

precipitation of druse calcite), followed by pedogenesis. The latter is shown through the corrosion and dissolution of carbonate grains and of previous cements, which led to the fragmentation, brecciation, nodulisation, and ferruginisation of the former lithified beach sand, creating a secondary porosity of vughs and fractures (Díaz-Molina et al., 2007).

The Nerets range, about 2.5 km East of Tremp, constitutes the western edge of the northern flank of the Tremp Syncline. It is formed by a sub-structural slope, excavated in the quartz sandstones of the Areny Formation, dipping ca. 15° S. At its footslope, just in contact with the loose materials covering the sandstones (basal part of the Tremp Formation, Maastrichtian, Rosell et al., 2001), there are two sets of alluvial fans attached to the slope, stepping at different altitudes.

2.3. METHODS

The geomorphological analysis of the alluvial fans of the Nerets site was based on geomorphological mapping techniques, granulometric and sediment analysis of alluvial bodies, and on dating in comparison with local deposits of similar characteristics with absolute dating. The geomorphological mapping of the quaternary alluvial bodies allowed us to determine the shape and surface extent of the formations and the spatial and temporal relationships between them and any older neighbouring substrates. The sedimentary analysis of the variations of particle size in the interior of the alluvial fans allowed us to determine the proximity or distance of the materials with respect to the source areas. Dating was determined through stratigraphic correlations, which allowed us to determine the approximate age of formation of the Nerets alluvial fans relative to similar sediments, dated through radio-isotope techniques of uranium and radiocarbon.

Six soil profiles, located at different sites within the Areny formation-outcrops or derived alluvial fans (Figure 1), were described and sampled for chemical, mineralogical, and micromorphological analyses. Two of them (Faidella and Comiols) are located at higher altitudes on the in situ weathering products of the sandstone. The other four were located (Nerets 1 to 4) on a system of alluvial fans (Nerets site) made of pedosediments from the sandstone outcrops north of the basin (Nerets range). Their main characteristics are found in Table 1.

Additionally, rock fragments were sampled for mineralogical, micromorphological, and chemical analyses. The profiles were described following the guidelines of SINEDARES (CBDSA, 1983). Undisturbed samples were collected at selected profiles and horizons for micromorphological analyses. The physicochemical analyses of the profiles was done according to MAPA (1993). Particle size distribution was determined by the pipette method, after the removal of organic matter with H_2O_2 and dispersion with Na-hexametaphosphate. Cation exchange capacity was determined by displacement with 1 M NH_4OAc (pH 7) and the exchangeable cations were measured by atomic absorption. Organic carbon was determined following the Walkley-Black method. Soils were classified according to Soil Taxonomy (SSS 2014) and WRB (IUSS Working Group WRB, 2015).

Total iron (Fe_t) was determined after digestion with HCl and HNO_3. Dithionite soluble Fe (Fe_d) was determined with dithionite citrate, buffered with the sodium bicarbonate method according to Mehra and Jackson (1960). Oxalate extractable Fe (Fe_{ox}) and Al (Al_{ox}) were determined through extraction with acid ammonium oxalate 0.2 M at pH 3 (Schwertmann, 1964). In all extracts, Fe was determined by atomic absorption.

Reddening was assessed as a colour (moist) index; the redness index has the following equation:

$$RI = [(10 - nhue) * chroma]/value$$

from Torrent (1983) with the constant nhue value being: 10YR = 10; 7.5YR = 7.5; 5YR = 5; 2.5YR = 2.5; 10R = 0.

We calculated the Fe-index (Wagner et al., 2014), defined by the following equation:

$$\text{Fe index} = (\%Fe_d - \%Fe_{ox})/(\%Fe_t/\%Clay)$$

Micromorphological analyses were performed in some of the profiles according to the procedures of Benyarku and Stoops (2005) for making vertical thin sections, 13 cm long and 5.5 cm wide, from air-dried, undisturbed soil blocks. Stoops' (2003) guidelines were followed for their description and study.

Semi-quantitative clay mineralogy of the selected samples (powder and oriented air-dry aggregates) was carried out through X-ray diffraction, using a Siemens D-5000 diffractometer. The mineralogy of the skeleton grains of the Areny sandstone (volume %), sampled at the Faidella site, was done through point-counting of 250 grains. The elementary composition of the same set of samples was determined by digestion in *aqua regia* mixture and determined by ICP-OES (Optima 5300DV, PekinElmer).

The Chemical Index of Alteration (CIA, Nesbitt and Young, 1982) and Chemical Index of Weathering (CIW, Harnois, 1988) were calculated as CIA=Al·100/(Al+Ca+K+Na) and CIW=Al·100/(Al+Ca+Na). The Weathering index (WI, Price et al., 1991) was calculated for Comiols and Faidella in reference to their respective underlying sandstones as WI = $R_{sample}/R_{reference}$, where R=Al/(Ca+Na).

3. Results

3.1. MINERALOGY AND PETROGRAPHY OF THE ARENY SANDSTONE

The composition of the Areny calcarenite is mainly calcium carbonate, either as cement (micrite and microsparite) or as calcite grains and fossils. The mineralogical analyses of one sample shows that the non-calcareous mineral grains are 39.2 % (weight), after removal of calcite (calcareous cement and calcareous sand). They are comprised of rounded quartz and quartzite grains (92.8 % vol) with minor amounts of other minerals (Figure 2a). Among them, the few plagioclases (1.6 % vol) and microclines (1.2 % vol) show a first stage parallel linear and crossed linear alteration to calcite (Figs. 2 b, c, d), according to the weathering path described for igneous rocks in Iran (Yousefifard et al., 2015). There are few chlorites (3.6 % vol) and biotites (0.8 % vol), as noted by Bech et al. (1985).

3.2. GEOMORPHOLOGY OF THE NERETS SITE

The profiles at the Nerets site are located on two alluvial fans (Figure 3). The upper fan level has a very small extension with a single outcrop of about 500 m long, parallel to the slope and 100-200 m wide. It is located just above and west of the Les Arenes quarry at an altitude of between 560 and 580 m. It consists of a very regular reddish level, about 8-10 m thick, with iron-rich quartz sand, accompanied by some well-rounded sandstone gravels, a few cm in diameter. Its surface dips 10 % to the south.

In the distal part, this fan level is penetrated and passes laterally to a level of calcareous gravels and boulders with some blocks with a certain degree of bedding that corresponds to the continuation of the oldest alluvial cones described in the Tremp basin (defined as Qv5; ICGC, 2007), whose closest remains would be at the top of the hill of the Sant Miquel hermitage, NE of Suterranya (Figure 3).

This upper level originated through the denudation and accumulation of sands and clays from the alteration

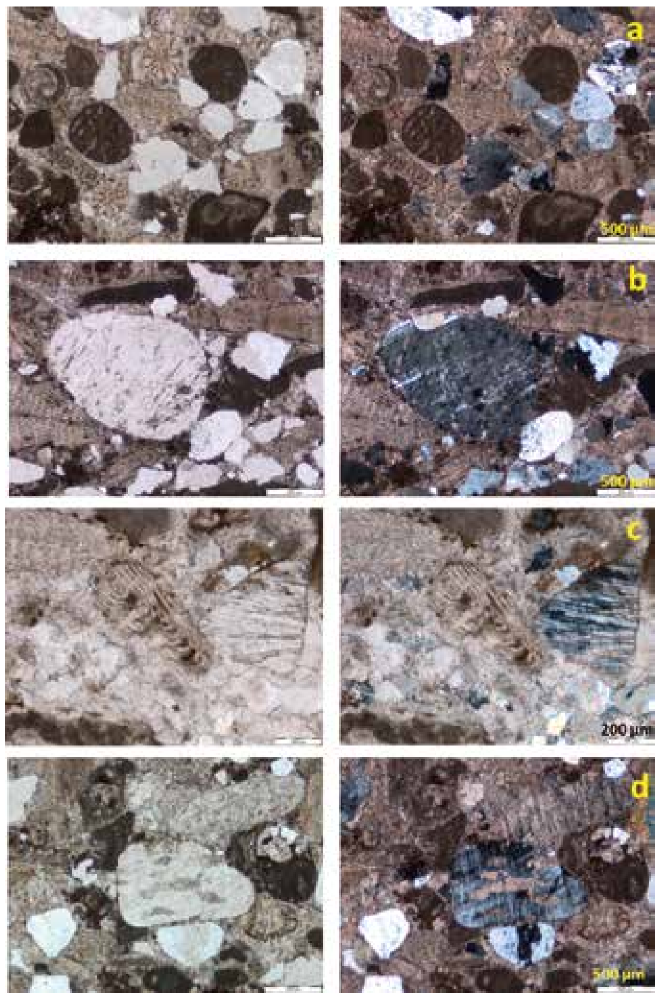

Figure 2. Micromorphology of the Areny calcarenite.

a. general appearance: note the abundance of fossils
b. and c. round microcline sand grains with slight cross linear and parallel linear weathering patterns
d. dotted alteration to micrite in a plagioclase

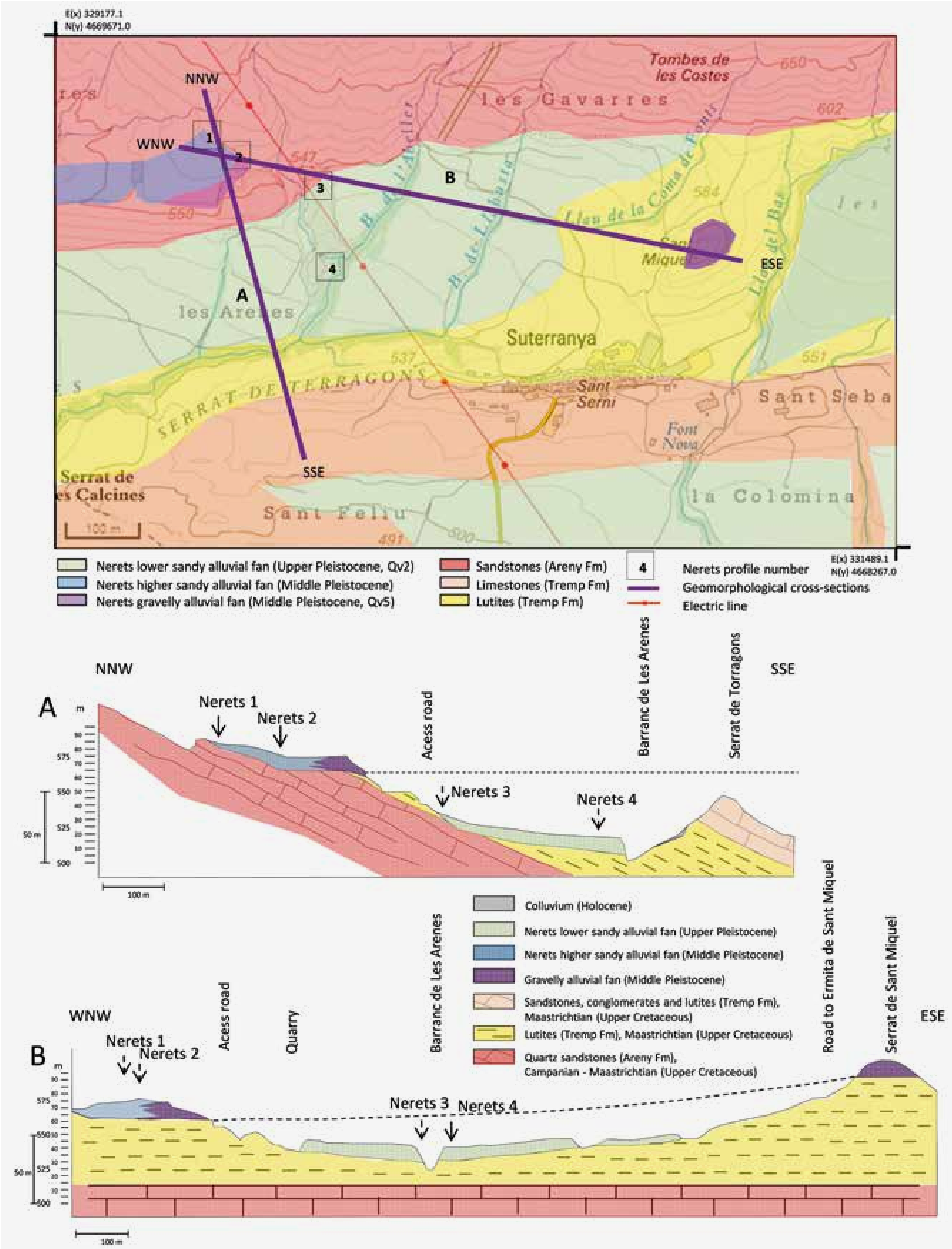

Figure 3. Geomorphological map and sections of the Nerets site (modified from ICGC, 2007).

and decomposition of the remains of the Areny sandstone at the footslope of the Nerets range. The karstification of the sub-structural surface of the Nerets range favoured the formation of rubefacted soils and the loosening of the sand grains forming the sandstones. The decomposition process was of a very high intensity, since there are no remains left other than the quartz granular components.

Its approximate age can be calculated through its correlation with the well-dated sets (U/Th series) of carbonate tobas (travertines) of the Basturs lake system covering them. The dating of Tufa 1 (the oldest one) that covers the Qv5 level is more than 350 ky (Pellicer et al., 2014), therefore the Qv5 level would be older. Materials on higher levels are synchronous to the deposition of the Qv5 level and, consequently, are considered the same age (> 350 ky) and thus attributed to the Middle Pleistocene.

The lower alluvial fan level covers the entire bottom (Figure 3) of the broad valley between the Nerets range and the reliefs of Suterranya at a height that oscillates between 550 and 500 m. At the southern side of the reliefs of Suterranya, this level can be correlated with the set of alluvial fans with a different composition that is defined as Qv2 (ICGC, 2007). The lower level shows very interesting outcrops in the Les Arenes quarry that produces loose quartz sands. The surface dips 11 % to the south.

The sediments of this fan are formed, as in the upper one, by quartz sands with scattered gravels of well-rounded quartz and red fine material. The lower fan has a maximum thickness of 2-3 m in the proximal part (apex) and 10-12 m in the central and distal parts.

This lower fan presents a clear correlation with the Qv2 surface formation materials (ICGC, 2004 and 2007), that are correlated with the T2 terrace of the Noguera Pallaresa River. In Basturs, the travertines of Tufa 3 (the lowest) are dated around 100 ky (Pellicer et al., 2014) and cover the Qv3 cone, at a higher level than the Qv2. Therefore, the age of Qv2 materials is much younger. On the other hand, the T2 terrace, located about 20-24 m above the Noguera Pallaresa river bed, has an Upper Pleistocene age (ICGC, 2004). In the Segre-Cinca system, this terrace has an age of about 50 ky (dated with OSL, Sancho et al., 2007; Lewis et al., 2009). In conclusion, we calculate the age of this lower fan to be around 50 ky.

The surfaces of the two alluvial fans have a height difference of about 40 m, which represents the erosion that separates them in the evolution of the drainage network. The sand level of the upper fan adjusts to the base level of the drainage network, excavated in the Dellà Basin in the Middle Pleistocene. As can be seen in the A section (Figure 3), this base level goes through the reliefs of Suterranya and connects with the slope of the wide valley of the Abella and Conques rivers. At that moment, the valley of Barranc de l'Abeller did not exist.

3.3. SOIL MORPHOLOGY AND PHYSICOCHEMICAL CHARACTERISTICS

The morphology of the profiles (Table 2) shows the development of B horizons and rubefaction (hues 2.5 and 5YR) in Comiols (Bw) and Nerets profiles (Bt, Btk, Bk, Bwk), while the Faidella profile only has very sandy Bw horizons and contains a buried profile without rubefaction. Redoximorphic features, as small mottles, are only observed at the bottom of Nerets 1.

All the Bt horizons described in the field correspond to an increase in the clay fractions (Table 3). These increases allow them to qualify for argillic horizons (SSS, 2014). Otherwise, the textures are sandy to sandy loam. Although Comiols, Faidella, and Nerets 1 are completely decarbonated (Table 2), only the Faidella profile has an acidic reaction throughout and the lowest base saturation (V=52 % at the surface, Table 3), followed by Nerets 1, which is partly desaturated (V between 80-90 %). Nerets 2 is decarbonated and Nerets 3 and 4 are partly decarbonated at the top horizons, but not decalcified since all of them have base saturations of nearly 100 %. In the case of Nerets 2, the underlying horizons show recarbonation processes, probably inherited from the dynamics in the fan. A clear colluvic character is observed in Faidella profile. Nerets 3 and 4 present frequent queras: biocalcifications similar to pseudomycelia, but composed of calcite pseudomorphs after root cells (Herrero et al., 1992). Besides the downward leaching of carbonates within the profiles, their accumulation within the fans proceeds roughly to the lowest (distal) sections, creating a complex spatial pattern with high variability in short distances. In spite of that, the lower boundary of the decarbonated horizons is clearly deeper in the upper fan (more than 1m) than in the lower one (about 40 cm, Table 2), which we can relate to their age.

Table 4 displays the different content of iron oxides of the studied soils as well as their ratios. The total iron strongly differs between and within profiles. In Nerets 1, it clearly increases with depth, but it does not follow the same trend in the rest of the profiles. Crystalline Fe (Fe_d-Fe_{ox}) of Nerets 2 tends to be lower in the carbonated horizons, but this trend does not apply to Nerets 3 and 4, with Fe contents unrelated to depth or to carbonate content. Nerets 3 and 4 have very high values of Fe_d/clay in the Bt horizons, which suggests a pedosedimentary origin of the parent materials. The Nerets1 profile shows the clearest weathering sequence: the amount of Fe-oxides (Fe_d-Fe_{ox}, hematite and goethite) and proportion of pedogenic iron (Fe_{ox}/Fe_d) increases in depth. Clear lithologic discontinuities are observed in Faidella and Nerets 2, 3 and 4, expressed as anomalous sequences of those indices, but all of them within the same range of values. This observation is in accordance with the colluvial material in Faidella and the

Table 2 Selected morphological characteristics of the profiles

Profile and horizon	Depth (cm)	Munsell colour (moist)	Redness Rating*	Structure	Mottles	Reaction to HCl	Pedofeatures
Faidella							
Oi	4 3						
Oe	-3-0	-	-	-	-	-	-
A	0-20	10YR 5/2	0.0	vw, cr, f	none	none	none
Bw	20-48	7.5YR 5/4	2.0	w, sab, m	none	none	none
Ab	48-65	7.5YR 4.5/3	1.7	vw, cr, m	none	none	none
ABb	65 82	7.5YR 5/6	3.0	w, sab, m	none	none	none
Bwb	82 110/120	7.5YR 5/8	4.0	w, sab, f	none	none	none
R	>110/120						
Comiols							
O	-1-0	-	-	-	-	-	-
A	0-15	2.5YR 3/3	7.5	mod, cr, m	none	none	none
AB	15-28	2.5YR 3/4	10.0	mod, sab, c;	none	none	none
Bw	28-80	2.5YR 4/6	11.3	faunal	none	none	Very few clay coatings
C	80-150	5YR 5/8	8.0	mod, sab, c	none	none	Very few clay coatings
Nerets 1							
A	0-11	2.5YR 5/4	6.0	vw, sab, m	none	none	none
AB	11-25	2.5YR 5/8	12.0	vw, sab, m	none	none	none
Bt1	25-42	2.5YR 5/8	12.0	vw, sab, c	none	none	Frequent clay coatings
Bt2	42-75	2.5YR 4/8	15.0	vw, sab, c	none	none	Abundant clay coatings
Bt3	75-113	2.5YR 4/6	11.3	w, sab, c	very few, Mn	none	Continuous clay coatings
Bt4	113 140	2.5YR 4/8	15.0	w, sab, c	very few, Mn	none	Abundant clay coatings
Nerets 2							
Bt	0-40/150	2.5YR 5/6	6.0	w, sab, m	none	none	Abundant clay and silt coatings
2Btk1	40/150-155/160	5YR 5/8	8.0	-	none	none	Few clay and silt coatings. Carbonate pseudomycelia, hard carbonate nodules.
2Bk2	155/160 160/200			apedal	none	very strong	Carbonate pseudomycelia and rhyzocretions.
3Bk3	160/200->230	5YR 5/8	8.0	apedal	none	very strong	Carbonate pseudomycelia and rhyzocretions
Nerets 3							
Oa	1 0						
A	0-9	5YR 3/4	6,7	m, cr, f	none	weak	none
Bt	9-38/49	2.5YR 4/5	9,4	m, sab, m	none	weak	Clay coatings
2Bwk1	38/49-41/70	5YR 5/6	6	m, sab, c	none	very strong	Frequent carbonate pseudomycelia and
2Bwk2	>41/70	5YR 4/6	7.5	m, sab, c	none	very strong	queras.
Nerets 4							
A	0-8	5YR 5/6	6.0	m, cr, f	none	none	none
Bt	8-36	2.5YR 4/6	11.3	m, sab, m	none	none	Few clay coatings around quartz grains
2Bk	36-127	7.5YR 6/6	2.5	vw, sab	none	very strong	Carbonate pseudomycelia and few queras
3Bwk	127-177	7.5YR 5/6	3.0	w, sab	none	very strong	Carbonate pseudomycelia, abundant queras and very abundant rhyzocretions (cm in size)
4Bk	177->277	10YR 6/6	0.0	w, sab	none	very strong	Generalized carbonate accumulation

vw: very weak; w: weak; mod: moderate; str: strong; sab: subangular blocky; cr: crumb; c: coarse; m: medium; f: fine
* Torrent (1983)

Table 3 Main chemical properties of the profiles

Profile and horizon	pH H_2O 1:2.5	$CaCO_3$ eq. (%)	OM (%)	Clay < 2µm	Fine Silt 2 20 µm	Coarse Silt 20 50 µm	Fine Sand 50 500 µm	Coarse Sand 0.5 2 mm	Texture	CIC (cmol+/kg)	CIC clay (cmol+/kg)	V%
				(%)								
Faidella												
A	5.1	0	0.97	2.4	2	1.5	11.6	82.5	S	2.4	98.1	52
Bw	5.8	0	0.38	2.7	1.8	0.5	11.1	83.9	S	1.6	58.5	68
Ab	6.6	0	0.45	3.9	3.9	1.3	10.8	80.1	S	2.1	52.9	93
Bwb	7.0	0	0.28	8.4	2.6	0.8	11.9	76.3	LS	2.4	28.0	100
Comiols												
A	7.5	0	2.89	7.5	6.9	2.2	16.2	67.2	LS	8.8	111.6	100
AB	8.1	0	1.33	13.3	7.1	2.6	19.1	57.9	LS	6.9	49.2	100
Bw	8.0	0	0.29	20.2	3.4	1.8	11.2	63.4	CL	7.6	37.0	100
C	8.1	0	<0.14	6	5.2	1.9	19	67.9	LS	1.6	26.4	100
Nerets 1												
A	7.1	0	1.1	6.9	1.1	3.4	40.2	48.4	S	2.7	36.9	100
AB	6.0	0	0.6	8.4	1.1	3.0	33.0	54.6	S	2.3	26.2	72
Bt1	7.2	0	-	11.1	2.1	3.4	43.5	40.0	LS	2.1	18.9	100
Bt2	6.7	0	-	10.1	1.1	3.7	45.9	39.1	LS	2.5	24.8	87
Bt3	6.4	0	-	18.2	2.7	3.1	25.5	50.6	SL	6.6	36.3	85
Bt4	6.1	0	-	17.3	1.1	3.0	36.3	42.2	SL	5.2	30.1	80
Nerets 2												
Bt	8.4	0	0.4	16.2	1.1	1.9	31.7	49.1	SL	5.6	33.8	100
2Btk1	7.2	0	0.5	18.2	2.1	2.7	34.7	42.4	SL	5.5	29.2	100
2Bk2	8.7	4.4	-	7.5	1.3	1.8	16.7	72.7	S	3.8	50.7	100
3Bk3	8.5	4.7	-	4.2	2.8	2.5	38.5	51.9	S	3.9	92.9	100
Nerets 3												
A	8.4	2	0.67	12.5	7.1	7.9	8.1	64.4	SL	6.6	51.5	99
Bt	8.5	3	0.36	22.3	7.1	8.4	8.2	54	SCL	9.9	43.7	100
2Bwk1	8.5	18	0.2	10.1	12	11	12.2	54.7	SL	5.1	50.1	100
2Bwk2	8.5	10	0.05	10.2	8.1	8.1	9.8	63.8	SL	3.4	33.2	100
Nerets 4												
A	7.6	1	2.22	6.9	3.6	4.9	20	64.6	LS	5.4	73.8	100
Bt	7.6	0	0.68	17	6.1	6.4	12.9	57.6	SL	8.2	46.9	100
2Bk	8.5	8	0.01	7.9	6.3	5.3	9.2	71.3	LS	2.9	36.7	100
3Bwk	8.6	8	0.1	14	10.1	8.1	12.2	55.6	SL	6.8	48.4	100
4Bk	8.2	23	0.1	12.3	9.3	6.6	9.3	62.5	SL	4.9	39.6	100

Table 4 Extracted iron composition of the profiles

Profile and horizon	Fe_{ox} (%)	Fe_d(%)	Fe_t (%)	Fe_{ox}/Fe_t	Fe_c/Fe_t	Fe_{ox}/Fe_d	Fe_d Fe_{ox}	Fe_t Fe_d	(Fe_d Fe_{ox})/Fe_t	Fe_d/clay	Fe index*
Faidella											
Bw	0.029	0.340	0.390	0.074	0.872	0.085	0.311	0.050	0.797	0.126	2.5
Bwb	0.040	0.950	1.320	0.030	0.720	0.042	0.910	0.370	0.689	0.113	8.1
Comiols											
Bw	0.029	2.150	2.420	0.012	0.888	0.013	2.121	0.270	0.876	0.106	19.9
C	0.007	1.180	1.170	0.006	1	0.006	1.173	0	1	0.197	6.0
Nerets 1											
A	0.007	0.270	0.480	0.015	0.563	0.026	0.263	0.210	0.548	0.039	6.7
AB	0.010	0.376	0.722	0.014	0.521	0.027	0.366	0.346	0.507	0.045	8.2
Bt1	0.016	0.660	0.919	0.017	0.718	0.024	0.644	0.259	0.701	0.059	10.8
Bt2	0.020	0.652	0.799	0.025	0.816	0.031	0.632	0.147	0.791	0.065	9.8
Bt3	0.050	1.366	1.738	0.029	0.786	0.037	1.316	0.372	0.757	0.075	17.5
Bt4	0.031	1.031	1.290	0.024	0.799	0.030	1.000	0.259	0.775	0.060	16.8
Nerets 2											
Bt 0-30 cm	0.036	1.009	1.499	0.024	0.673	0.036	0.973	0.490	0.649	0.062	15.6
Bt 90-120 cm	0.035	1.033	1.455	0.024	0.710	0.034	0.998	0.422	0.686	0.057	17.6
2Bk2	0.023	0.522	0.830	0.028	0.629	0.044	0.499	0.308	0.601	0.070	7.2
3Bk3	0.036	0.375	0.528	0.068	0.710	0.096	0.339	0.153	0.642	0.089	3.8
Nerets 3											
A	0,045	0,857	1,217	0.037	0.704	0.052	0.812	0.360	0.667	0.069	11.8
Bt	0,078	1,291	2,016	0.039	0.640	0.061	1.212	0.725	0.601	0.103	11.7
2Bwk1	0,029	0,775	1,222	0.024	0.634	0.037	0.746	0.447	0.611	0.035	21.5
2Bwk2	0,048	0,820	1,525	0.032	0.538	0.059	0.772	0.705	0.506	0.081	9.5
Nerets 4											
A	0,033	0,581	0,921	0.036	0.631	0.056	0.549	0.340	0.596	0.057	9.6
Bt	0,053	1,147	1,387	0.039	0.827	0.047	1.094	0.240	0.788	0.166	6.6
2Bk	0,017	0,533	0,832	0.020	0.641	0.031	0.517	0.299	0.621	0.077	6.7
3Bwk	0,043	0,869	1,820	0.023	0.477	0.049	0.826	0.951	0.454	0.051	16.2
4Bk	0,035	0,566	0,891	0.039	0.635	0.061	0.531	0.325	0.596	0.072	7.4

ox: extracted with (oxalic acid+ ammonium oxalate) 0.2M pH 3; d: extracted with Na citrate, Na bicarbonate and Na dithionite; t: total digestion with HCl and HNO_3

*Wagner et al., 2014.

Table 5 Elemental composition of the profiles (macro-elements, values in g/kg) and different weathering indices

	Ca	Mg	K	Al	CIA[1]	CIW[2]	WI[3]	Ti/V
Faidella								
Bw	0.2	0.5	2.4	5.6	68.1	96.2	219.2	11.0
Bwb	0.8	1.5	2.4	13.2	80.2	93.9	121.5	10.1
Sandstone	214.9	2.6	0.4	3.7	1.7	1.7		4.8
Comiols								
Bw	2.2	1.0	1.2	18.2	82.6	87.5	68.7	4.1
C	0.6	0.4	3.4	16.1	79.9	95.8	205.0	6.2
Sandstone	300.7	0.8	1.1	3.2	1.1	1.1		3.8
Nerets 1								
A	0.9	0.7	4.6	10.9	66.0	91.5		17.8
AB	0.3	0.5	1.5	10.7	85.3	96.5		16.9
Bt1	0.6	0.8	1.7	16.2	86.9	95.9		19.3
Bt2	0.5	0.7	4.9	15.3	73.5	96.0		16.1
Bt3	1.4	2.1	4.7	34.2	84.5	95.6		10.3
Bt4	0.8	1.4	6.6	29.9	79.8	96.9		11.1
Nerets 2								
Bt	1.9	1.4	8.7	27.0	71.4	92.6		11.7
2Btk1	1.0	1.6	7.9	27.9	75.2	95.7		13.8
2Bk2	14.0	1.3	4.9	19.4	50.4	57.8		15.2
3Bk3	17.7	0.8	1.2	14.4	43.2	44.8		23.5

[1]Chemical index of alteration (Nesbitt and Young, 1982);

[2]Chemical index of weathering (Harnois, 1988);

[3]Weathering Index (Price et al., 1991).

Table 6 Semi-quantitative fine earth and clay mineralogy of the profiles

Profile and horizon	Fine earth mineralogy					Clay mineralogy							
	Q	K-Fld	Pl	Phy	Ca	K	I	Sm	Chl	V	Chl/Sm	I/Sm	Chl/V
Faidella													
Bw	89.0	0.4		10.5		25.4	5.2		1.6			41.0	26.7
Bwb	82.9	2.4		14.7		12.5	1.0					74.9	11.5
Sandstone	46	0.4	-	3.5	49.5	2.0	5.3	-	-	-	-	92.8	-
Comiols													
Bw	88.1	0.3	-	11.6	-	78.2	1.3	-	-	5.1	-	15.4	-
C	91.6	0.6	-	7.9	-	82.9	3.0	-	-	-	-	14.1	-
Sandstone	17.5	0.2	-	1.5	80.9	90.0	9.8	-	-	-	-	-	-
Nerets 1													
A	60.0	21.0	-	19.0	-	50.0	8.3	8.3	-	-	20.0	16.7	-
AB	67.8	3.0	2.0	27.2	-	46.7	13.3	6.7	6.5	-	19.0	6.4	-
Bt1	85.2	2.1	-	13.1	-	42.9	14.3	4.8	9.5	-	20.0	4.8	-
Bt2	37.8	15.2	5.2	41.8	-	42.1	26.3	5.3	-	-	18.0	5.3	-
Bt3	27.0	1.4	0.9	70.7	-	40.0	24.0	4.0	-	-	20.0	12.0	-
Bt4	42.3	2.6	1.8	53.3	-	88.9	4.4	0.7	-	-	19.0	2.2	-
Nerets 2													
Bt	44.8	5.2	1.4	48.6	-	33.3	25.9	3.7	-	-	20.0	11.1	-
2Btk1	57.6	2.0	0.9	39.6	-	28.6	21.4	3.6	-	-	20.0	28.6	-
2Bk2	57.8	1.1	11.4	29.7	-	50.0	50.0	-	-	-	18.0	-	-
3Bk3	50.6	15.3	22.9	11.2	-	33.3	41.7	4.2	-	-	20.0	4.2	-

Q: Quartz, K-Fld: K-Feldspar, Pl: Plagioclases, Phy: Phyllosilicates, Ca: Calcite; K: Kaolinite, I: Illite, Sm: Smectite, V: Vermiculite.

alluvial fan evolution in Nerets. Additionally, it shows that the weathering degree does not depend on the age of the geomorphic unit, which would correspond in increasing age to Faidella/Comiols/Nerets 3 and 4/surface of Nerets 2/Nerets 1.

The elemental composition of Faidella, Comiols, and Nerets 1 and 2 (Table 5) shows a downward leaching of Ca, Mg, K in all profiles, and a relative enrichment of Al and Fe in the top horizons of Nerets 2 and Comiols, while they increase in depth in Nerets 1. Faidella has an anomalous behaviour in depth, due to the buried soil. The chemical weathering and alteration indices (Nesbitt and Young, 1982; Harnois, 1988), calculated with the element content, distinguishes the original sandstones (lowest indices) from the Bk (medium indices) and from the A and Bt horizons (highest indices) of the profiles.

3.4. SOIL MINERALOGY

Table 6 presents the profile mineralogy, both of the fine earth and of the clay fraction. The fine earth is mainly composed of quartz, with varying amounts of K-feldspars and plagioclases, which were inherited from the parent material. The absence of plagioclases in the sandstones must be attributed to the resolution of the method, which could not detect the plagioclases (Table 6), even though these were identified in the thin sections (Figure 2). Most of the phyllosilicates (reaching over 70 % in the Bt3 horizon of Nerets 1) are therefore pedogenetic. They consist of kaolinite (from 30 to 80 %) and illite (1 to 50 %), with considerable amounts of mixed layers of chlorite/smectite (around 20 % in Nerets1 and 2) or illite/smectite (2 to 75%). Minor components are chlorites, smectites, and mixed layers of chlorite/vermiculite, although the latter is only present in Faidella (11 to 27 %). These results are similar to those of Bech et al. (1985), who reported a predominance of kaolinite in similar profiles of the area.

The mineralogy of the two Areny sandstone samples is very different: the one at Comiols is more calcareous (81 % calcite), and the clay (1.1 %) is composed mainly of kaolinite with a little illite. The one at Faidella is less calcareous (50 % calcite) and the clay (3.5 %) is composed of mixed layers of illite/smectite. These compositions reflect that some pedogenesis took place during an early diagenesis that was not spatially homogeneous (Díaz-Molina et al., 2007).

3.5. SOIL MICROMORPHOLOGY

The common feature in all horizons is the coarse fraction, made up of coarse to very coarse sand and gravels of rounded quartz, equant and fresh that correspond to the skeleton of the sandstone, once decarbonated. The distinctive micromorphological characteristics are displayed in Table 7.

Contrary to the clearly microlaminated clay coatings of the Nerets1 and 2 profiles, the Bw of the Comiols profile does not show clear illuviated clay coatings. Very rarely, fine moderately anisotropic, dusty clay coatings appear around the quartz sands (Figure 4a). Instead, a chitonic c/f related

Table 7 Main micromorphological characteristics of selected horizons

	Microstructure and porosity	c/f related distribution	Micromass and b-fabric	Pedofeatures
Comiols				
Bw	Pellicular grain, compound packing pores.	Chitonic.	Dark reddish clay, mottled, stipple-speckled to undifferenciated b-fabric.	Few fine, moderately anisotropic, dusty clay coatings around the quartz sand grains.
Nerets 1				
Bt	Pellicular grain / vughy. Compound packing pores and vughs.	Chitonic.	Reddish clay, mottled, undifferenciated b-fabric.	Frequent microlaminated clay coatings on pore walls.
Bt2 47-67cm	Pellicular grain / vughy. Compound packing pores and vughs.	Chitonic.	Reddish clay, mottled, undifferenciated b-fabric.	Very few microlaminated clay coatings on pore walls.
Bt2 80-93	Vughy. Vughs and vesicles.	Closed porphyric.	Reddish clay, mottled, mosaic speckled b-fabric.	Microlaminated clay coatings and infillins around coarse fragments, fragmented and incorporated to the groundmass.
Bt4	Vughy. Vughs and vesicles.	Closed porphyric.	Reddish clay, mottled, undifferenciated b-fabric.	Microlaminated clay coatings and infillins around coarse fragments, fragmented and incorporated to the groundmass.
Nerets 2				
Bt	Single grain pellicular/ vughy. Compound packing voids and vughs.	Chitonic to close porphyric.	Reddish clay, mottled, mosaic speckled and granostriated b-fabric.	Microlaminated clay coatings and infillings, with different fragmentation and deformation degrees, frequent.
Bt/2Btk1	Single grain pellicular/ vughy. Compound packing voids and vughs.	Chitonic to close porphyric.	Reddish clay, mottled, mosaic speckled and granostriated b-fabric.	(1) Microlaminated clay coatings and infillings with different fragmentation and deformation degrees, frequent. (2) Loose discontinuous infillings of micrite aggregates and microsparite (rods) in pores, superposed to (1). (3) Agregate nodules and incomplete dense infillings of calcite, pseudomorphs of plant components, irregular distribution, superposed to (1), breaking them and mixing them with calcite. (4) Nodules of Fe oxi hydroxides, aggregate, few, associated to (3).
2Bk2	Vughy, vughs.	Close porphyric.	Grey, fine silt, clay and micrite, cristallitic micritic b-fabric.	(1) Strongly impregnated micrite hypocoatings on vugh walls, abundant. (2) Dense incomplete infillings of micrite and acicular calcite on vughs, interlaced. (3) Micrite nodule, gravel size, with internal interlaced fabric. (4) Nodules of Fe oxi-hydroxides, aggregate. (5) Coatings of silt and clay around coarse fragments, mostly on sandstone fragments, isotropic.
2Bk2 (150 cm)	Intergrain microaggregate. Vughs, compound packing pores.	Enaulic.	Grey, fine silt, clay and micrite, crystallitic micritic b fabric.	(1) Strongly impregnated micrite hypocoatings on vugh walls, abundant. (2) Dense incomplete infillings of micrite and needle calcite in vughs, very frequent, following interlaced patterns. (3) Aggregate nodules of Fe oxy-hydroxides.
3Bk3	Id.	Id.	Id.	Id.

distribution, with a stipple-speckled to undifferentiated b-fabric is observed (Figure 4b). This is why, despite the description of some coatings in the field, we designate this horizon as Bw and consider it a cambic horizon. However, the weak anisotropy of the micromass may be due to the high Fe-dithionite (Table 4) contained in cryptocrystalline Fe-oxides, which can mask any orientation of the clay particles; therefore, clay illuviation should not be discarded.

The upper horizons of Nerets 1 (down to Bt2) have a chitonic c/f related distribution, with a reddish mottled clay as the micromass, isotropic under crossed polarizers, that covers the quartz grains. In these horizons, varying amounts of microlaminated clay coat the pore walls (Figure 4c). Below these horizons, clay illuviation, more frequent microlaminated clay coatings, and infillings around coarse fragments can be observed. They are fragmented and incorporated into the groundmass. The c/f related distribution becomes close porphyric in depth (Figure 4d).

The upper horizons of Nerets 2 are very similar to the bottom horizons of Nerets 1 (see Table 7): the micromass has a mosaic speckled and granostriated b-fabric and the clay coatings and infillings are fragmented and

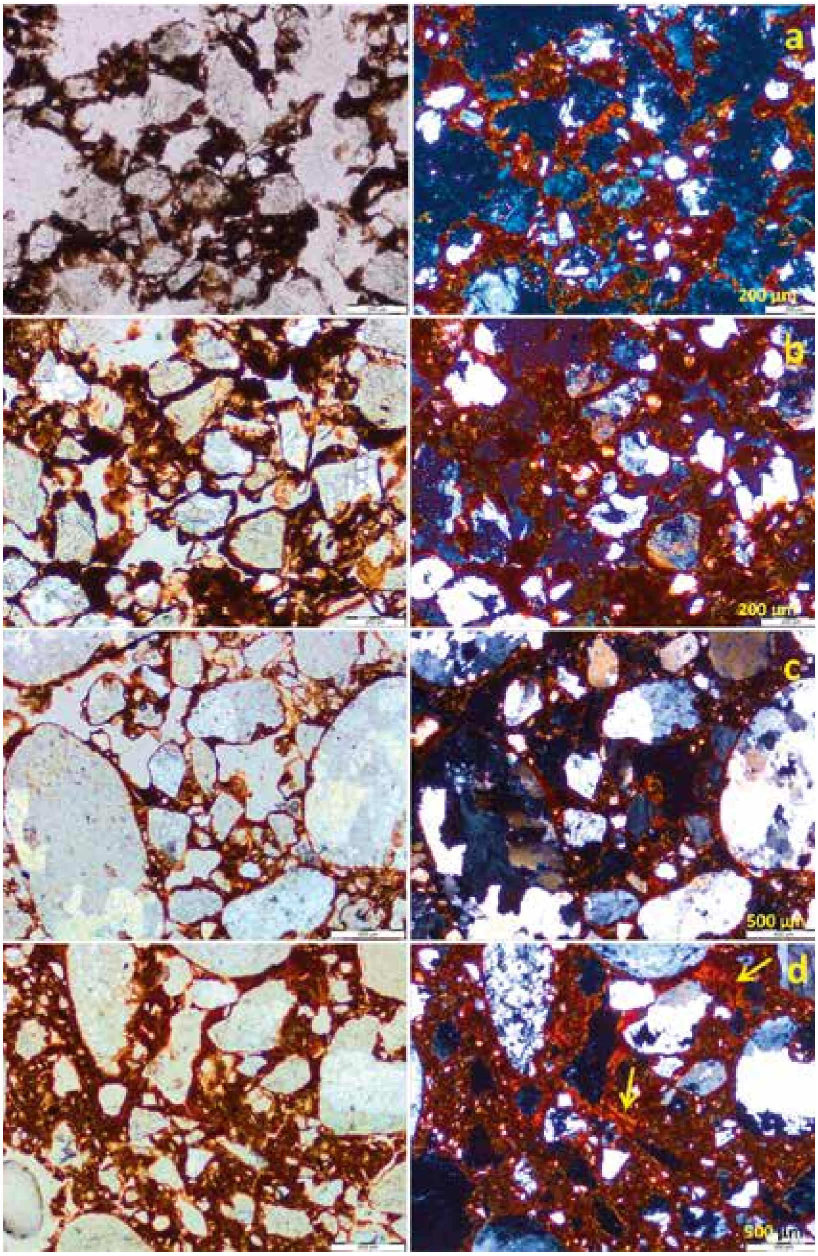

Figure 4. a. moderately microlaminated clay coatings in Bt horizon of Comiols

b. chitonic c/f related distribution and almost undifferentiated b-fabric, probably due to an abundance in Fe oxi-hydroxides in the Bt horizon of Comiols

c. chitonic to gefuric c/f related distribution and fine microlaminated (anisotropic) clay coatings in Bt1 horizon of Nerets 1

d. progressive clogging of packing pores by micromass in Bt2 horizon of Nerets 1, resulting in a close porphyric c/f related distribution, note the clay coatings (arrows) deformed at various degrees (Figure 5a). Below the non-carbonated part, calcitic pedofeatures are present. They are superposed to the clay coatings, breaking them and mixing them with calcite (Figure 5b). The coarse fraction of the 2Btk1 horizon contains some rounded gravels made of fragments of the original calcareous sandstone and sparite, besides the quartz grains (Figure 5c). The micromass has a micritic cristallitic b-fabric. The calcitic pedofeatures are represented by hypocoatings and needle fiber calcite (Figure 5d).

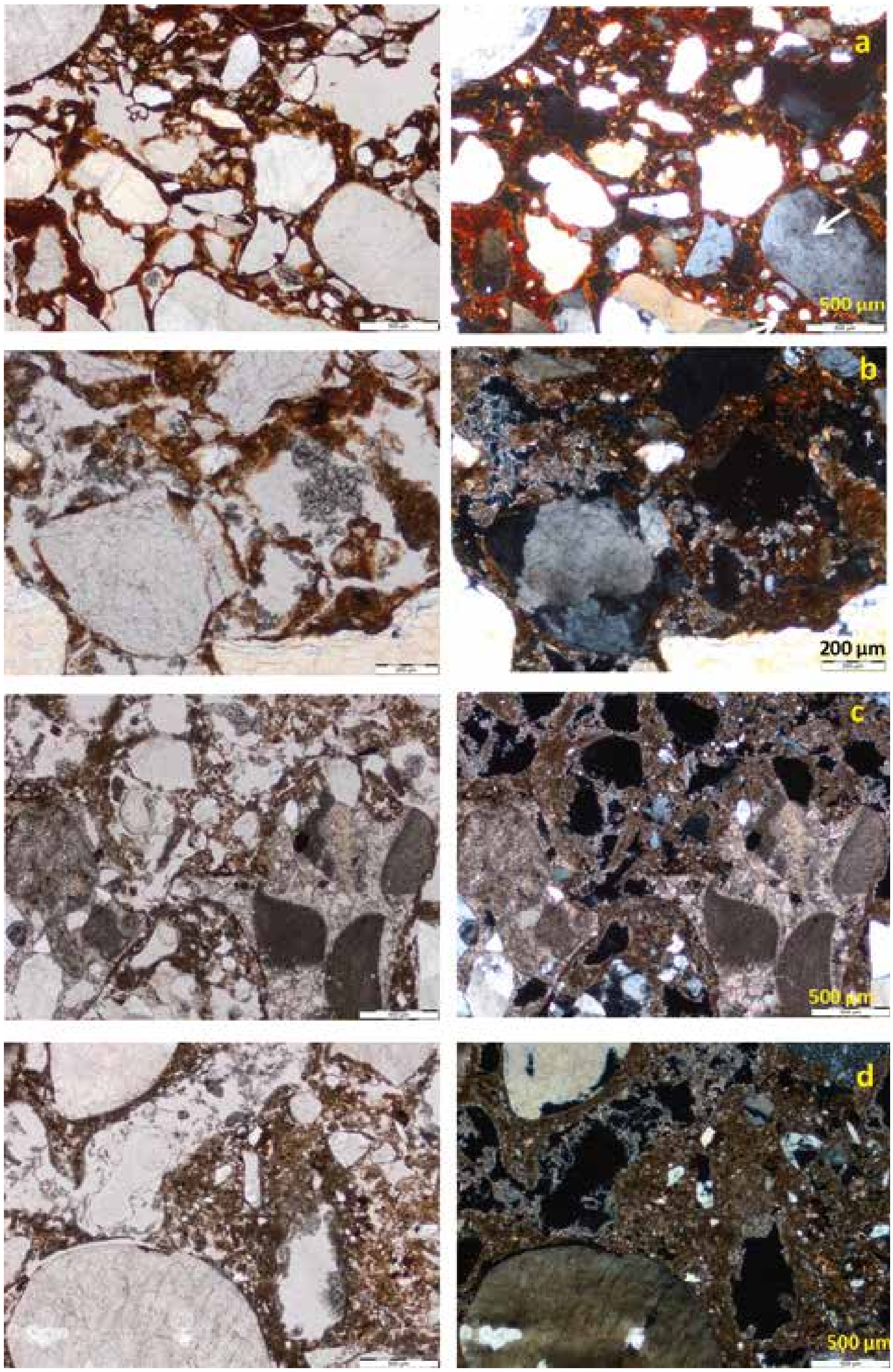

Figure 5.
a. micromass with a chitonic to close porphyric c/f related distribution and a mosaic speckled b-fabric, due to deformation and fragmentation of previous clay coatings in Bt horizon of Nerets 2
b. loose discontinuous infillings of needle calcite (upper left) and micrite coatings (lower center) in Btk2 horizon of Nerets 2
c. fragments of the original Areny sandstone in Nerets 2
d. loose discontinuous infilling of needle calcite in a channel (upper left) and micrite coating and impregnative hypocoating in a pore (lower right) in 2Bk horizon of Nerets 2, (100-110 cm)

3.6. SOIL CLASSIFICATION

Table 8 shows the classification of the six profiles according to the two international soil classification systems. According to Soil Taxonomy (SSS, 2014), Faidella and Comiols are Entisols and Inceptisols respectively, while all the profiles at the Nerets site are Alfisols (Xeralfs). This classification allows the distinction between the older Nerets 1 and 2 (Palexeralfs) and Nerets 3 and 4 (Haploxeralfs). According to WRB (IUSS Working Group WRB, 2015), Faidella and Comiols are Arenosols and Cambisols, Nerets 1 is a Lixisol and the rest are Luvisols, reflecting the result of the different durations of the soil-forming processes.

4. Discussion

An advanced weathering stage can be observed in some of the studied soils, as evidenced by the red colour (Nerets 1 in particular), the decarbonation, and by the predominance of kaolinite in the clay fraction. While the red colour might be attributed to present-day processes under a Mediterranean climate, decarbonation and kaolinite are apparently not in agreement with the climate of the area. Indeed, carbonate mobilisation and accumulation is one of the main soil-forming processes in the rest of the parent materials under the same climate. Kaolinite is the typical 1:1 clay under highly weathering environments (high temperature and high water availability throughout the year). Nevertheless, the Areny sandstone presents a higher susceptibility of being decarbonated than the neighbouring marls because of its sandy nature and partial brecciation during diagenesis (higher permeability) and because calcite is mainly present as a cement of the quartz sand.

Nevertheless, only two of the profiles (Faidella and Nerets 1) are partly decalcified. In the first case, it is due to its position at a higher altitude and consequently receiving more precipitation (Ustic regime) and lower evapotranspiration. In the second case, it is due to a limited lateral calcium-rich flow component, which in the rest of the profiles prevents decalcification and maintains the base saturation near to 100 %. In spite of that, the vertical flow has played a clear role in the decarbonation of the soils, shown by the lower depth of decarbonated horizons in the soils of the lower fan.

Regarding clay illuviation, it should be seen as the result of clay dispersion in decarbonated material, since in nearby areas in the Pyrenees, on carbonate-free parent materials, clay illuviation is a present-day process (Poch et al., 2013). It is interesting to see that neither the development degree of the clay-illuviated Bt horizons, nor the redness rating, nor the Fe-index are related to the age of the geomorphic unit, where they develop, or their altitude. This supports the thesis of a pre-weathering of the materials that were redistributed on different levels of alluvial fans during the Quaternary. The meta-analysis of Sauer (2010) reports that a time span of 100 to 300 ky is necessary to develop the redness ratings we found in Nerets profiles. These values are in the range of the age of the landform where Nerets 1 and 2 profiles are found, but not of that of Nerets 3 and 4, which is much younger, and therefore it is an indication of redistribution of pedosediments down the slope. Additionally, the Fe_d/Fe_t and $(Fe_d\text{-}Fe_{ox})/Fe_t$ indices, which can be used as age indicators in Mediterranean environments, correspond to profile developments older than 800 ky (Calabria, Scarciglia et al., 2015) or than 600 ky (Southern Spain, Martín-García et al., 2016) on surfaces of the Conca de Tremp that are actually about 350 ky (Nerets higher alluvial fan) and 50 ka (Nerets lower alluvial fan) or on slope colluvium (Faidella and Comiols profiles).

Table 8 Classification of the studied profiles according to the Soil Taxonomy (SSS,2014) and World Reference Base (IUSS Working Group WRB. 2015)

Profile	Soil Taxonomy	World Reference Base
Faidella	Typic Usthorthent	Eutric Brunic Arenosol (Colluvic, Nechic)
Comiols	Typic Haplustept	Eutric Chromic Cambisol (Loamic, Ochric)
Nerets 1	Arenic Palexeralf	Chromic Lixisol (Arenic, Cutanic, Hypereutric, Ochric)
Nerets 2	Calcic Palexeralf	Calcic Chromic Nudiargic Luvisol (Cutanic, Loamic)
Nerets 3	Calcic Haploxeralf	Calcic Chromic Luvisol (Cutanic, Loamic, Ochric)
Nerets 4	Calcic Haploxeralf	Calcic Chromic Luvisol (Cutanic, Loamic, Ochric)

5. Conclusions

The fast pedogenesis rates of the Areny sandstones, which has been taking place since its diagenesis in the Upper Cretaceous, is responsible for the lack of a correlation of the different age proxies used in Mediterranean environments (redness indices and iron ratios) with geomorphic position (geomorphic unit ages). The formation of kaolinite, karstification and partial decarbonation are considered as inherited processes, which have been acting since the pre-Quaternary period, while reddening and clay illuviation together with calcium carbonate redistribution may be more recent. The present-day soils are therefore developed on pre-weathered pedosediments that underwent some of the typical Mediterranean weathering under very different environments. This advanced pedogenesis is confronted, in the same basin, with a different pedogenetic path, i.e. calcium carbonate mobilisation and the formation of calcic and petrocalcic horizons on surfaces of similar ages developed on different materials.

Our findings allow us to conclude that the degree of development of the studied soils is controlled by the nature of the parent material, which masks, in our case, the effect of the rest of the soil-forming factors.

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5

Present and future use of soil data

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THE DATABASE OF THE SUBSOIL IN FLANDERS (DOV) RELATED TO SOIL AND ARCHAEOLOGICAL RESEARCH

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ABSTRACT
Soil data in Flanders are included in the DOV soil database available to all users. As such, the work done by soil surveyors and scientists is still very relevant today. This paper explains what kind of soil data are included in DOV and how they can be consulted. The aim of DOV is to become the reference for sharing data, knowledge and services, about the soil and subsoil of Flanders. It concerns open data, which can be integrated and linked to other data sources. In addition to raw data, DOV offers professional knowledge and interpreted information, as well as the services and applications to activate and mobilize these data.

KEYWORDS
soil, soil data, database, DOV, soil profile, soil map, soil heritage, photographs, erosion, soil organic carbon content, landslides, archaeological research

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1. Introduction

In Belgium, a huge amount of soil surveys has been effectuated in the 1950s to 1970s. The result of this intensive soil research is the Belgian Soil Map (Marechal and Tavernier, 1974). This large number of data is nowadays included in a database available to all users, and as such the work done by hundreds of surveyors and scientists is strongly useful still today.

Databank Ondergrond Vlaanderen (Database Subsoil Flanders) or DOV in short, connects, develops and disseminates information and knowledge about the soil and subsoil of Flanders, according to the specifications of the European INSPIRE Directive (2007). DOV is a partnership of three divisions within the Flemish government. The products of DOV can be used free of charge. DOV offers data on the themes soil, geology, geotechnics, groundwater, mineral resources and geothermics for the Flemish region. The data are publicly available through the online DOV-Verkenner, a geoviewer capable of both accessing detailed geo and non-geodata and creating and editing data. Furthermore, the data are offered for internal use through read-only databases and for public (re-)use as Open Data in the form of over a thousand data layers. Most of the data are in Dutch, but some data products are also provided in English.

2. Soil data in DOV

The paper focusses on the available soil data that can be consulted in DOV. The other themes of DOV will not be described in this paper. The theme 'soil' offers data on the following topics:

- The DOV soil database contains '**Soil locations**' ('bodemlocaties') with soil profile and soil auger data. This dataset contains both the soil data resulting from the mapping campaign of the Belgian soil map (1947-1973) as other historical or recent soil data (e.g. from archaeological investigations).

- There are **soil maps** available with different levels of detail: the Digital Soil Map of the Flemish Region (1:20 000) (Oorts et al., 2017) derived from the Soil map of Belgium (1:20 000) (Marechal and Tavernier, 1974), the Soil Association Map (1:500 000) (Tavernier and Maréchal, 1959) and the Soil Map of Belgium according to the international soil classification system World Reference Base (WRB) (Dondeyne et al., 2014 and 2015).

- **Erosion** is an important cause of soil degradation in Belgium, mainly in hilly areas with sandy loam and loamy soils. DOV offers several thematic maps focusing on soil erosion: the yearly updated potential soil erosion map on parcel level (Oorts et al., 2019), the erosion susceptibility map of the Flemish municipalities and the map with the preferential runoff.

- The **soil organic carbon content** is a good indicator of soil quality and very important in climate issues. In DOV you can find the Soil Organic Carbon Stock Maps for Belgium (40 m grid and 1 km grid) which are also incorporated in the Global Soil Organic Carbon Map (FAO and ITPS, 2018; GLOSIS - GSOCmap (v1.5.0), 2019).

- Finally, there is the susceptibility map for landslides and the actual mapped landslides (Van Den Eeckhaut and Poesen, J., 2009). **Landslides** are defined by a downslope movement of soil material.

3. The DOV-verkenner: a starting point to explore soil data

The following part will describe how the DOV soil data can be consulted in the online DOV-verkenner. When searching for soil information, the easiest way to start is to enter an address in the entry field of the online DOV-Verkenner, which will zoom to the area of interest.

The button 'kaartlagen toevoegen' (add map layer) allows the users to add the soil layers they need. For reasons of visualisation, the online Soil Map of Belgium (*Bodemkaart van België* (1:20 000)) is subdivided into 5 data layers: soil types ('bodemtypes', this layer contains all the information of the soil map), substrates ('substraten'), phases ('fasen'), variants of the parent material ('varianten van het moedermateriaal') and variants of the profile development ('varianten van de profielontwikkeling'). In order to see the necessary detailed information, the user must zoom in to at least 1:150 000.

Once the user has added the online Soil Map of Belgium in the DOV-verkenner, he can click on any location to get information about the soil type. This soil type ('bodemtype') will appear in the results ('Resultaten voor de doorprik') below the map.

By clicking on soil type ('bodemtype') in the information table, a pop-up window will open giving additional information about this soil type.

The pop-up explains the different properties/characteristics and gives a general description of this soil type. In addition, there are several interesting links to: a pdf-file of the explanatory note, the analogue original map sheet (published on 1:20 000), and the maps with the location of the original augerings of the specific map sheet

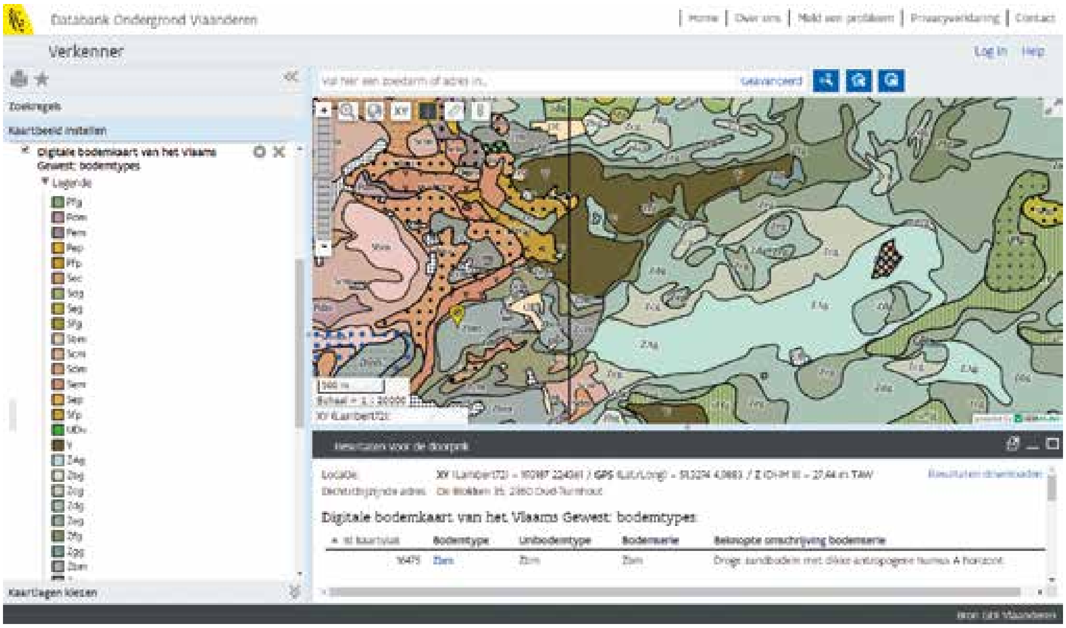

Figure 1. Visualization of the soil map in the DOV viewer.

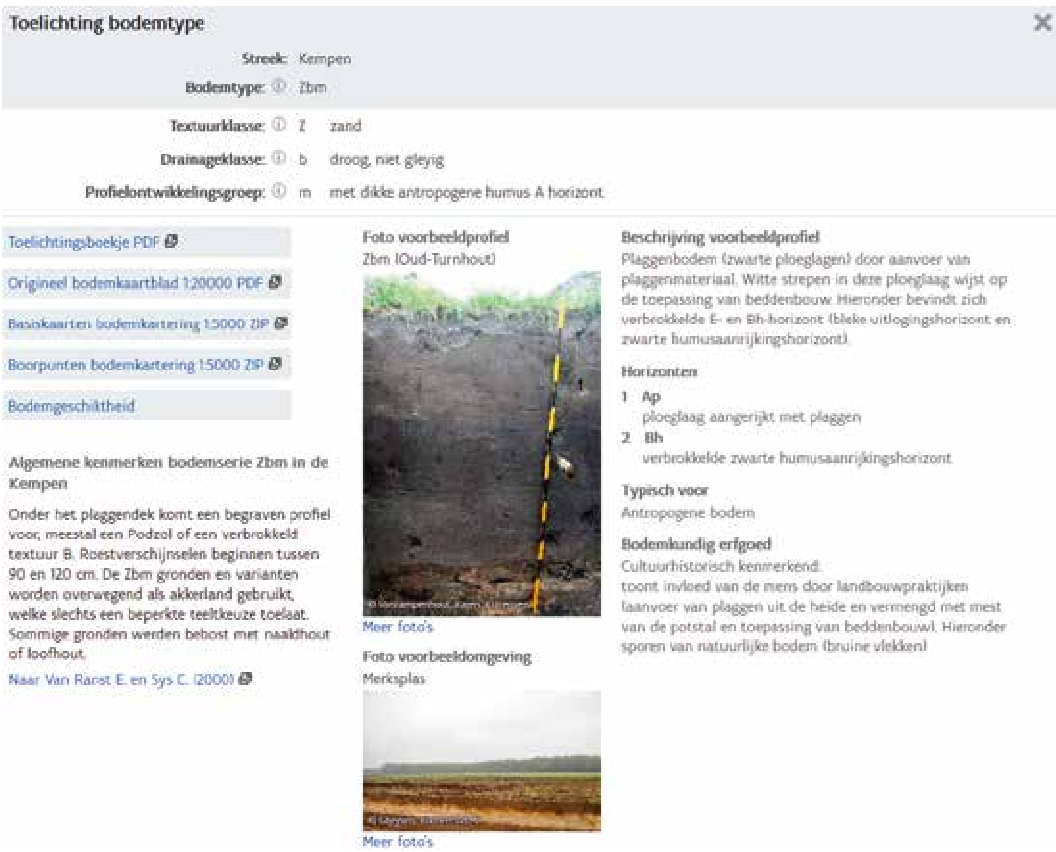

Figure 2. Pop-up window of a specific soil type.

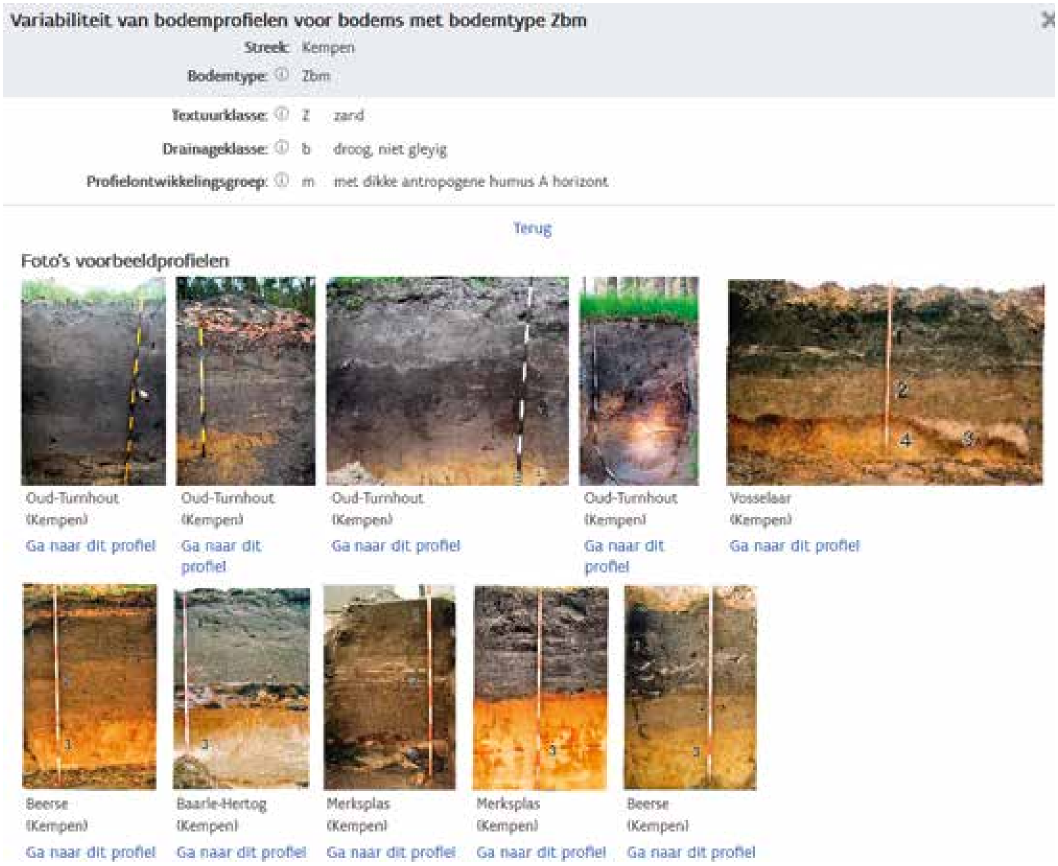

Figure 3. The variability of soil profiles for a soil type.

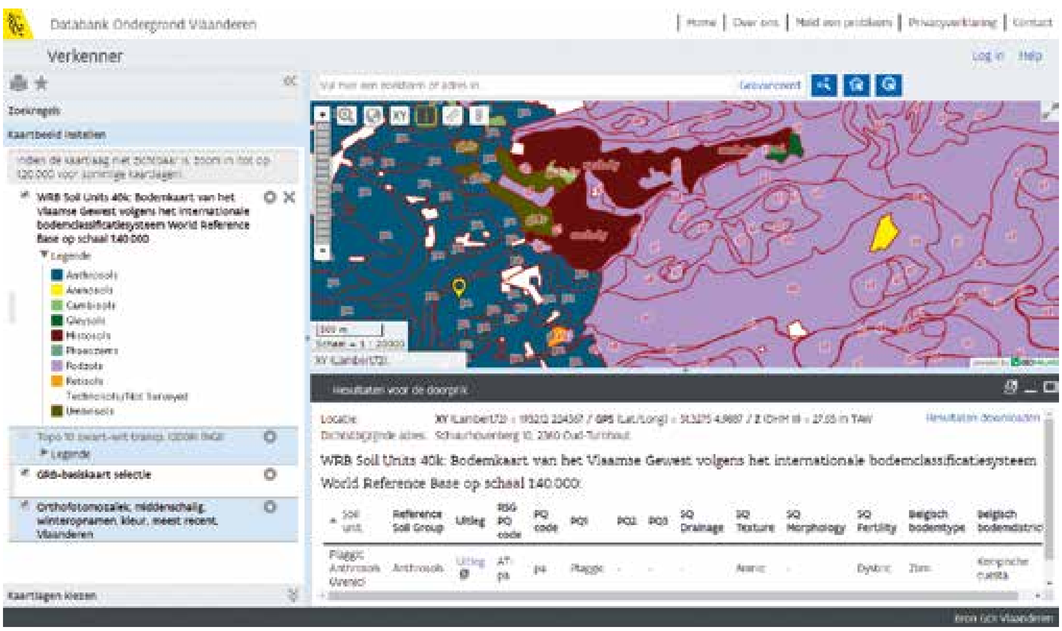

Figure 4. The Belgian soil map according to the international soil classification system WRB.

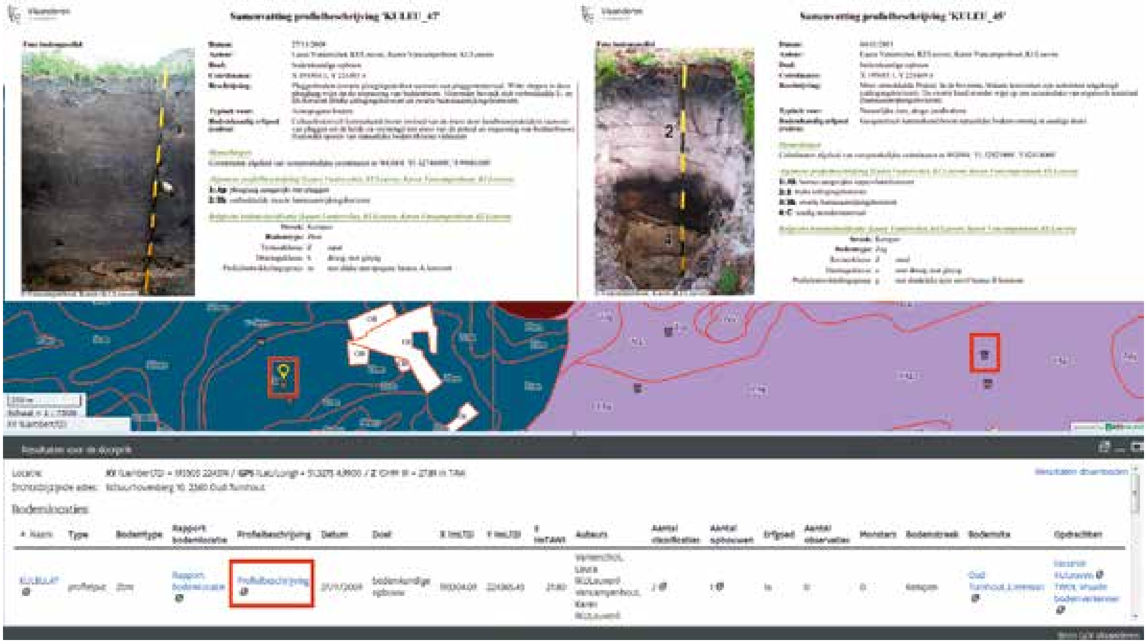

Figure 5. Example soil profiles from the layer 'Bodemlocaties' in the zone with anthropogenic and the zone with natural soils.

of the soil mapping project (analogue version on scale 1:5 000). There is also some information available on the soil suitability for different agricultural land uses from a point of view of agricultural economics.

Finally, the pop-up gives an example of a typical soil profile and its surroundings in which such a soil might occur, illustrated with photographs, a soil profile description and the soil heritage evaluation (Ampe et al., 2006). To get an idea of the variability of a certain soil type, one can click on the hyperlink 'Meer foto's'. Dondeyne et al. (2017) stated that such visual information layers should contribute to a better interpretation of the soil maps and soil data.

Below each of these profiles there can be found another hyperlink ('ga naar dit profiel'), which enables you to get a closer look at the characteristics of that specific soil profile.

The soil map according to the international soil classification system WRB gives a different view on soils in a region. For example, in Figure 4 the same region as in Figure 2 is presented. Two zones now become clearly visible on the soil map: a zone with anthropogenic soils (Anthrosols with plaggen) corresponding to former infields of the villages and a zone with natural soils (Podzols) corresponding to former outfields.

By using the layer 'Bodemlocaties' containing soil profiles from the DOV soil database, the user can select soil profiles in the zones with Anthrosols and Podzols in order to study the differences between the anthropogenic and natural soils. The soil profile descriptions of these soil profiles from the layer 'Bodemlocaties' can be visualized by clicking the link to the profile description ('Profielbeschrijving') in the results ('Resultaten voor de doorprik') for this layer.

In this way users of the DOV application have a vast amount of soil information available at their fingertips.

4. Virtual borehole

The newest tool in DOV is the 'Virtual Borehole' ('Virtuele Boring') (De Nil et al., 2018). This tool allows the user to carry out a (virtual) drilling at any location in Flanders. The result provides information on the geology, the hydrogeology and the soil type. Evidently one always needs to bear in mind that this application is the result of interpolation and interpretation. It can never replace a real drilling or a real soil profile in the field, but it can be a very practical tool for a preliminary investigation.

The 'Virtual Borehole' tool immediately proved to be very convenient and even more so when the mobile version was launched in 2018. The web application (DOV, 2018) can easily be installed on smartphone or tablet computer and can be used at any location, for example, during an excursion or when doing fieldwork.

Figure 6. The mobile version of the 'Virtual drilling' tool proves very useful in the field.

5. Conclusions

Since the start of DOV, the soil data in DOV have grown from a collection of a few GIS-layers to a soil database with many soil profiles and a large amount of data layers. Soil data from different disciplines (e.g. archaeological research, soil science, etc.) are brought together in the DOV soil database. A vast amount of soil data from numerous soil scientists, among them Roger Langohr, are already incorporated in the DOV soil database and available for soil scientists, archeologists, spatial planners, farmers, etc.

However, still many especially recent soil data are not yet incorporated in the DOV soil database. Moreover, the interest in the soil in building areas is growing but the Belgian soil mapping campaign omitted these building areas, resulting in a lack of soil information. Soil data from archaeological investigations are particularly valuable to provide recent soil information, especially for these building areas. The challenge for DOV in the coming years is to support an open, multidisciplinary soil community that shares and centralizes their data in the DOV soil database, making soil data integrated and accessible, instead of locked up in separate private databases. Regarding this, DOV offers applications and xml-import to add new soil data to the DOV soil database. A significant increase of data in the DOV soil database will facilitate an integrated multidisciplinary use of soil data for Flanders and allow updated soil maps, and several models based on soil data.

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SOIL AND ARCHAEOLOGICAL GROUNDWORKS FOR LANDSCAPE DEVELOPMENT PROJECTS OF THE FLEMISH LAND AGENCY

The case study of Assebroek

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ABSTRACT
This paper describes the preliminary soil and archaeological research carried out by the Flemish Land Agency, to achieve a well substantiated project design. At the circular structure of Ver-Assebroek (Bruges), the site of a former medieval castle, a landscape development project aims to increase the visibility of the structure while respecting the soil values and archaeological structures on the site.

KEYWORDS
circular structure, peat, limnic material, land development project

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1. Introduction

In Ver-Assebroek (Bruges, Belgium) a large man-made circular structure is positioned on the edge of humid meadowlands (Assebroekse Meersen) and a dry sandy ridge on which the church of Ver-Assebroek is located. Ameryckx (1955) was the first to describe this structure in detail. During the '80s, the site was further examined by De Meulemeester (1981), Soers (1987) and the University of Ghent (UGent) and afterwards a multi-disciplinary research (combining historical, geophysical, soil and archaeological analysis) was contracted (Ryssaert et al., 2010) by the Flemish Government in preparation of the protection of the site as an 'archaeological zone' (2012).

The meadowlands and the archaeological site are part of a land development project called 'Groene Fietsgordel' (VLM, 2009). The project aims to increase the quality of the 'green belt' around the city of Bruges and to complete the missing links between the green spaces of the cycling network encircling the city. A land development plan was agreed between different governmental partners, town councils, farmers, NGO Natuurpunt, and the Water Board (polder). At Assebroekse Meersen the measures consist of restoring the nature values of the humid meadowlands by improving the water management system and securing the future of the archaeological site through visualisation and maintenance.

2. Study area

The circular structure of Assebroek is located on the edge of a large basin-shaped depression (called Assebroekse Meersen) that lies between 3,75 and 5 m TAW (m a.s.l.) south of a cover sand ridge with altitudes of up to more than 10 m TAW.

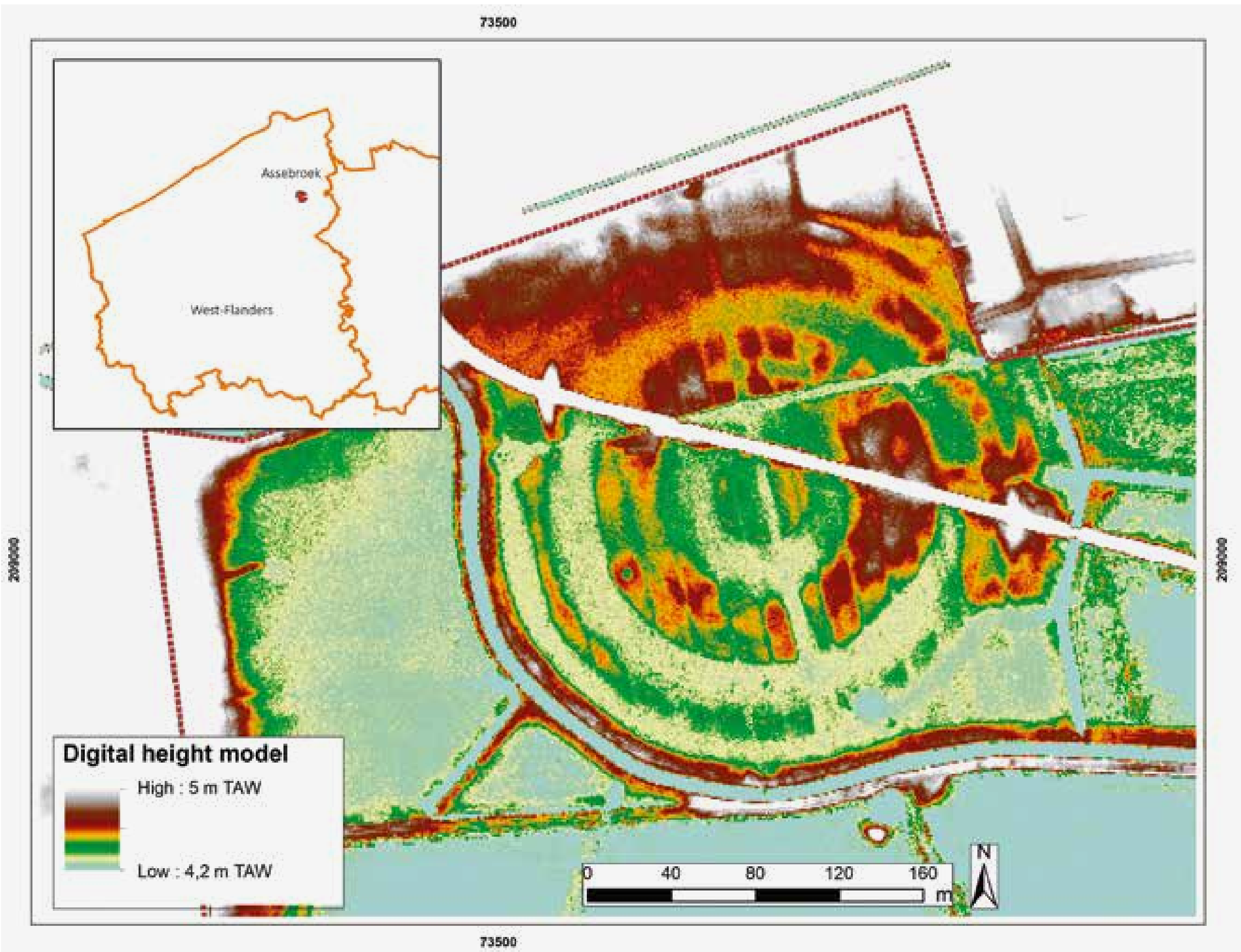

Figure 1. Location of the Assebroekse Meersen in West-Flanders, Belgium and the digital height model (*Digitaal Hoogtemodel Vlaanderen* II, 2013) showing the four circles of the archaeological site.

The Assebroekse Meersen have a very specific landscape position within the Sandy region. They are part of the 'Zuidbrugse dallandschap' (Deduytsche, 1974), a wide basin-formed depression south of Bruges in which different valleys convene. During the Late Glacial period the cover sands were reworked to a broad cover sand ridge from Gistel to Stekene (De Moor and Heyse, 1978) obstructing the river systems. At the Assebroekse Meersen a palaeolake was formed and filled with lake marl sediment. The lake evolved to a swamp and in due course peat developed (soil series V) (Soil map of Belgium, Brugge 23W, MGI, 1958). The soils and former hydrological conditions form a very suitable environment for the development of *Calthion palustris* grasslands.

The circular structure of Assebroek consists of 4 concentric ditches separated by banks. The inner ditch is up to 40 m wide, the second 20 m, the third and fourth only 7 m. The outer circle has a diameter of 260 m. The concentric ditches surround a central platform mound with a diameter of approximately 50 m (Figure 1). The platform was elevated by sand and held a castle in the form of a fortified house or tower. The site was built in the 13th century, but already abandoned at the end of the 15th or early 16th century (Ryssaert et al., 2010). The archaeological findings in the ditches are covered by peat, which suggests water saturation conditions after the abandonment of the site. In the 19th century the area was remediated for agricultural use. New parcelling was applied, ditches were dug and the mound, banks and historical ditches were levelled. In 1863 a tramway was constructed through the site.

3. Aim of the study

The interdisciplinary approach has two objectives: restitution of the original ecosystem and a visual representation of the archaeological site.

The main bottlenecks for the preservation of intended habitats in the meadowlands are 1) excessive drainage in summer causing deep groundwater tables and degradation of the peat; 2) flooding during winter with nutrient rich water from polluted ditches; 3) spilling over of excess water on the meadows of the sewage system after heavy rainfall; 4) changes in the last decades towards a more intensive agricultural use of the meadowlands.

Additionally, the visual observation of the archaeological site of Assebroek is at present very difficult. The microrelief of ditches and banks is hardly observable. Heavy trampling by cattle, drainage by recently made ditches cutting through the site, and the tramway track splitting the site in two are the main causes for the decreased visibility of the site.

The aim of the landscape restoration project is to optimise the water management (both water quality and quantity) on the archaeological site and in the meadowlands. The project will also improve the visibility and 'readability' of the circular structures and the landscape of the archaeological site.

4. Material and methods

The study of the soil and ecology by the VLM and the inventory of the archaeological structure formed the basis of the project design. At the same time, Ryssaert et al. (2010) collected historical data and soil data by augering, geophysical survey and 3 trenches in preparation of the designation of the site as a protected heritage site.

In order to refine the data, additional research by VLM was necessary. Soilscape research through augering consisted of 10 transects in a radial pattern according to the terrain conditions starting from the centre of the archaeological structure. Augerings were placed every 10 m as long as profiles were intact. Distances in between were shortened to 0,5 m whenever the profile morphology changed. Each augering was located by dGPS and combined with the digital height model (*Digitaal Hoogtemodel Vlaanderen* II, DSM, *raster*, 5 m; 2013) and an ecological recording. Soil profiles were described according to FAO guidelines (2006).

5. Results

The digital height model (DTM) (*Digitaal Hoogtemodel Vlaanderen* II, DSM, *raster*, 5m; 2013) was used for an easier location of the structures on the field. By manipulating the height interval, it became possible to recognize the ditches of the archaeological structure and the ditches and drainage ditches of the 19th century parcelling pattern. Across the structure the track of the tramway runs with different elevated access ramps to the parcels.

The soil – landscape research by augering resulted in a distinction into 3 soil units:

1. Natural profile: the substrate is formed by Eemian sediments. On top of these are limnic sediments with gyttja in the lower part and marl in the upper part (Figure 2). The surface horizon consists of peat (dated on the site between approx. 1750 – 1400 BC, Ryssaert et al., 2010). This peat was probably exploited in medieval times, and most likely this horizon was originally thicker. Towards the sandy ridge in northern direction, the surface horizon gradually changes from peat to clayey to sandy material, and the thickness of the marl gradually peters out towards the sand ridge.

2. Ditches: the study of Ryssaert et al. (2010) showed that the 2 most inner ditches were dug through the limnic sediments into the sandy layer. Moreover, the trenches showed a 2-stepped profile with a first level on the limnic layer and a second level cutting through this layer into the substratum of the sandy material. The slope is very gradual from the onset of the ditch towards the first level. Because of natural accumulation of organic matter in water saturated conditions after the site had been left, the peaty layer was much thicker in the ditch than in the natural profile, with an abrupt lower boundary. In this recent peat, plant remnants are often visible unlike in the older peat which is amorphous. The older peat showed a natural transition to the limnic layer, which helped to distinguish the boundary between the original soil and the ditch. Finally, the shallow depressions of the ditches were recently (in the 19th and 20th centuries) refilled with heterogenous materials up to 10 – 20 cm thick of humiferous sandy loam to sandy material. Most archaeological information lies in the slope of the ditches and in the deeper central part of the ditches. In the project design, these zones had to be excluded from any disturbance in order to protect the archaeological heritage features. The outermost (fourth) circular ditch and part of the third ditch, in the northern part of the structure, are situated in the transition zone between the sandy ridge and the peaty depression. The argument of the absence of the marl layer as an indicator for the existence of a ditch could not be used here. In this case, it was only the presence of a humiferous horizon indicating the refill of the ditch.

Figure 2. Assebroekse Meersen. The natural profile shows a horizon of about 45 cm thick consisting of amorphous peaty material, underlain by marl sediments with former root galleries (bar = 80 cm).

3. Mound and banks between the ditches: the natural profile has been buried with (on average) a 40 cm thick mixture of peat, marl and sandy material. The closer towards the centre of the site, the more archaeological artefacts (bricks, pottery, ...) appeared (Ryssaert et al., 2010). The profile sequence is all the way through made up of mixed materials of limnic material with peat and sand originating from digging the ditches and used for the construction of the mound (in a latter phase this material is ploughed) – peat – limnic materials – sandy/loamy material.

Based on the soil typology and the DTM is was possible to delineate, with high accuracy, the ditches and to determine their width. The central island has a diameter of 48 m. The width of the first ditch, between the cutting through the marl, is 20 m. In the ditch lies a recent secondary fill on top of the recent peat, which has developed since the abandonment of the site. The bank between the first and second ditch measures 38 to 40 m. The bank was raised with a mixture of peat, sand and marl on top of the original peat. The second ditch is, between the cutting of the marl, about 12 m wide, the next bank between 20 to 23 m. The third ditch is about 7 m wide. The fourth and outermost ditch could not be identified in the trenches nor through augerings at the SE side. However, at the NW and NE side a ditch was encountered with a width of 5 to 6 m and identified through the presence of humiferous sandy material up to 160 cm deep. At the S and SW-side, the fourth ditch continues in a brook called Sint-Trudoledeken. Whether this brook was incorporated into the site or vice versa is still a question to be answered (Figure 3).

6. Progress of the project

The aim of the landscape restoration project is to optimise the water management on the archaeological site and in the meadowlands and to improve the hydrological and soil conditions for the development of high quality meadowlands. The first phase of the project was completed in 2016. In the meadowlands, the water management works involved the instalment of weirs and earth dams to regulate the water level and to retain more water during summer. Clearing water courses, ditches and drainage ditches was needed to improve water flow and to increase the buffer capacity of the area. A bypass of the Meersbeek towards the meadowlands ensured the supply of good quality water. The cycle path was rerouted and the tramway track was removed.

The second phase includes the upgrading of the archaeological site to improve the visibility of the archaeological structure. It includes the removal of the felted turf in the ditches of the southern part, of the recently (19th and 20th century) applied heterogenous materials in the ditches of the northern part, and of the access ramps. A recently dug ditch that drains the site will be refilled with locally recuperated sandy material. Finally, a walking path will lead to the core of the archaeological structure where a viewpoint will be established.

As the circular structure of Assebroek is legally protected as an archaeological site, it is a challenge to develop a restoration plan without damaging the site and the soils and to safeguard the ecological values. The soil – landscape reconstruction through augering made it possible to establish the exact thickness of the recent deposits, which can be removed without disturbing the archaeological structures.

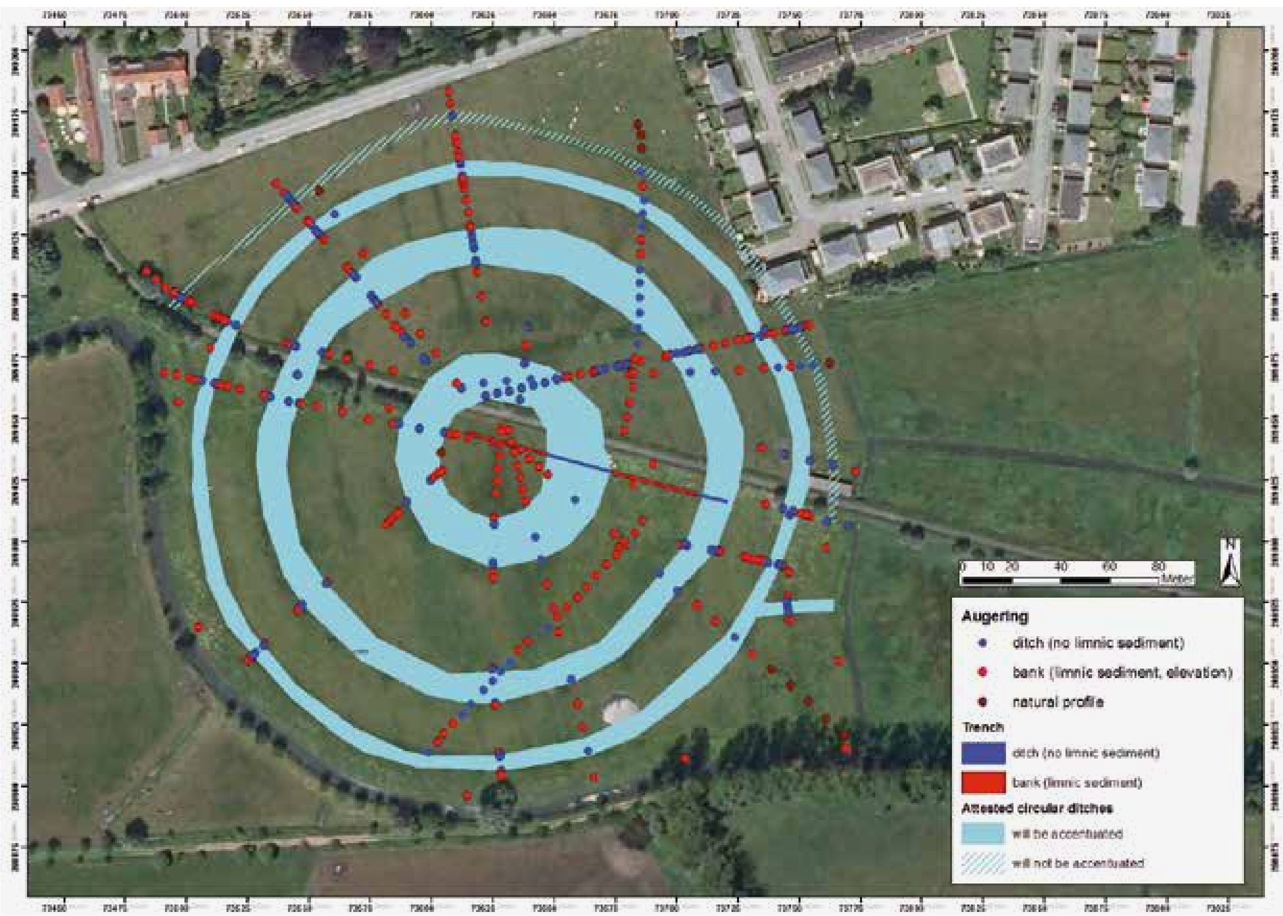

Figure 3. Localisation of the circular ditches separated by banks, position of the augerings and trench (Ryssaert et al. (2010); research VLM).

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ARCHAEOLOGY AND SOIL SCIENCE IN FLANDERS

Personal reflections of an archaeologist in 2019

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ABSTRACT
This paper presents some of the personal reflections of an archaeologist who studied soil sciences at Ghent University in the 1980s. The paper focuses on how soil science, amongst other sciences, gradually found its place in archaeological practice in Flanders, in part thanks to opportunities and activities at Ghent University between 1984 and 2005. Nowadays, the curricula/ educational programmes of the universities in Flanders do not at all stimulate the interaction between soil sciences and archaeology. This feels like a setback, back to the pre-1984 era, which is unfortunate, as earth scientists familiar with archaeology are needed more than ever for archaeological fieldwork in 21st century Flanders.

KEYWORDS
soil science, archaeology, educational programmes, 1963-2019, personal reflections, code of good practice

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1. Introduction

This short paper presents some of the personal reflections of an archaeologist who studied soil sciences in the eighties of the previous century. It describes how soil science gradually found its place in archaeological studies in Flanders. Ghent University and especially Prof. R. Langohr had a key role in this evolution over the period 1980-2005. The personal reflections are, where possible, supported by published information, which is listed in the bibliography. It is clear that the curricula of the universities in Flanders play an important part in the discussion of this evolution. Finally, the paper refers to 'a soil science or pedological approach' *sensu stricto* and consequently does not include a geological nor a geomorphological approach.

Archaeologists and soil scientists both study the upper part of the earth's crust. Generally speaking, archaeologists generally look for information about past human behaviour and its relation with the natural environment archived on and in the soil. Soil scientists study soils more holistically to understand their genesis, evolution, distribution, properties and qualities, how to manage soils sustainably and beneficially and finally, improve them. Human activity is more and more often considered to be an important soil forming factor by soil scientists (Dudal, 2004). Archaeologists spend a tremendous amount of their research time digging into soils to obtain the information they are looking for. Thus, as both soil scientists as well as archaeologists have the soil as a primary research object, one would expect both fields of study to have some parts of their curriculum in common. A quick look at the present-day archaeology and soil science programmes of universities in Flanders (Leuven, Ghent and Brussels) shows that this is not the case. At best, the archaeology programmes offer an introduction to soil sciences. Additionally, the soil science programme jointly organized by Ghent University and the Free University of Brussels called 'Master of Science in Physical Land Resources (Soil Science)' is not open for students with a bachelor's degree in archaeology (studiekiezer.ugent.be, consulted June 2019). This situation is at odds with the growing demand from the archaeological sector in Flanders for experts in earth sciences, especially since the introduction of the new archaeological legislation in June 2016. The fact that the above-mentioned master's programme in soil sciences is not open for students with a degree in archaeology is comparable to a similar situation in Flanders 35 years ago.

2. Soil Science and archaeology at Ghent University 1963/1983-1984

After following the optional 'Introduction to soil science' course for archaeology and history students at Ghent University, lectured by the late professor R. Tavernier in 1982-1983, I became strongly interested in this field and decided to continue with soil science studies from 1984-1985 onwards. At the time, a post-graduate master course in soil science was organised at Ghent University. Unfortunately, this 2-year course only admitted geologists, geographers, agronomists, botanists, ... and not archaeologists or historians from the humanities department.

Thus, in 1983, I contacted Professor R. Tavernier, director of The International Training Centre (ITC) for Post-Graduate Soil Scientists (Van Ranst and Stoops, 2013), hoping to find a way to overcome the diploma issue. Prof. Tavernier was thoroughly convinced of the need for archaeologists to possess more than just notions of soil science and completely agreed that it was very useful for archaeologists to be able to study soil science as well. He promised to do everything he could to officially allow students with a degree in archaeology to enrol in the 'Licentiate degree in Soil Science' at the ITC, which he had founded 20 years earlier. Negotiations lasted nearly a year as Prof. Tavernier had to convince his colleagues to open up the degree to archaeologists in a time in which only a few shared his views on the topic. On the 10th of October 1984, just in time for me personally, I received a letter from the rector of Ghent University stating that the diploma requirement was withdrawn, thus allowing me (and other archaeologists) to start the studies in soil science. In the meantime (1983-1984), I had followed a preparatory course in chemistry, as suggested by Prof. Tavernier.

The presence of Prof. Tavernier in his function as director at the ITC in 1983-1984 was a first important element for archaeologists who wanted to become more knowledgeable in soil sciences in Flanders.

A second important element for archaeology and soil science in Flanders was the presence of Professor R. Langohr at the ITC at the same time. From the early 1980s onwards, Prof. Langohr developed a growing interest in archaeopedology and geopedology (Ampe, 2006). Students interested in archaeology and palaeoenvironment reconstruction were given the opportunity to do archaeo- and/or geopedological research for their master's dissertation in soil science. For me personally, this meant that I started preparing my master's dissertation in soil science right from the start of the 2-year cycle in October 1984, under the supervision of Prof. Langohr. As an archaeologist interested in studying soil sciences applied to archaeology, I could not ask for more.

Because of my combined qualifications in archaeology

Table 1 Master dissertations and Ph.D. theses at Ghent University on soil science for archaeology/paleo-environment reconstruction performed on archaeological sites or finds from archaeological sites in Belgium

Master theses		
Farah O. M.	1985	Study and survey of particular soil characteristics in relation to the archaeological site of Kerkhove, North-western limit of the Belgian Loess Belt
Pieters M.	1986	Ontwikkeling en Toepassing van Bodemprospektietechnieken voor archeologische sites van de Belgische Zand- en Leemstreek
Mees F.	1989	Base Maps and Soil Survey of Undisturbed Iron Industry Sites in the Zonien Forest (Loess Belt, Belgium)
Vandeweghe F.	1989	Soil Variability at the Archaeological Sites of Aubechies (Loess Belt) and Adegem (Coversand Belt, Belgium)
Mestdagh H.	1990	Introduction to the micromorphological study of mortar-, plaster- and pavement fragments in the civitas Menapiorum
Fechner K.	1991	Soil characteristics due to water in archaeological contexts in the sandy to sandy loam area of Northern Belgium. A contribution to paleoenvironment reconstruction
Becze-Deák J.	1993	Geo-pedological study of selected profiles along the gas pipeline through the Polder and Coversand areas of East and West Flanders (Belgium)
Louwagie G.	1996	Geo- and archaeopedological study of the 'Old Colluvium' on the sites of Chièvres and Taintignies (Province of Henegouwen, Belgium)
Fockedey L.	2003	Soilscape and Landuse Evolution in Maldegem-Adegem (East-Flanders): Reconstruction Based on Historical-Geographical and Archaeological data using GIS
PhD Thesis		
Louwagie G.	2004	Palaeo-environment reconstruction and evaluation based on land characteristics on archaeological sites. Case study I: Verrebroek "Dok" and Doel "Deurganckdok" (Belgium, Province of East-Flanders). Case study II: Easter Island (Chile)

Sources: i. Pedon (25 volumes, 1990-2014); the Newsletter for alumni and staff from the International Training Centre for Post-Graduate Soil Scientists, yearly overview of the master- and PhD-theses at the International Centre for Eremology and the International Centre for Physical Land Resources and ii. personal information

and soil science, I was hired as a soil scientist for the archaeological excavations at the site of the Louvre museum (1989-1991) (Van Ossel and Pieters, 1998) in Paris (France), where someone with these qualifications was required. Apparently in France, the combination of soil science and archaeology was also not readily available at the time.

3. Soil science and archaeology at Ghent University 1985-2005 and after

The combination of the possibility to officially take the courses in soil science (the Licenciate degree of 2 years as well as the advanced studies of 1 year) and the presence of Prof. Langohr, strongly interested in the connection between soil science and archaeology, attracted many local and international archaeologists and earth scientists interested in archaeology, mainly in the period of 1984-2005, . This is reflected in the number of master and Ph.D. dissertations during this period, focusing on soil science in archaeology/palaeo-environment reconstruction (Table 1), and also in numerous scientific articles published by fellows from all over Europe who, for various periods, had the opportunity to learn to read the "Book of Nature" under the supervision of Prof. Langohr.

In addition to the above listed master and Ph.D. dissertations, the archaeo- and geopedological research coordinated at the ITC also resulted in a wealth of research papers in scientific journals and chapters in books. An exhaustive overview of these types of research activities performed on archaeological sites in Flanders, similar to the overview made in 1990 for the province of East-Flanders (Pieters, 1990), is out of scope for this contribution. This overview is currently being prepared at the Flanders Heritage Agency as a chapter for the second generation of the Research Balance Archaeology (onderzoeksbalans.onroerenderfgoed.be) (Pieters et al., in preparation).

The archaeo- and geopedological work at ITC also had an impact on archaeological practices and research far beyond Flanders and Belgium, as illustrated by the master and Ph.D. dissertations below (Table 2).

The screening of 25 volumes (1990-2014) of 'Pedon' made it painfully clear that after 2005 no more dissertations (master or Ph.D.) in Physical Land Resources (Option Soil Science) with an archaeo- and geopedological subject are mentioned in the published lists of graduates. This

Table 2 Master dissertations and Ph.D. theses at Ghent University on soil science for archaeology/paleo-environment reconstruction performed on archaeological sites abroad

Master Theses		
Fulatjar E.	1993	Impact of human activity on the development of chernozems in the Loess hilly Land north-east of Risnovce (Nitra Department, Slovakia)
Buysschaert X. J. G. C.	1995	Study of the Eemian Soil Complex at the archaeological site of Tönchesberg II (Eifel-Germany)
PhD Theses		
Becze-Deák J.	1997	Study of secondary CaCO3 in the frame of geopedological research and reconstruction of the environment evolution of the last interglacial-early glacial sequence at the Wallertheim site (Rheinhessen-Germany)
Mestdagh H.	2005	Environmental reconstruction of the Last Interglacial and early Glacial based on soil characteristics of Pedocomplexes on loess at selected sites from Atlantic Coast to Central Asia

Sources: cfr. Table 1.

possibly suggests that no soil scientists with experience in archaeo- and geopedology have graduated from Ghent University after 2005. This is regrettable, as the archaeological sector, and thus also the need for archaeopedologists, in Flanders has started to expand and evolve quickly from 2004/2005 onwards.

4. The expansion of the archaeological sector in Flanders from 2004/2005 onwards and the growing need for earth scientists

The expansion of the archaeological sector in Flanders from 2004/2005 onwards is mainly the result of the gradual implementation in Flanders of the so-called 'the-polluter-pays-principle' according to the treaty of La Valletta/Malta (1992) (www.coe.int).

The implementation process of the La Valletta treaty started in Flanders in 1993 with the commissioning of the Archaeology Decree. This decree, in over 20 years of existence, allowed for several changes to systematically improve the degree of implementation of the treaty of La Valletta in Flemish law. The Archaeology Decree was eventually incorporated into the 'Immovable Heritage Decree (Onroerenderfgoeddecreet)' in 2013. But, as this new decree only became fully effective concerning archaeology in June 2016 (codex.vlaanderen.be), the Archaeology Decree of 1993 stayed in force until that date. The new legislation for archaeology was accompanied by a 'Code of good practice for conducting and reporting on archaeological research and metal detection (CGP)'. This code replaced the 'Minimal requirements for the registration and documentation of intrusive archaeological research and the way of reporting' in use from 01/11/2011 until 31/03/2016 (https://codex.vlaanderen.be).

A very important step in this historical process of implementation was the creation in 2004 of a unit of archaeologists devoted exclusively to the management and protection of the archaeological heritage in Flanders (Meylemans and Vanderbeken, 2008). The creation of this unit in the Flemish administration combined with the improvements to the archaeology decree stimulated the archaeological sector to expand from the above-mentioned years onwards.

Over the timespan of 1993 to 2016, Flanders moved from a government-dominated (regional as well as local) archaeology to an archaeological sector predominantly consisting of private companies. One of the consequences of the expansion of the archaeological sector and the growth of the number of excavations is the increasing need for experts in earth sciences devoted to archaeological problems.

The need for and the lack of available earth scientists able to perform relevant fieldwork and earth science research in an archaeological context in Flanders is clearly illustrated in the evolution of the consecutive versions of the 'Code of good practice for conducting and reporting on archaeological research and metal detection (CGP)'. The first version of this code, published at the end of 2015 by the Flanders Heritage Agency and to be used from the 1st of April 2016 onwards, reserved earth science-related activities, such as soil profile descriptions, exclusively for earth scientists. By the second version of the code, the Agency introduced the role of the so-called 'assistant-earth scientist' (Ribbens, 2018, 14), mainly to reduce the research assigned to earth scientists to those which truly require the expertise of an earth scientist. Less complicated aspects of the earth sciences could be handled by an 'assistant-earth scientist', which can be an archaeologist with a lot of fieldwork experience. This change was partly inspired by the lack of earth scientists available on the job market to carry out the CGP required research activities.

To obtain some quantitative information on the relationship between soil science and archaeology in

Flanders the Open Access Repository (OAR) published by the Flanders Heritage Agency is an important source of information. From 2004 onwards, private companies active in the archaeological sector have realised many archaeological research projects (prospection trench diggings as well as full-scale excavations). 3718 reports from these projects realised according to the 'Archaeology Decree of 1993' were recently published online through the OAR of the Flanders Heritage Agency (consulted on July 12, 2019). This is a very valuable source of information and can help gain insight in the relationship between soil science and archaeology in Flanders. A first observation is that of the 3718 reports, only 8 mention the word 'pedological' (in Dutch: 'bodemkundig') in the title, about 0.2 % of the reports. More positive is that at least 140 reports have an earth scientist devoted to archaeology as a co-author, about 4% of the published reports. This figure is still rather low and clearly too low for tackling all the earth science related problems, probably mainly due to the above-mentioned shortage of available experts. The reports with an earth scientist as a co-author (Table 3) occur from 2010 onwards and in general show an increase until 2015. The decreasing trend after 2015 can be explained by the new legislation, the 'Immovable Heritage Decree' (2015), which fully became functional for archaeology on the first of July 2016 and which significantly changed the reporting modalities for archaeologists. Reports realised according to the Archaeology Decree of 1993 will gradually fade out over the coming years. The observed decreasing number of reports with an earth scientist as a co-author is thus a 'legal artefact' and does not indicate a lesser involvement of earth scientists in archaeological excavations.

The publication of the 'Code of good practice for conducting and reporting on archaeological research and metal detection (CGP)' coincided more or less with the introduction of the new archaeological legislation and replaced the formerly used 'minimal requirements' (codex.vlaanderen.be). The change from 'minimal requirements', in use from 01/11/2011 until 31/03/2016, to a 'Code of good practice' introduced new specifications to earth science related research. As noted before, after a while these specifications had to be adapted to the introduction of an 'assistant-earth scientist' as a result of the lack of earth scientists available to do the work (cfr. supra).

One would expect that from the 1st of April 2016 earth scientists became more frequently involved in excavations (full-scale or trial trenching), as the code of practice is more demanding in this respect than the 'minimal requirements' that didn't mention the role of earth sciences in archaeology.

A quick screening of the documents (in Dutch: 'nota's') that have to be submitted to the Flanders Heritage Agency after (postponed) intrusive research in an area to be archaeologically evaluated in order to obtain a building or a re-allotment permit seems indeed to point towards a growing involvement of earth scientists in archaeological projects. On the 1158 '*nota's*' published on the archaeology portal (https://loket.onroerenderfgoed.be/archeologie/notas/notas/goedgekeurd, consulted on June 15, 2019) at least 151 show the involvement of an earth scientist. Thus, in at least 13 % of the archaeological projects an earth scientist was involved. Based on a brief examination, most of these earth scientists seem to be geologists. Soil scientists with experience in archaeology are only involved in about 3 % of all projects.

Table 3 Number of reports per year with an earth scientist devoted to archaeology as a co-author

2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	0	7	14	24	17	11	40	18	4	4

The above mentioned 'Code of good practice' also stipulates that the valuable earth science data obtained during archaeological fieldwork in the form of descriptions of reference soil profiles (including pictures) and the data of soil augering campaigns also have to be submitted separately to the Database subsoil Flanders (*Databank Ondergrond Vlaanderen*/DOV) in specific formats. DOV will make these data available online in due course (www/dov.vlaanderen.be), which is an important added value for pedological research in an archaeological or palaeo-environmental context.

5. Conclusions

The growing involvement of earth scientists in archaeological projects and the DOV-initiative are certainly positive and will definitely contribute to the quality of the archaeological research. The status quo, or maybe even decrease, in the involvement of soil scientists with expertise in archaeological research is deceptive and can probably be related to the lack of possibilities for archaeologists to study soil science (applied to archaeology) after 2005 in Flanders/Belgium, after the retirement of Professor R. Langohr. Therefore, I hope that the program in physical land resources (option soil science) at Ghent University will include courses on and dedicate research to archaeopedology and, most importantly, will be open for students in archaeology as was the case in the eighties and nineties of the previous century (see also Van Hecke, 2019).

The combination of Archaeology and Soil Science is not at all a 'strange' combination, but on the contrary an evident, logic and fruitful combination. Unfortunately, this combination is still not facilitated at a university level, notwithstanding the opportunities created by the late

Professor R. Tavernier in 1984 and the remarkable efforts and results in this field realised by Professor R. Langohr.

Part of the solution to bridge the gap between soil scientists and archaeologists in Flanders could be to provide archaeologists with a practical and down to earth field guide, specifically accommodated to the practicalities of archaeology. I'm glad to conclude this short contribution with the announcement that the Flanders Heritage Agency has decided to make such a field guide in a way that will allow the expertise and approach of Professor R. Langohr to be included within archaeological practices.

René Tavernier (1914-1992) founder and first director of the International Training Centre for Post-Graduate Soil Scientists (ITC Gent) (private archive: Paul De Paepe).

Soil scientists graduating in 1994 at University of Ghent in front of the Geological Institute, Ghent, Belgium.

An important part of the curriculum at the ITC were the field excursions. On the left visit to the Zonian forest, on the right the archaeological excavation at the Tweekerkenstraat, Ghent.

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