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The Archaeology of Erosion, the Erosion of Archaeology

CONFERENCE BRUSSELS - APRIL 28-30 2008

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ERWIN MEYLEMANS, JEAN POESEN &
INGRID IN 'T VEN (EDS)

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Proceedings of the Brussels Conference, april 28-30 2008

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Roman tumulus near the Roman aqueduct of Tongeren.
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Index

The Archaeology of Erosion, the Erosion of Archaeology: an introduction

Erwin Meylemans[1] & Jean Poesen[2]

The articles presented in this volume are a selection of papers presented at a conference titled 'The Archaeology of Erosion, the Erosion of Archaeology', held in Brussels from april 28th to april 30th 2008. The primary goal of this conference was to bring together a wide variety of disciplines (archaeology, soil science, geomorphology, geography, geology,…) focusing on topics related to the interplay between landscape taphonomy and the preservation state of the archaeological record. The duality in the conference title entails a twofold approach. The 'Erosion of Archaeology' part deals with the enormous impact of current land use on the archaeological record, and relates to heritage management challenges and approaches. The 'Archaeology of Erosion' focus deals with (pre-)historic erosion and sedimentation processes, of which the traces are often archaeological relics in itself. Especially in complex geomorphological and sedimentary areas such as alluvial zones this duality is strongly intertwined. The focus of the conference within this framework was methodological, aimed at providing insights into the nature and preservation state of, and of current threats to the archaeological record.

FIG. 1 **Sheet (interrill) and rill erosion in cropland (Heers, May 2008).**

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FIG. 2 **Soil tillage leads to significant soil losses on convex slope sections (Huldenberg, December 2007).**

FIG. 3 **Deforestation of continental dunes to enhance wind erosion in order to create an active dune landscape. Note the soil surface lowering by wind erosion in the vicinity of the tree stumps with exposed tree roots (Oudsberg, Meeuwen-Gruitrode, April 2011).**

Considering the rapidly eroding archaeological resource, human impact on landscape formation processes has increased at an enormous scale from the 1950s onwards. The most obvious and visible aspect of this is the dramatic increase of built surface areas, and landscape 'scars' caused by quarrying for clay, loam, sand and gravel. Another important aspect however, because of its large spatial extent, is the impact of agriculture and other intensive land management schemes. The CORINE Land cover map for example shows that ca. 33% of the land area of Europe consists of arable land[3]. For the loess area of Central Belgium, cumulative erosion rates induced by sheet and rill erosion (fig. 1), (ephemeral) gully erosion, bank gully erosion, tillage erosion

3 EAA2006.

FIG. 4 Old gully channel in Meerdaal Forest (December 2009) most probably initiated during the Roman period (Vanwalleghem *et al.* 2006).

(fig. 2) and by soil loss due to root and tuber crop harvesting, result in a mean soil loss of 26 ton per hectare per year[4]. This figure corresponds to a mean soil profile lowering of 1.73 mm per year (assuming a soil bulk density of 1.5 ton per m^3). But also outside the erosion-sensitive loess areas agricultural practices have a heavy negative impact on the archaeological heritage, with intensive ploughing (and land levelling) practices inducing intense tillage erosion of topographical features and truncation of soil profiles, reducing numerous archaeological sites to 'ploughsoil scatters'[5]. Elsewhere in the sandy areas, deliberate deforestation in order to create active dune landscapes causes significant wind erosion (fig. 3). Protection of digging animals (e.g. badgers) causes significant bioturbation and soil erosion on archaeological earthen monuments.

Until recently, wetland areas were in the main outside the scope of these large scale destructions. However in the last couple of decades this has changed[6]. One of the aspects threatening the valuable wetland archaeological resources is again agricultural intensification in these areas, with intensive irrigation schemes causing the lowering of groundwater tables and subsequently the decay of archaeological organic and palaeo-ecological resources. Another main disturbing factor is steered by climate change issues and the accompanying increasing number of flood events. These are mainly being remedied by the creation of tidal restoration areas, which also pose a number of threats to the archaeological and cultural historical record[7].

National policies regarding these aspects (soil erosion, water management etc.) are directed through a number of European policies and directives, such as the '*Common Agricultural Policy*' (CAP), the '*European Soil Framework Directive*' and the '*Water Framework Directive*'. Cultural and archaeological aspects are largely overlooked however in these directives. Indeed, in contrast with developer-funded archaeology as stipulated in article 5 of the Valetta Convention, archaeological heritage management in light of these issues is mostly of an *ad hoc*, limited, or even absent nature[8]. However, within national agro-environmental schemes the possibilities for the integration of archaeological and cultural historical heritage management aspects do exist, through for example soil erosion prevention (soil conservation) schemes, and mechanisms as heritage management stewardship[9].

A primary requirement to do so is the application of efficient toolkits, regarding survey, evaluation and risk assessment of the archaeological record. However, as the presentations at the conference and the articles presented in this volume demonstrate, a wide variety of instruments and methods exist. The development and growing availability of GIS and geospatial data such as high resolution *LiDAR* digital terrain models for example, and derivative products as detailed erosion and sedimentation maps, can assist vastly in surveying, assessing and visualising of the risk to the cultural and archaeological heritage at regional and local scales[10]. But these GIS-based approaches always need to be tested through detailed field studies assessing for example the

4 Poesen *et al.* 2001; Verstraeten *et al.* 2006.
5 *cf.* for example Darvill & Fulton 1998; Trow 2010; Rijksdienst voor het Cultureel Erfgoed 2009.
6 Coles & Coles 1995.
7 *cf.* for example Van den Berg 2008.
8 Trow 2010.
9 *cf.* Carey & Lynch 2010; Cordemans 2010.
10 *cf.* Ducke this volume; Meylemans *et al.* this volume.

impact of tillage practices on archaeological sites[11]. With respect to alluvial archaeology, a multidisciplinary survey approach is always a requirement[12]. But also insights in historical large-scale taphonomic events in 'dryland' environments can provide valuable evidence for the interpretation of the archaeological record and a better understanding of human – environment interactions[13] (fig. 4).

One of the main points emerging from the conference discussions was the need for a multi-disciplinary dialogue and cooperation. It is in the combination of a broad spectrum of approaches from a multitude of research disciplines (geomorphology, soil science, geography, geology, archaeology etc.), that true advances can be made. Although this seems to be an overly logical and evident conclusion, especially in heritage management circles, this is most often not the case. For example, a large gap seems to exist between users and developers of GIS-based models and field researchers.

We are convinced that the collection of papers presented in this volume, through its multitude of approaches, can assist in the development of such toolkits. The inspiring discussions at the conference in any case leads us to believe that this certainly can be the case. For this we would like to thank all the contributors to this volume as well as the conference participants.

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11 De Bie *et al.* this volume; Trow & Holyoak this volume; Wuyts this volume.
12 Challis & Howard this volume, Meylemans *et al.* this volume.
13 Van den Eeckhaut *et al.* this volume; Dreesen *et al.* this volume; Cruz *et al.* this volume; presentations by Van Walleghem and Gerlach.

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An integrative approach to archaeological landscape evaluation: locational preferences, site preservation and uncertainty mapping

Benjamin Ducke[1]

Abstract

Buried, hidden sites constitute the most numerous and perhaps most vulnerable type of the world's archaeological resources. Protecting this invisible cultural wealth remains one of the great challenges of heritage management. GIS technology and powerful computational methods have dramatically improved the potential for efficient spatial management and conservation practice. With the increased availability of detailed geodata and cheap processing power, predictive mapping and erosion modelling have become practices possible with most GIS applications. Indeed, their usefulness is now defined by how well they integrate into a robust decision support toolkit allowing the combination of multiple model outputs, the generation of easily interpretable maps, and by how elegantly they handle the considerable uncertainty inherent in archaeological datasets. Dempster-Shafer Theory (DST) is a flexible mathematical framework that allows pooling of data from a variety of sources in a natural, straight-forward manner, explicitly representing uncertainty and producing a range of interesting output metrics that can be used in decision making processes. This article looks at how DST can be employed as a framework in heritage management, combining information about site location preferences and preservation conditions towards a unified assessment of archaeological value.

Keywords

Predictive modeling, erosion and deposition, GIS, Dempster-Shafer Theory, uncertainty

1 Introduction

The fate of buried archaeological sites is directly linked to landscape evolution and the many natural and anthropogenic processes that drive it. The key questions "where are the sites?" and "what may be left of them?" must be answered by heritage managers with equal competence to achieve efficient protection of archaeological monuments. This requires a sound understanding of the nature and significance of the processes involved in shaping the landscape and the monuments embedded therein. It also requires powerful mathematical and computational tools for building formal, spatially explicit models of those processes and their complex interactions. This article presents a heritage management case study from the federal state of Brandenburg in eastern Germany. In this region, accelerated soil erosion caused by human land-use has been identified as an important source of uncertainty in attempting to assess a landscape's archaeological value. It will demonstrate a way to combine sources of information about site location preferences and sediment transportation processes into a coherent modeling and decision support system for cultural heritage management.

1.1 Predictive modeling

Reliable assessment of the potential presence of archaeological sites is a key component in modern archaeological landscape management. Nothing seems more detrimental to the archaeological record than unaccounted sites being destroyed without proper documentation. For decades, predictive models have been used to minimize the net negative effect of surprise discoveries on planning processes and archaeological resources. A wide range of computational methods have been used to calculate predictive maps, including regression models, Bayesian models and machine learning techniques. An extensive body of literature has been produced on the theory and practice of archaeological predictive modeling, which is still evolving at an undiminished rate[2].

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2 E.g. van Leusen *et al.* 2005; Whitley 2005; Kvamme 2006.

Predictive modeling as understood here is a quantitative, objectified approach that does not favor specific site types but supports the preservation of diversified archaeological landscapes by:

1. providing decision support maps to streamline heritage management guidelines and practice;
2. providing a good base for leveraging protection of archaeological monuments in planning procedures and making sure that resources are allocated to those places where they are most effective;
3. generating information that helps to gain insight into large-scale processes that have driven past settlement strategies, patterns and systems.

The attribute "predictive" is actually somewhat misleading in this context. The output of an archaeological predictive model (APM) is really an indication of an area's assumed suitability or potential for e.g. prehistoric farmsteads rather than the actual existence of a preserved site at any given location. The latter is subject to a variety of sources of uncertainty which makes a straight progression from "there should be a site" to "there is a site" impossible.

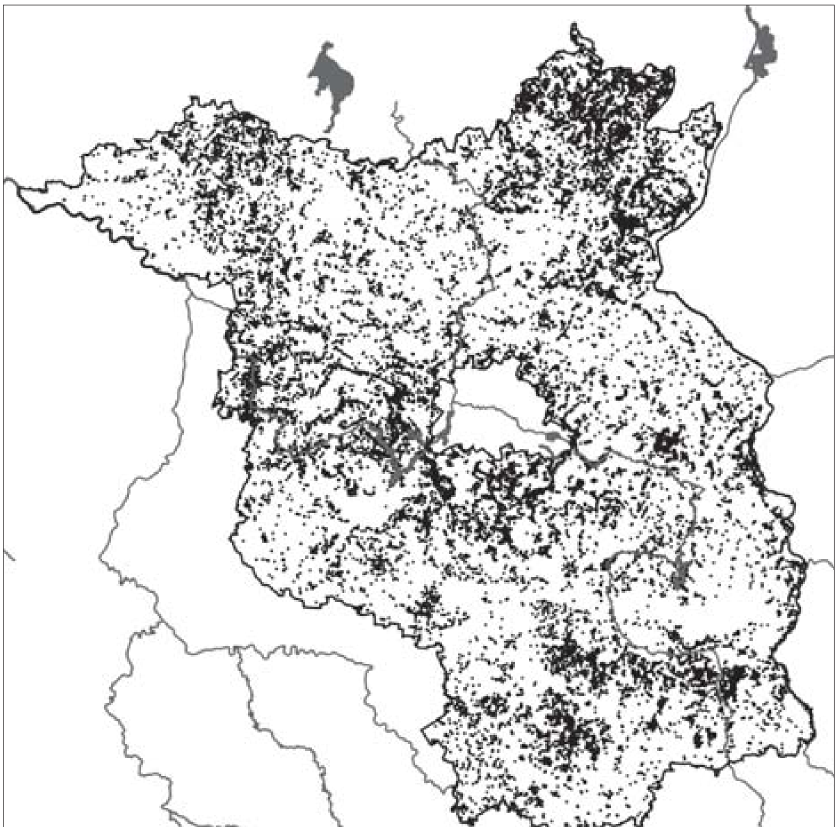
1.2 Archäoprognose Brandenburg

The predictive modeling project Archäoprognose Brandenburg[3] was started in Germany in February 2000 as a joint endeavor by the Brandenburg State Authority for Heritage Management and the Department of Prehistory of the University of Bamberg. It was funded by the Fritz Thyssen Foundation in Cologne.

Its aim was to provide an archaeological predictive model for the federal state of Brandenburg in north-eastern Germany[4]. Brandenburg has an area of c. 30,000 km^2, and 2.6 million inhabitants. Its central archaeological archives have registered c. 25,000 find spots of various types and ages, most of which were reported by amateur archaeologists. Archaeological sites are distributed across the state but form recognizable clusters in the north-east, south-east, and west of the area (fig. 1). The majority of the archaeological records refers to finds that can be attributed to settlement sites dating from the Early Neolithic (c. 5200 BC) to the Slavic period (c. 700 - 1200 AD).

Brandenburg has strict legislation that requires developers to pay for the excavation and documentation of archaeological sites affected by their projects. In practice, this means setting aside a budget for preventive archaeology. No developer can however be burdened with the prospect of unlimited financial risk. Heritage managers are thus required to specify the amount of money (which must not exceed a fixed percentage of the total development value) and time needed for excavation as part of the planning process.

FIG. 1 Distribution of registered archaeological sites in the state of Brandenburg, Germany. The cut-out area in the center of the map is Berlin. Source: Ducke & Münch 2005.



3 Ducke & Münch 2005.

4 Kunow & Müller (eds) 2003.

An efficient predictive model can be of great help here, especially where developments are concerned that demand large-scale planning processes such as, in the case of Brandenburg, opencast mines, gas pipelines and major communication and transport route upgrades. Arguing for the protection of invisible, intangible cultural resources remains however a delicate problem to say the least. As concerns Brandenburg's archaeological heritage, current estimates set the number of known and registered sites to only five to ten percent of the preserved total.

2 Erosion as a planning problem

Buried sites are a difficult planning problem. Knowing their presence is not enough to make well-informed decisions regarding resource allocation and mitigation procedures. The long term history of land-use is an important indicator of site preservation potential. Processes of predominantly agriculturally induced erosion and sedimentation were identified as the most significant agents in Brandenburg's geomorphological and historical environment.

Throughout the body of archaeological literature and field reports, the topic of soil erosion appears with some frequency. In most cases however, sporadic observations and summary estimations of soil volumes are published instead of more explicit, quantified information. For Brandenburg some data can be derived from geo-scientific studies relating to the area itself and regions with similar geomorphological characteristics[5].

2.1 The need for quantitative models

Soil erosion and deposition flattens slopes and buries sites underneath or in colluvial sediments, thus smoothing the original topography and making it harder to judge geomorphological settings by visual inspection. Even in a flat landscape, the accumulated effects can be considerable. Studies by Bork *et al.* (1998) and Schatz (2000) estimate 0.5 m of relief tension loss *on average* for the Central European Plains, with up to several meters in locations that are particularly prone to erosion. Understanding the embedding of sites in their geomorphological matrix is therefore key to better planning and protection.

The extent to which a naïve approach to this problem can cause havoc to archaeological resources has been illustrated for the prehistoric settlement site Dyrotz 36[6]. Prospection through fieldwalking of the site's environs had been conducted in light of a large-scale development project with a potentially profound destructive impact on any buried monuments. The low number and quality of recovered artefacts as well as the general terrain properties seemed to indicate a site that had been subjected to and largely destroyed by erosion processes. Accordingly, a minimal amount of resources was allocated to its documentation and excavation. It came as no small surprise when the excavation revealed some of the finest examples of Neolithic and Bronze Age settlement remains in the region, including some outstanding remains of wooden Neolithic well constructions, all preserved under thick layers of accumulated soil (fig. 2).

Such planning failures are especially regrettable in view of the fact that even a relatively simple GIS-based model would have been able to distinguish more reliably between areas of high and low preservation potential.

2.2 Choosing a model

Decades of research have produced quantitative erosion and sediment transportation models that range from very simple empirical to highly complex, process-based models. A complete coverage would be well outside the scope of this text.

Representing the lower end of complexity, the Universal Soil Loss Equation (USLE) allows farmers to reliably predict the magnitude of erosion threat to their fields. The Revised Universal Soil Loss Equation (RUSLE) remains a simple and cost-efficient empirical model based on soil and terrain properties with LS = slope factor, R = rain intensity, C = vegetation cover, K = soil erodibility and P = preventive stabilization:

$$E = LS \times R \times C \times K \times P$$

The (R)USLE model however is meant for averaged per-field erosion assessments and does not model sediment deposition, a critical component for heritage management.

As an example for the other end of the scale, the Channel Hillslope Integrated Landscape Development (CHILD) model is highly complex, based on process descriptions and includes a temporal output dimension[7]. Both powerful and accurate, it is very expensive to parametrize and the processes need to be well-defined. Apart from one actual deployment on an exceptionally well-funded military installation[8], the only other published application of CHILD seems to be a synthetic study that demonstrates the potential for geo-archaeological research[9].

For the Brandenburg case study, the choice of model was guided by the need to find a compromise between cost-efficiency and descriptive power. The Unit Stream Power Based Erosion Deposition (USPED)[10], model combines the simplicity of RUSLE with just enough process modeling power to suit the purpose. It models sediment transport on the physical terrain (transport capacity limit T) and calculates net erosion and deposition values. USPED requires the same parameters as RUSLE plus a high-quality digital elevation model. RUSLE's LS parameter is replaced with a slightly more complex term that calculates catchment per area unit (A):

$$T = A^{m} \times \sin b^{n} \times R \times C \times K \times P$$

Finally, the net erosion or deposition volume (*ED*) is estimated based on terrain geometry as derived from several curvature measures:

$$ED = \frac{d(T \times \cos a)}{dx} + \frac{d(T \times \sin a)}{dy}$$

5 Bork *et al.* 1998.
6 Ducke 2004.
7 Tucker *et al.* 1999.
8 Zeidler (ed.) 2001.
9 Clevis *et al.* 2006.
10 Mitasova & Mitas 1999.

2.3 Practical considerations

When deployed for large-scale archaeological planning, practical considerations and budget constraints will necessitate a certain degree of deviation from any erosion model's ideal usage. Since detailed soil data may not be available at the resolution required, rougher, approximate measures have to be used. Similarly, limits of historical data necessitate using modern proxy variables. Further compromises may be enforced by constraints regarding computer processing and storage capacities as well as the unavailability of high resolution digital elevation data for large areas.

The approach taken in the Brandenburg case study focuses on soil erosion as the most important type of erosion. Other, potentially more complex types, such as fluvial and wind erosion, were not taken into consideration, as they are significant mostly in regions outside the study area. It was felt that a reliable spatial prediction of overall erosion and accumulation strength would be sufficient for the project's purposes. No temporal differentiation or insight into processes on a site scale were sought. Some USPED parameters had to be approximated, sometimes based on simplistic assumptions. Rainfall intensity was extrapolated from historical records and projected back in time. Soil types were taken to be locationally stable on the model scale, i.e. it was assumed that their current spatial distribution reflects the prehistoric situation well enough. Despite all these simplifications, the USPED model gave a good estimate of erosion and deposition patterns. It correctly predicted zones of soil accumulation and erosion with a spatial accuracy that would have been more than sufficient for both planning and guiding the excavation at Dyrotz 36 (fig. 3).

FIG. 2 Some well-preserved prehistoric features and finds *in situ* at Dyrotz 36. Images courtesy of State Heritage Management Brandenburg, Germany (BLDAM).

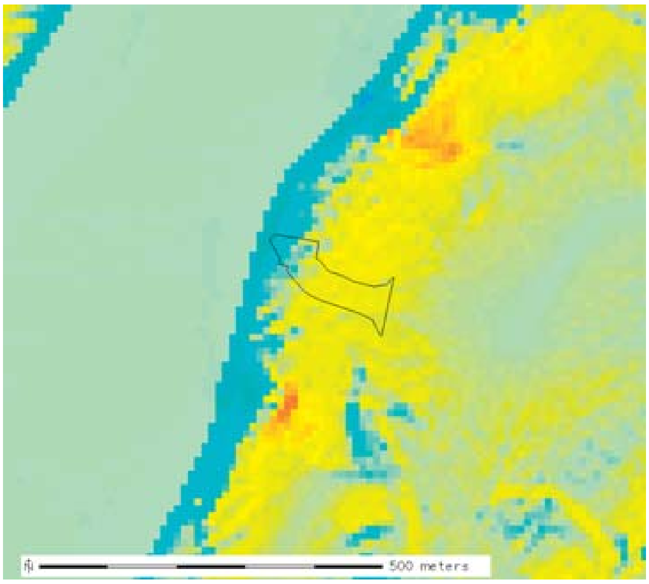


FIG. 3 Left: Zones of soil accumulation (blue) and erosion (yellow) in the area of the archaeological site Dyrotz 36 (center), as predicted by the USPED model. Right: Stratigraphy of the site's western tip. Image on the right courtesy of State Heritage Management Brandenburg, Germany (BLDAM).

3 Managing uncertainty

Even with such flexible tools as GIS, predictive maps and erosion models, considerable uncertainty is always involved in archaeological decision making; owing to the very nature of the discipline and its sources. What, then, does it mean to be able to manage uncertainty? There is really no way to reduce uncertainty other than by introducing more information into the model. This is often not a viable option due to financial and time constraints. From an operational point of view, managing uncertainty mostly refers to the ability of measuring its magnitude, mapping its spatial pattern and using the available regulatory leverage to delay or alter decisions based on that knowledge. All of this starts with an appropriate quantitative framework that constitutes the "mathematical glue" to bind data from different models into a coherent decision support system.

Dempster-Shafer Theory (DST) is a theory of uncertainty that is mathematically related to both set and probability theory[11]. DST is a flexible framework that has many interesting properties when it comes to handling uncertainty. Different applications and research interests focus on different aspects of DST and keep producing new interpretations of the theory[12]. This has led to some confusion and different opinions on how to calculate a valid DST model[13]. However, DST as proposed by Shafer (1976) and used in this study is really a well-defined, reasonably simple tool that has applications in a wide range of research problems.

The following section is a very brief introduction to the mathematical framework of DST. Many details have been left out. The full background can be found in the original publication by Shafer (1976) and, perhaps more accessibly, in numerous papers, also published online, by Smets and colleagues[14].

3.1 Building models using Dempster-Shafer Theory

The first archaeological case study using a DST predictive model was published by Ejstrud (2003, 2005) - although he points out that the IDRISI GIS software used for his research actually features an archaeological scenario in the manual for its DST modeling tools. Ejstrud demonstrated the principal superiority of DST over various other predictive modeling approaches in terms of model performance[15]. But DST is really a universal framework that can be used to model numerous research problems. The basic ingredients for building a DST model are:

1. The basic hypotheses. They cover all possible outcomes of the model.
2. A number of variables which are deemed to be of importance to the model.
3. A method to quantify the degree of support those variables lend to specific hypotheses (probabilities, rankings, etc.).

For each hypothesis, it is then possible to check to what extent the provided variables support or refute it and calculate the total degree of belief in that hypothesis. This is not the same as the probability of a hypothesis being true, as that would imply using the more rigid mathematical framework of probability theory. At this point, some more precise definitions need to be made:

- The set of hypotheses $H = \{h_1, h_2, .., h_n,\}$ which represent all possible outcomes, is called *Frame of Discernment* (FoD).
- A variable with relevance to the FoD is a *source of evidence*. The entirety of sources of evidence is called *body of evidence*. A variable's value is transformed into an evidence by calculating a *Basic Probability Number* (BPN) for it (this is also sometimes referred to as a *basic probability assignment*).

11 Shafer 1976; Zadeh 1984.
12 See Smets 1994.
13 Ejstrud 2005, 184.
14 E.g. Smets 1994.
15 Kvamme 2006.

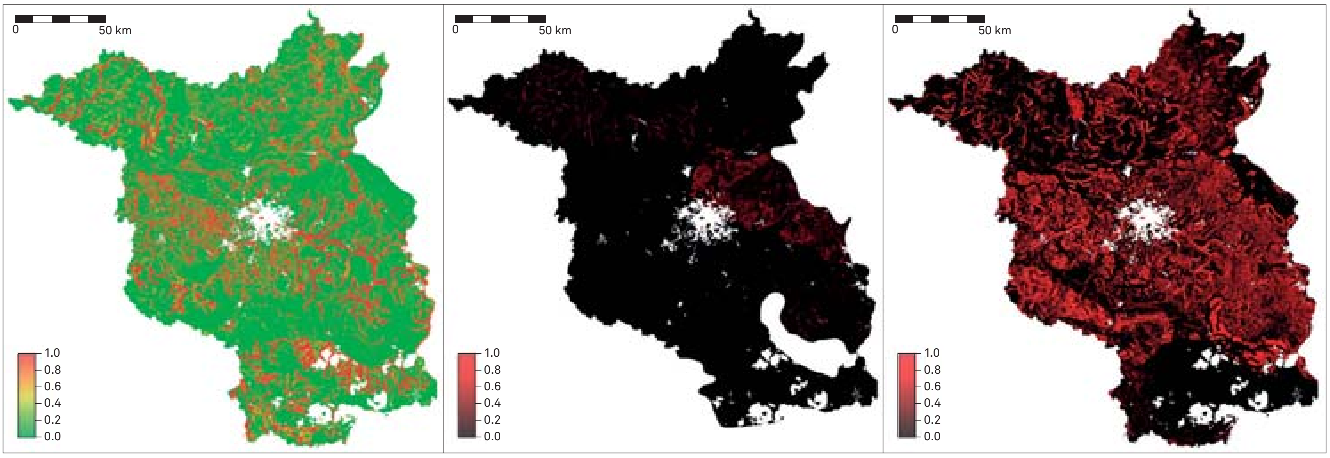


FIG. 4 Some illustrative DST metrics from the archaeological predictive model of Brandenburg. Left: the basic Bel ("site") values. Center: Belief interval for the "site" hypothesis. Right: Weight of conflict.

- A BPN is the basic quantification of evidence in the DST. It consists of a value m_n in the range "0" to "1" for each hypothesis in the FoD. The restriction is that $m(1..n)$ must sum to "1", i.e. the entire basic probability mass must be distributed over the given FoD.

BPNs can be assigned to a singleton hypothesis in H as well as to subsets of it. What this means is that DST has the ability to represent uncertainty as subsets of H. Thus, if two hypotheses h_1={"a"} and h_2={"b"} are supplied, then by implication there will also exist an additional *uncertainty hypothesis* $\{h_1,h_2\}$ for the belief that both could be true ("a" or "b"). This is perhaps the most distinguishing and useful property of DST as a theory of uncertainty.

As an example, modeling the archaeological site prediction problem using DST is a straight-forward procedure:
- The FoD is the exhaustive set of outcomes {"site", "no site"} plus the uncertainty hypothesis.
- Each GIS map that encodes a variable with relevance to the FoD is a source of evidence.
- The entirety of GIS maps provided constitutes the body of evidence.
- Each mapped feature or raster cell is transformed into an evidence by calculating a BPN for it.

In the case discussed here, the FoD is taken to consist of h_1={"site"}, which proposes that an archaeological site is present, h_2={"no site}", which proposes that no archaeological site is present and $\{h_1,h_2\}$, which is the uncertainty hypothesis, stating that no decision can be made about site presence or absence.

3.2 Combining evidence

Any number of sources of evidence can be combined using Dempster's Rule of Combination. It computes a measure of agreement between two sources of evidence for various hypotheses (A, B, C) in the FoD:

$$m(A) = m_2 \otimes m_2 = \frac{\sum_{B \cap C = A} m_1(B)\, m_2(C)}{\sum_{B \cap C \neq \emptyset} m_1(B)\, m_2(C)}$$

In doing so, it focuses only on the hypotheses which both sources support[16]. From the result, a number of useful DST metrics can be derived (fig. 4).

The following is a brief description of basic Dempster-Shafer outputs:
- **Belief(A)** is the total belief in hypothesis A. It tells us how much of the evidence speaks for A. This is the most basic DST function.
- **Plausibility(A)** is the theoretic, maximum achievable belief in A. From a different point of view, it tells us "how little evidence speaks against A"[17]. **Doubt** is simply defined as the inverse of plausibility: 1 - plausibility(A).
- The **belief interval** measures the difference between current belief and maximum achievable belief, thus representing the degree of uncertainty. It is defined as plausibility(A) - belief(A). Areas with high belief intervals may represent poorly researched regions where additional/better information could improve model results[18].
- Finally, the **weight of conflict** indicates that evidences from different sources disagree with each other. A high weight of conflict might indicate a serious flaw in the model design or disagreement of evidences supplied by different data sources.

The most important ones are belief and plausibility. The *belief function* Bel(A) computes the total belief in a hypothesis A:

$$Bel(A) = \sum_{B \subseteq A} m(B)$$

As mentioned before, DST has an important characteristic that sets it apart from probability theory: if Bel(h_1) < 1, then the remaining evidence 1 - Bel(h_1) does not necessarily refute h_1.

16 Lalmas 1997.

17 Ejstrud 2005.

18 See Ejstrud 2003.

TABLE 1

Example of bias quantification for sources of uncertainty in field walking. The numbers reflect subjective, independent expert opinions collected by the Dutch heritage management service (ROB).

class	description	land-use	bias
1	built up	urban	0.4
2	grassland	pasture	0.7
3	deciduous woodland	woodland	0.7
4	coniferous woodland	woodland	0.7
5	maize, grain	arable	0.1
6	water	water	0.9
7	potatoes, beets	arable	0.2
8	other crop	arable	0.2
9	heather	moor	0.5
10	bare soil	none	0.0

Whereas in probability theory, owing to the *Law of Total Probability*, $h_2 = 1 - h_1$. Thus, some of the remaining evidence might plausibly be assigned to (sets of) hypotheses that are subsets of or include A. This is represented by the *plausibility function*:

$$Pl\,(A) = \sum_{A \cap B \neq \emptyset} m\,(B)$$

In other words, Pl(A) represents the maximum possible belief in A that could be achieved if it was known that the remaining uncertain information (caused by errors in the input data, incomplete data, contradictory evidence etc.) does not refute A.

Again, as an example, the predictive modeling process can now be outlined like this:

1. Split archaeological site data into a modeling and a testing set using a random sampling procedure.
2. Provide GIS raster maps for all relevant sources of evidence (soil, terrain, visibility, etc.).
3. Determine BPNs for all evidences using the modeling set.
4. Combine all sources of evidence using Dempster's Rule of Combination.
5. Verify results and estimate model performance using the testing set.

Exactly how the BPNs are quantified depends on the problem at hand and the quality of data available. Possible schemes include ranking methods, correlation measures and statistical significance tests[19].

3.3 Introducing more uncertainty

In predictive modeling, uncertainty often arises because there is direct evidence for "site", but only indirect evidence for "no site". E.g., the fact that no sites have been reported on terrain type "A" might mean that (a) prehistoric settlers actually avoided this type of terrain or (b) some source filter has introduced bias into the observation. This bias may for example relate to terrain types less suitable for archaeological prospection, or land uses with a negative effect on site visibility. In cases like these, it can be impossible to decide between "site" and "no site". This inability to decide is the very nature of uncertainty.

As an example, fig. 5 shows the proportion of sites detected on areas of strong soil accumulation against those on eroded areas. A significant visibility bias is clearly involved, and this needs to be expressed in the predictive model.

The amount of uncertainty in a DST model can easily be raised by transferring belief mass to the uncertainty hypothesis. As an example, a simple quantification of bias for sources of uncertainty in field walking could look like Table 1.

Converting the output of an erosion model to a source of uncertainty is an equally simple procedure. Assuming that soil accumulation has a negative impact on site visibility, belief mass needs to be transferred from the site hypothesis to the uncertainty hypothesis, according to the magnitude of sedimentation in a specific location. The USPED model does not provide meaningful output in the form of e.g. soil volume. The output range depends on the input data and needs to be normalized on a per-model basis before calculating BPNs.

Depending on the real scenario, further sources of uncertainty may be of importance, such as differences in surveyors' skills, surveying intensity, collection preferences, recognizability of material, etc. With some creativity, any of these can be quantified and added into the DST model, providing a flexible framework for representing uncertainty in site and landscape data sets. In combination with the many useful outputs of a DST model run, it becomes possible to explore the spatial distribution and

19 See Rogerson 2001 for some geographic significance tests; Lalmas 1997 for a point scoring system.

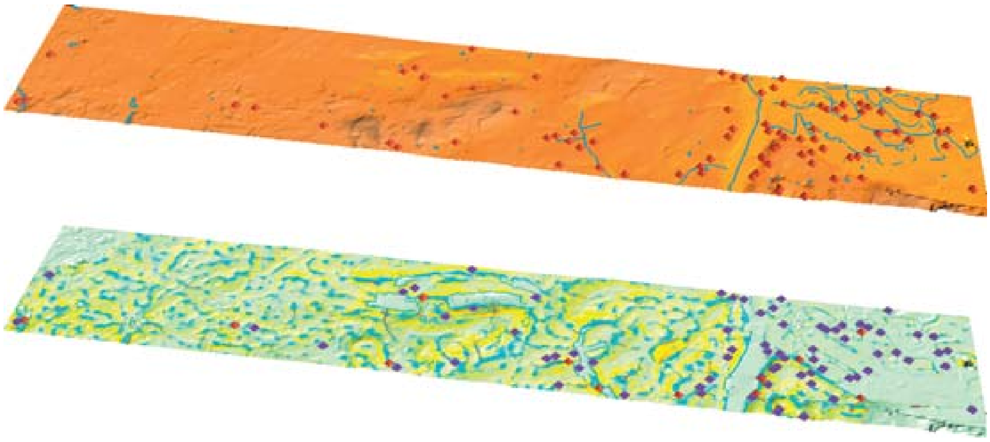


FIG. 5 **Archaeological sites in a part of the "Havelland" area of western Brandenburg. Above: distribution of detected sites. Below: sites detected on areas of net soil erosion (red dots) and accumulation (blue dots). USPED model with color coding as in fig. 3. Source: Ducke 2004.**

impact of uncertainty and create decision support tools based on best available knowledge rather than idealized scenarios.

Since there are many interesting DST metrics, choosing a single output for the decision support map can be a challenge. In some situations, it may be desirable to use a transformation function that summarizes the total information in a formally correct way[20].

3.4 Software implementation

Upon review of available DST support in software packages, it became clear that no available implementation could offer the modeling flexibility needed. In addition, the use of proprietary, commercially licensed software as part of a research project has severe scientific limitations. Without access to the software's source code, it becomes hard or impossible to understand unexpected results and compare outputs of different implementations. A closed source, heavily copyrighted software system essentially acts like a black box for data. Expensive and exclusive license agreements prevent other researchers from reproducing methods and results, creating barriers to further development and collaboration.

For these reasons, a new, free DST implementation was created based on open source GRASS GIS. It allows efficient processing of large datasets, with minimal storage and memory requirements. GRASS GIS already contains an abundance of powerful geomorphological modules and erosion models, USPED being just one of them. The DST modules support designing models, quantifying BPNs and combining evidence. Contact the author for information on how to obtain the software.

Summary

For the sake of efficiency and transparency, archaeological resource management needs to be based on spatially explicit and stringent, formalized criteria. Quantitative, GIS-based models enable the change from vague notions of threat to preservation or of archaeological values to powerful decision support systems. The general availability of cheap processing power, storage capacity and open source GIS technology has removed cost-related operational barriers for complex, realistic and highly detailed models. The focus can now shift again to the mathematical framework, modeling flexibility, accuracy and explanatory power.

A key concept here is the management of uncertainty as introduced by missing data, incomplete models, errors and diverse sources of bias. Catering for this is an important prerequisite for effective management of the impact of land use practices on buried archaeological resources. Dempster Shafer Theory is one way to allow such improved understanding to find its way into actual computer applications and decision support systems.

In addition, thanks to highly efficient models such as USPED, locating areas of erosion and deposition is possible with little cost and sufficient accuracy.

The "Archäoprognose Brandenburg" project has provided fundamental research to tackle a number of important problems involved in building decision support models for heritage management. As is always the case with such limited-time projects, much was left undone at the end of it, including, sadly, a new generation of the basic predictive model with bias sources for the whole of Brandenburg. In terms of method, however, the way seems clear now and the next big challenge will be the integration of refined digital decision support systems with legal procedures and established workflows.

Finally, it seems worth mentioning that while both software and results of the project have been made available, the high-resolution soil and elevation data used in all models is still restrictively licensed under terms not set by the project team but the producers, which are state-owned agencies. This means that the full project assets remain unavailable to the wider community of researchers, even to those that paid for them with their own tax money. Such restrictions harm reproducibility of research and constitute the last remaining barrier to bringing valuable computational tools to the wider heritage management community and putting them into good practice for the benefit of our cultural heritage.

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20 E.g. Jsang 2002.

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The evaluation of archaeological sites using LIDAR and erosion/sedimentation modelling

Erwin Meylemans[1], Bart Vanmontfort[2] & Anton Van Rompaey[3]

Abstract

From 2004 onwards a LIDAR scan of the whole area of Flanders (Belgium) was developed. This new instrument presents a high resolution basis for erosion and sedimentation modelling. In this paper we present the application of such models on two sites: the Roman earthwork aqueduct of Tongeren, and the Neolithic causewayed enclosure of Ottenburg. In both cases it is shown that erosion has a significant impact on the preservation of these sites.

These examples demonstrate the possibilities these modelling approaches show for the build up of primary taphonomic bases in erosion sensitive areas, and by consequence for a first assessment of the 'preservation potential' of the archaeological record.

Keywords

Tillage erosion, water erosion, GIS, Roman Aqueduct, causewayed enclosure

1 Introduction

The loam area of Central Belgium (fig. 1) is characterised by the presence of a quaternary loess cover of up to several metres thick. Due to its undulating topography, combined with soil texture and extensive agricultural exploitation, the area is subjected to intensive soil erosion and sedimentation processes[4]. Although the first agricultural exploitation of the area is attested as early as the late 6th millennium cal BC, with the arrival of the *Linear Bandkeramik* culture (LBK)[5], alluvial sedimentation budgeting shows erosion processes predominantly started in the Iron Age, with over 50% of the alluvial sediment storage deposited from the medieval period onwards[6]. Tillage erosion is shown to have had a minimal impact until the large scale mechanisation of agricultural practices in the 1950s. From this period on, however, tillage erosion has increased dramatically, and has become dominant over water erosion[7]. This has been further stimulated by a large number of agricultural re-allotment projects in the 1980s and 1990s, increasing the size of field plots.

The overall effect of this evolution is shown in a number of archaeological excavations to have resulted in up to more than a metre of soil loss in convex upslope areas and the creation of 'ghost scatters' of archaeological materials in downslope, colluvial, positions[8]. In the Netherlands, an evaluation of a number of Roman *villae* in the loess region clearly demonstrated the negative impact of tillage practices on the present archaeological features[9]. The combination of upslope erosion and downslope colluviation severely hampers the interpretation of the archaeological record of the loess region[10].

Archaeological heritage management in Flanders mainly focusses on preventive archaeology in the light of large infrastructural projects, and has up to now paid very little attention to the destructive effects of erosion. In part this can be ascribed to the lack of a consistent methodology. However, in the last decades a number of important instruments have become available: the development and implementation of sedimentation modelling and the high resolution digital elevation models (DEM) obtained

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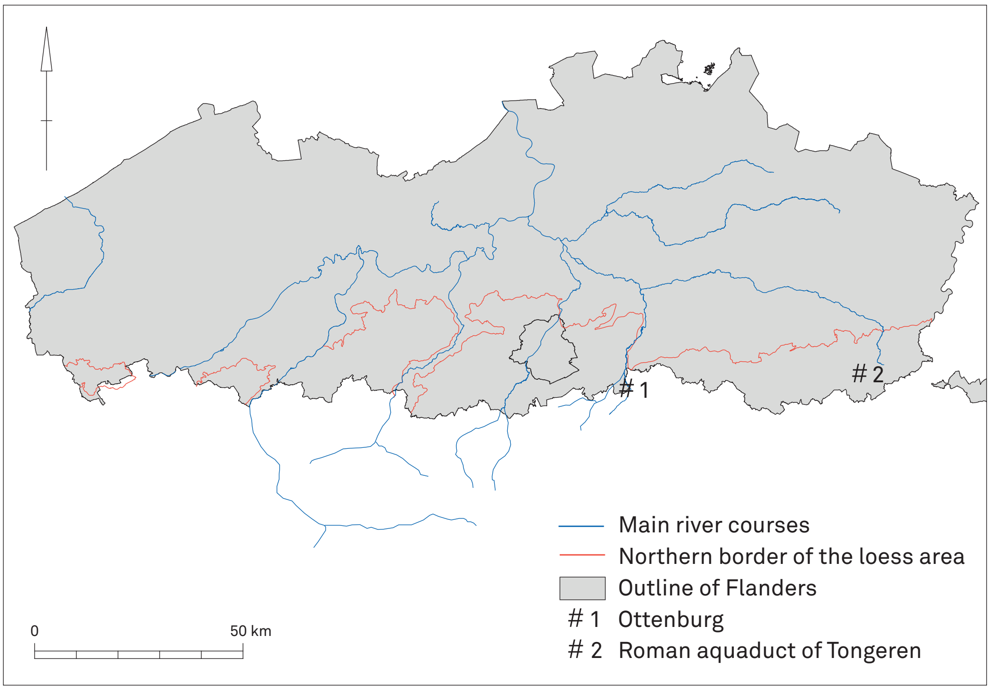
4 E.g. Verstraeten *et al.* 2006.
5 E.g. Jadin 2003; van Berg & Hauzeur 2001.
6 Rommens *et al.* 2006.
7 Van Oost *et al.* 2005.
8 For example Scheys 1962; Vanmontfort *et al.* 1999.
9 De Groot 2006.
10 See also Vermeersch 1985.

FIG. 1 Map of Flanders with indication of loess area, main drainage pattern and sites mentioned in the text.



by LIDAR scanning[11]. In Flanders, such detailed DEM was created between 2001 and 2004, the so-called *Digitaal Hoogtemodel Vlaanderen* (DHMV) with a standard resolution of 1 measure point per 20m[2] [12]. This instrument, together with the development of erosion and sedimentation modelling[13], allowed the creation of a high resolution erosion risk map for the whole of Flanders, based on the 'Revised Universal Soil Loss Equation' (RUSLE)[14].

In this contribution we implement these instruments at two archaeological sites: the Neolithic enclosure of Ottenburg, and the Roman earthwork aqueduct of Tongeren. We first present the results of the different mapping and modelling approaches at both sites. This allows us to subsequently reflect on the possibilities of these approaches for the development of archaeological heritage management strategies for these particular sites, and for the Flemish loess area in general. Following these evaluation projects, both sites were scheduled as protected archaeological sites in 2010.

2 Case study 1: the Neolithic enclosure of Ottenburg[15]

2.1 Introduction to the site

The *Ottenburg* site (communities of *Huldenberg* and *Grez-Doiceau*) is one of four known Middle Neolithic enclosures in Flanders, attributed to the *Michelsberg* culture (ca. 4300-3800 cal BC). It is situated on a distinct and large plateau, with steep hillslopes on all sides. The only access to the plateau not hindered by these slopes is situated in the west (fig. 2). Although the site has been known since the beginning of the 20th century, fairly little fieldwork has been executed. Preserved wall and bank structures of the enclosure under forest, in the southern part of the plateau, were partially excavated during the early 20th century[16] (fig. 3). The central part of the plateau was surveyed through several fieldwalking campaigns[17]. A limited trial trenching survey by a team of Namur University focussed on the south-western part of the plateau, in an area with concentrations of surface finds. This showed, next to the presence of two protohistoric soil marks, parts of eroded Neolithic pits and postholes[18]. Surprisingly the most obvious archaeological feature on the plateau, the so-called *Tomme*, has never been subjected to an archaeological investigation. This earthwork of ca. 125 m long, 25 m wide and 3.5 to 4 m high has been scheduled as a protected landscape since 1974. An interpretation as being a Neolithic longbarrow is possible given the limited number of archaeological features and finds from other than the Neolithic period and its prominent position on the plateau entrance, but needs to be confirmed by future fieldwork.

The central part of the plateau is currently in use as agricultural land, while the slopes of the plateau are forested. The south-western part of the site, including the *Tomme* earthwork, is part of a hamlet constructed in the 19th century.

2.2 Objectives and methodology

The objectives of an evaluation project carried out in 2003 were twofold: assessing the possibilities of the DHMV for archaeological surveying; and evaluating the preservation of the site through assessing the historical erosion on the site and current erosion and sedimentation modelling.

At the time of the project the DHMV data were still being processed to its standard resolution. For the project, however, the

11 Light Imaging Detection And Ranging: for an introduction the technique e.g. Wehr & Lohr 1999.
12 De Man & Brondeel 2004; De Man *et al.* 2005; OC-GIS Vlaanderen 2003.
13 Van Rompaey *et al.* 2001.
14 Notebaert *et al.* 2006.
15 Vanmontfort *et al.* 2006.
16 De Loë 1910; De Loë & Rahir 1924.
17 Clarys *et al.* 2004; Dijkman 1981; Knapen-Lescrenier 1960.
18 Burnez-Lanotte *et al.* 1996.

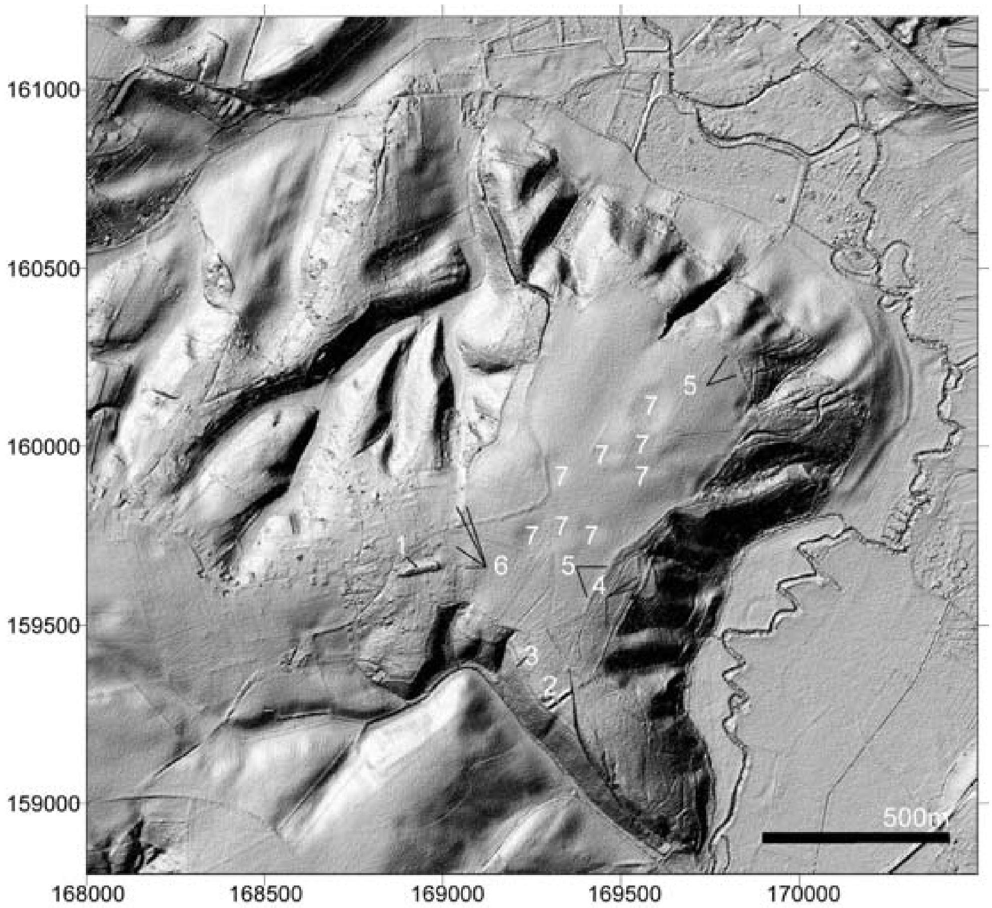


FIG. 2 **Hillshade DEM of the Ottenburg plateau, with indication of the main features. 1: 'De Tomme'; 2, 3, 4: earthen wall structures under forest; 5: soil accumulation ridges due to modern erosion; 6: earthen wall structures in the west of the plateau; 7: circular closed depressions.**

unfiltered data were made available, offering an average resolution of 1 measure point per 4m². This data was processed to a DEM with raster cells of 4m² using natural neighbour interpolation, and visualised with hillshade and colourscale techniques.

This DEM was also the main source for the development of the current erosion/sedimentation model. For this, the so called 'WaTEM/SEDEM' modelling technique was used[19]. This model simulates processes of water and tillage erosion and assesses for each raster cell soil erosion and sediment deposition, both expressed in ton/ha/year. WaTEM/SEDEM assesses erosion rates based on average rainfall erosivity, soil and topographic properties and applied crop rotations. The eroded sediment is routed via topographically-derived flowpaths to permanent river channels. Along the flowpaths sedimentation occurs if the transport capacity is insufficient to transfer the incoming sediment to the downstream raster cell. The transport capacity of a grid cell depends on topographic properties and soil cover.

Three model outputs were generated: an assessment of the average yearly erosion/sedimentation through water erosion; an assessment of the average yearly erosion/deposition resulting from tillage operations, and finally an assessment of the average yearly total erosion/sedimentation by summing the predictions for water erosion and tillage erosion.

Long term erosion and sediment deposition was assessed by conducting 200 hand augerings with a so-called Edelman auger.

FIG. 3 **Neolithic earthen wall and ditch under forest (e.g. fig. 2.2).**

For every augering mainly the depths of two soil horizons typical for the local Albeluvisol were noted: the base of the Argic B horizon (Bt) and the lower limit of decalcification of the loess. These depths were compared with those of undisturbed, reference soil profiles, for instance in the nearby situated *Bertembos*[20], in order to estimate the total amount of historical erosion. As the development of these horizons and their depth is strongly dependent

19 Van Oost *et al.* 2000; Van Rompaey *et al.* 2001. 20 Roovers 2000.

on local circumstances such as vegetation, slope orientation and slope angle, the resulting amounts should be regarded as approximations rather than as exact determinations.

Finally, the erosion data were compared with the available archaeological data, amounting to a an assessment of the preservation of the site.

2.3 Results

2.3.1 The LIDAR survey

The high resolution DEM shows numerous features that can be regarded antropogenic in origin. The most apparent of these are '*De Tomme*' (fig. 2.1) and a 100 m long stretch of the ditch and wall structures in the southern part of the plateau (fig. 2.2 & 2.3). The DEM confirmed the continuation of the latter towards the north-east as was suggested by Clarys *et al.* (2004) (fig. 2.4). This way, the enclosure ditch flanks the south-eastern side of the plateau. In the southwestern part of the plateau, slightly east of the *Tomme*, another ditch and bank structure is faintly visible (fig. 2.6). A low ridge on the edge between agricultural land and forest (fig. 2.5), is attributed to sediment accumulation as a result of sheet wash erosion (*infra*). Finally, a number of closed depressions are visible central on the plateau (fig. 2.7). The hand augering campaign on the *Ottenburg* plateau shows that these depressions were dug out including the calcareous loess (fig. 4).

2.3.2 Erosion modelling

The reference depth of the top of decalcification in *Bertembos* is ca. 2.5 m, that of the base of the Argic B horizon between 100 and 130 cm. The augering survey showed that on the *Ottenburg* plateau the depth of decalcification varied between ca. 100 and 245 cm. In the central, flat, part of the plateau this ranged between 200 and 245 cm, in the north-west and south-east corners of the plateau between 150 and 190 cm (fig. 5). The base of the Argic B horizon shows a similar pattern (fig. 6). On the central part of the plateau it is situated at a depth of ca. 100 cm, while in the north-east and south-western parts it can be found less deep, between 50 and 70 cm.

These patterns indicate that the central part of the plateau only suffered from very limited amounts of erosion, and that much intenser erosion can be assumed for the slightly sloping north-eastern and south-western parts.

The results of the WATeM-SEDEM models show only minimal erosion rates on the central, flatter part of the plateau. Highest erosion rates are situated near the edge of the plateau. This eroded sediment is deposited at the edge of the agricultural plots, as is confirmed by a small ridge visible in the DEM survey (*supra*; fig. 2.5 and 7). High erosion rates are also present on the slopes of the closed depressions. This process is responsible for a gradual infilling of these depressions, as well as an increase in size through regression of the depression edges.

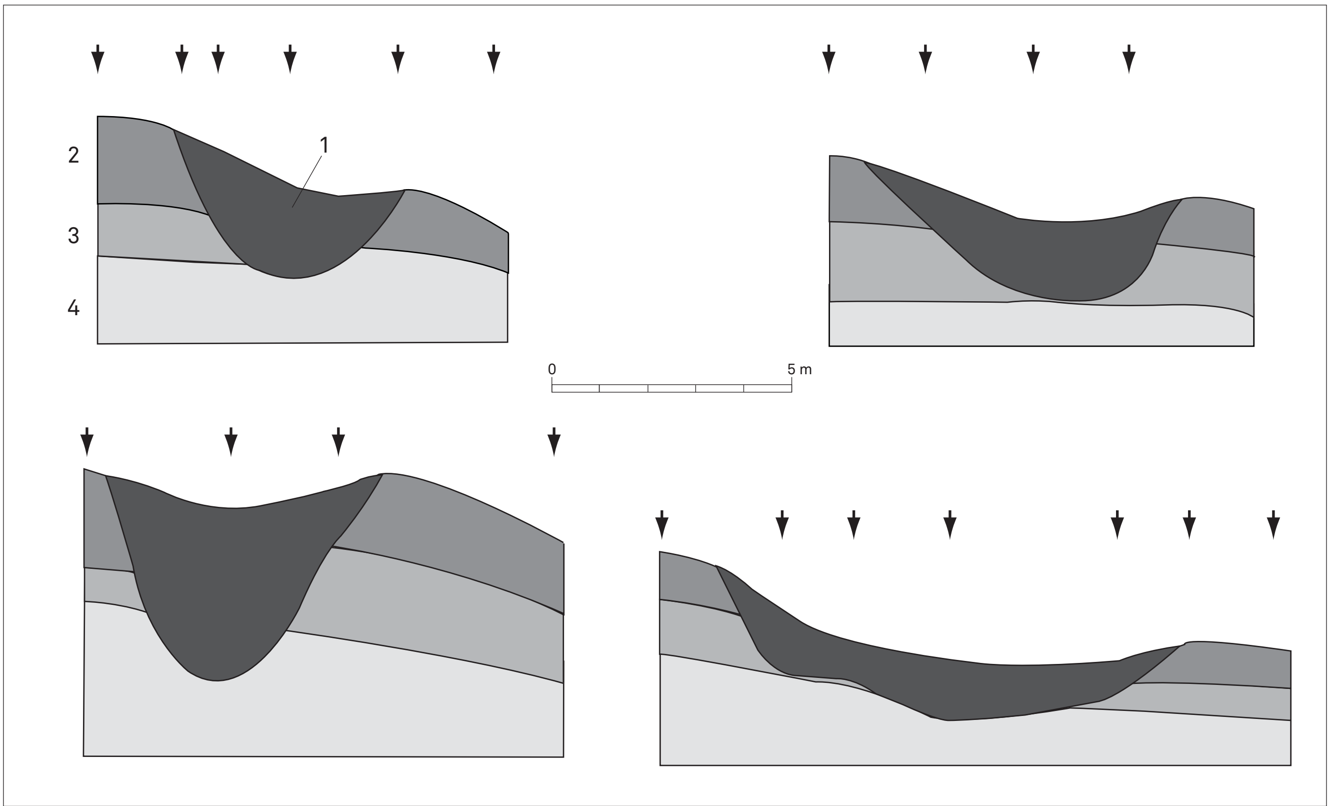


FIG. 4 Hypothetical sections of some of the closed concavities based on hand augering. 1: Colluvium/ filling 2: Decalcified loess 3: Calcareous loess 4: Pre-quaternary sand substrate.

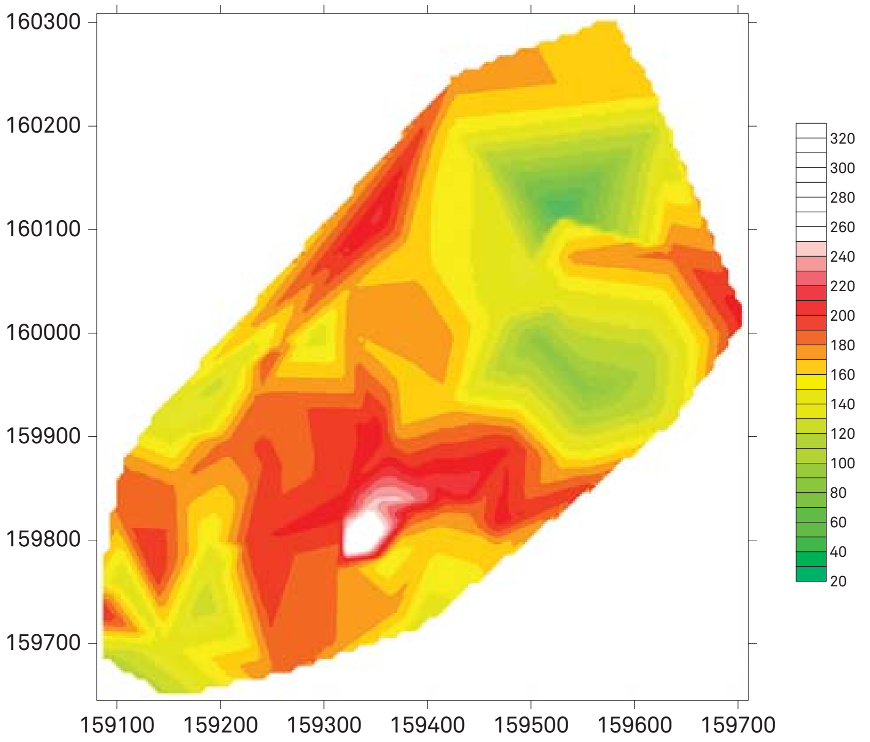


FIG. 5 Depths of the subsurface calcareous loess relative to the current surface minus the colluvium.

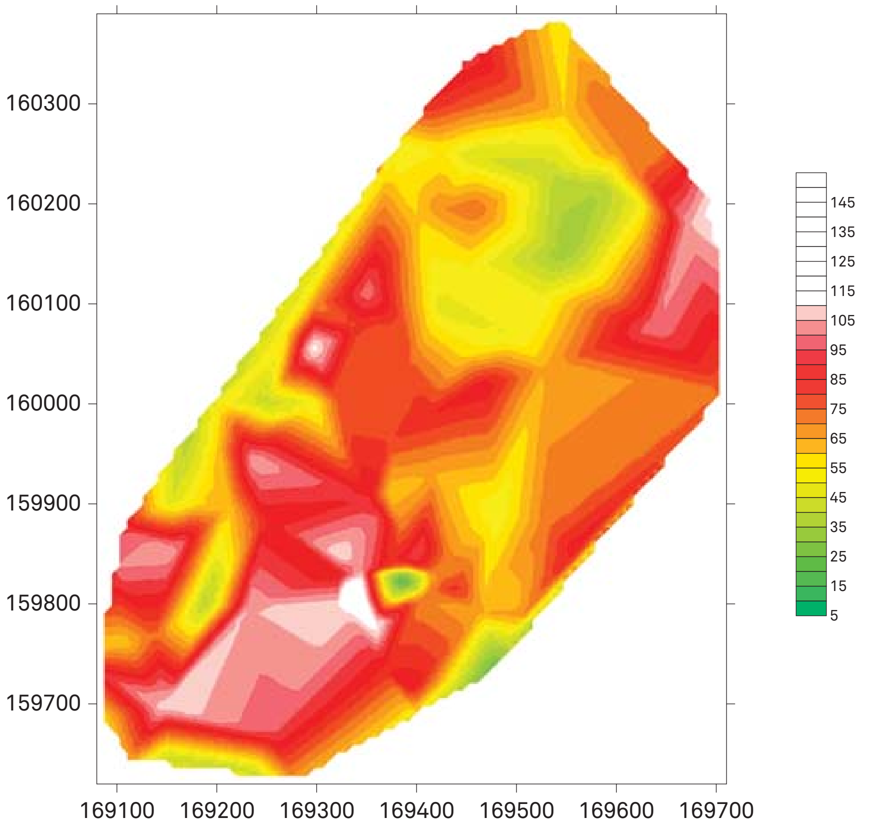
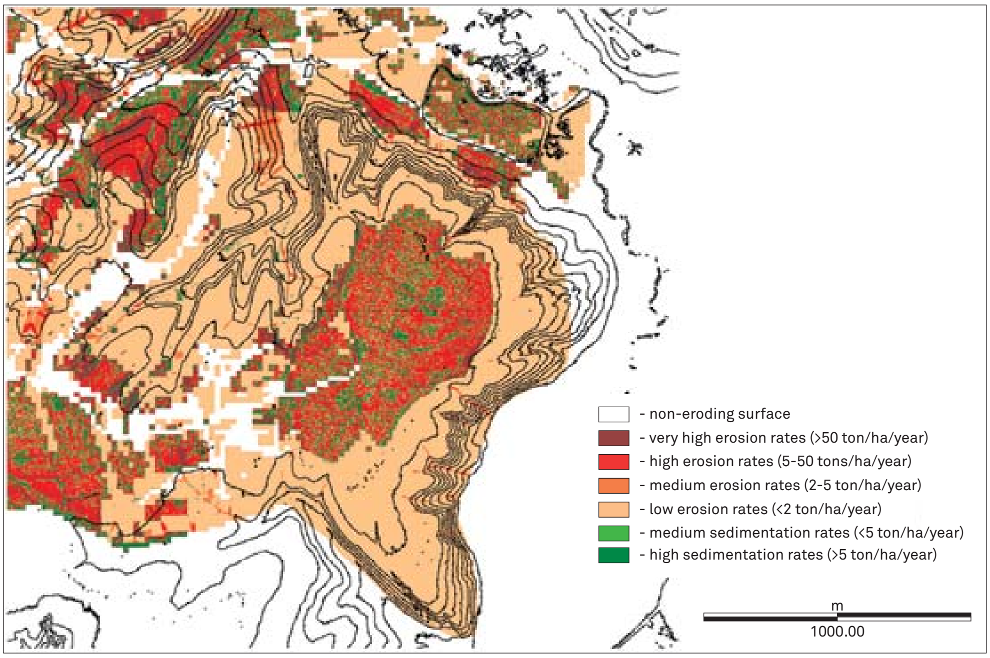


FIG. 6 Depth of the subsurface clay-eluvation horizon relative to the current surface minus the colluvium.

FIG. 7 Integrated (water and tillage) erosion/sedimentation model.



2.4 Discussion and conclusions

The historical and current erosion models give us an indication of the variations in site preservation potential on the plateau. When compared with the spread of surface finds from the most recent fieldwalking campaigns[21], a correlation becomes apparent between areas with higher erosion rates and the high densities of surface finds. It is tempting to regard the concentration of artefacts to the erosion of archaeological features. This fits with the observation of eroded Neolithic features in the south-western part of the plateau (see above). Following the same reasoning the general scarcity of surface finds in the central part of the plateau can be aligned with low erosion rates, indicating that this part potentially harbours a well preserved portion of the site. The LIDAR survey, demonstrating the presence of several ditch and wall constructions encompassing the entire south-eastern flank of the plateau, in any case suggests that the entire plateau is to be considered as belonging to the enclosure site. The closed depressions on the plateau, however, have undoubtedly destroyed significant portions of the Neolithic site. The age and specific nature of these antropogenic structures is unclear. Similar depressions in Meerdaal forest were dated with OSL in the Iron age/Roman period[22].

The *Ottenburg* project for the first time demonstrated the potential of the DHMV LIDAR data for archaeological surveying in Flanders. A series of antropogenic features was observed and mapped and the use of the DHMV in the modelling of historical and current erosion helps to evaluate the preservation state of the site and current erosion risks.

3 Case study 2: The Roman aqueduct of Tongeren[23]

3.1 Introduction to the site

The known part of the Roman aqueduct of Tongeren consists of a monumental earthwork, of which the best preserved part (known as the '*Beukenberg*') is situated under forest (fig. 8-9). About 3/5 of the monument is situated in agricultural land. The earthwork is clearly visible on the DHMV as a ca. 4.1 km long ridge, situated on the hill crescent which constitutes the border between the Meuse and Scheldt basins. In the east, the *Beukenberg* adjoins the course of the 2nd century wall of the Roman city of *Tongeren*. The *Beukenberg* and the part of the aqueduct in agricultural land are separated by the presence of a school, which was constructed in 1970-1971. Earlier aerial photographs show the aqueduct in this area to curve to the NE with two distinct bends.

While earlier interpretations of the earthwork ranged from a dyke structure to a defensive wall against invasions of Germanic tribes[24], the possibility that this could be a Roman aqueduct was first supposed in the 1930s[25]. Although no clear evidence has since then been gathered to confirm this hypothesis, it is seeing the location and nature of the monument the most likely one (*infra*). This places the monument in the category of a small number of other Roman earthwork aqueducts in NW Europe, together with these from *Dorchester* (UK)[26] and *Nijmegen* (Netherlands)[27].

Archaeological investigations of the monument have to date been of a piecemeal nature. A trial trenching survey on the eastern edge of the *Beukenberg* attested that the construction of the

21 Clarys *et al.* 2004.
22 Vanwalleghem *et al.* 2007.
23 Meylemans 2009a & b.
24 Huybrigts 1896.
25 Sengers 1935a, b, c.
26 Burgers 2001; Putnam 1997.
27 Schut 2005.

monument is to be dated after the destruction of the city in 69-70AD, and before the construction of the first city wall in the 2nd part of the 2nd century AD[28]. It is therefore assumed that this construction constituted an element of the rebuilding phase of the Roman city under the reign of *Vespasianus*. When part of the aqueduct was destroyed with the construction of the already mentioned school in 1970-71, this part was observed to consist of a ca 2,5 m high and 30 to 50 m wide earthwork built up with 'yellow-grey' loam[29].

The origin and water source of the aqueduct are still unknown, as no clear earthworks or soilmarks attributable to it are visible on the LIDAR data and aerial photographs further 'upstream' on the watershed ridge. However, with the construction of a gas pipeline in this area parts of two ditches were discovered, running parallel with the Roman road of *Tongeren* to *Kassel*. These are interpreted as possibly being part of the aqueduct, the natural decline of the watershed ridge in this area being sufficient for water transport[30].

A first appraisal of the preservation state of the monument was the subject of a GPS survey in 2002[31]. This report issued a 'red alert' concerning the part of the aqueduct in agricultural land, mainly because of intensive tillage practices, which constitute mainly a threat only from 1993 onwards when a large agricultural re-allotment project was executed. On historical and cadastral maps before this project the aqueduct is clearly present as a structuring landscape element, with parcel patterns oriented on the presence and shape of the monument. The re-allotment project however did not take this into account, creating large field plots over the aqueduct ridge (fig. 10).

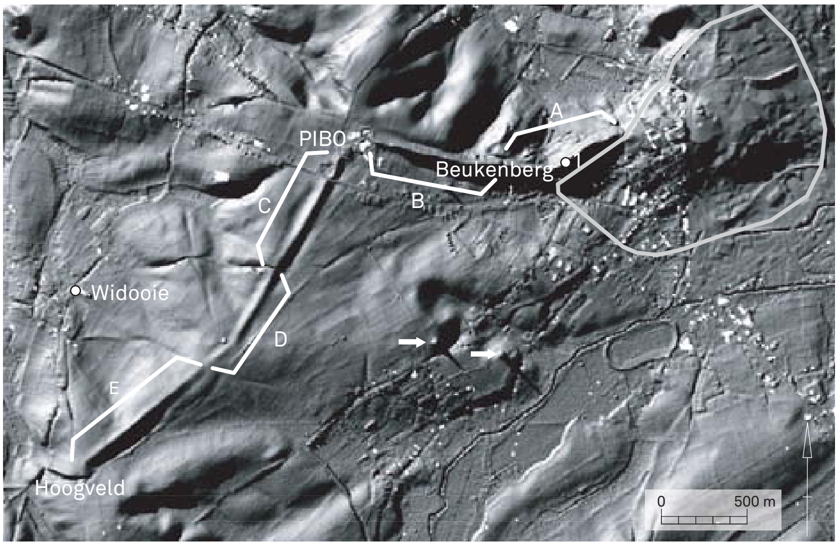


FIG. 8 Hillshade DEM of the aqueduct, with indication of the different zones (A-E), the loam quarry Baillien (1), Roman tumuli (arrows), and the extent of the Roman town of Tongeren (grey line).

FIG. 9 View of the Beukenberg.

28 Vanvinckenroye 1985, 45.
29 Vanvinckenroye 1971.
30 In 't Ven *et al.* 2005.
31 Ponzetta *et al.* 2002.

FIG. 10 Aerial photograph of the part of the aqueduct in agricultural land. The eroding core of the monument is clearly visible as a lighter strip.

3.2 Objectives and methodology

The aim of our evaluation was, through the use of the newly available DHMV LIDAR data (the standard available dataset with a mean resolution of one measure point/20m^2) and erosion modelling, to assess in a detailed way the current preservation of the aqueduct, as well as current erosion threats on the part situated in agricultural land. To this purpose the aqueduct was divided in five zones, separated from each other by recent disturbances such as hollow roads (fig. 8).

To perform the necessary measurements DEM's of the isolated aqueduct were created. This was done by defining the edges of the aqueduct through different *hillshade* visualisations of the DHMV. The LIDAR points within this perimeter were then cut from the rest of the surrounding DHMV LIDAR data. A *natural neighbour* interpolation of this dataset thus simulates the 'natural' surface of the area without the aqueduct. By subtracting this grid from the original DHMV grid, DEM's of the different zones of the aqueduct were created (fig. 11). These DEM's allow to perform a great number of measurements on the earthwork, such as slope analysis, volume, height, width *etc.*

In a next step, by using slope and height as defining criteria, it was possible to construct first 'preservation' models of the different zones of the monument, thus also identifying the best preserved parts. This showed that the flanks of these best preserved parts of the aqueduct, situated on the *Beukenberg*, have slope angles of ca. 30°. By using this slope angle as the probable original slope for the whole of the aqueduct, and based on the total volume of earth within the monument per zone, it was then possible to make a hypothetical reconstruction of the original appearance of the monument, thus also presenting a clearer view on the overall current preservation state.

For the assessment of current erosion impact the water- and tillage erosion models developed by the KU Leuven were used[32]. These were compared with other data such as aerial photographs, soil maps, and a *flow accumulation* modelling also based on the DHMV data.

3.3 Results

3.3.1 Measuring the aqueduct

On the aqueduct DEM's per zone the following measurements were taken: length, width, flank slope, volume, and relative height ('thickness')[33]. This shows that while slope angles on the *Beukenberg* zones range between 15 and 37°, slope angles in the other zones are much lower, ranging between 2 and 10°. This sharp decline of flank slope angle is undoubtedly attributable to the preservation state of the monument and accounts for its greater width in these zones, due to the 'sagging' of the earthwork. An impressive number is presented by the calculation of the total volume of earth in the aqueduct, amounting to more than 800.000m^3.

3.3.2 Assessment of the current preservation and hypothetical reconstruction

By using preserved slope angles and height as defining parameters it was possible to define the best preserved parts of the aqueduct in general (the zones of the *Beukenberg*), and per zone (fig. 12). Next, by using 30° as the probable original flank slope angle for the whole of the aqueduct, combined with the total volume of earth per zone, it was possible to hypothetically 'pull up' the aqueduct to its presumed original dimensions[34]. This shows that the aqueduct must have been originally ca. 4 m higher in zone C, and ca. 3,5 m higher in zone D. By using these reconstructed heights and the heights of the best preserved parts of the *Beukenberg* the decline of the earthwork ranges between 1,4 and 1,7‰, corroborating the aqueduct interpretation.

3.3.3 Assessing current erosion

The water erosion model uses an adapted version of the '*Revised Universal Soil Loss Equation*' (RUSLE2)[35], and maps erosion rates expressed as soil loss per grid cell in tons/ha/year. These values should be regarded as being indicative rather than absolute, as they depend strongly on grid resolution. This model shows highest erosion values on the flank slopes of the aqueduct (fig. 13). On the crest of the aqueduct, where the topography is flatter and without 'upslope contributing areas', predicted erosion rates are minimal.

32 Notebaert *et al.* 2006.
33 Meylemans 2009a.
34 *Ibid.*
35 Notebaert *et al.* 2006, 14.

The tillage erosion model[36] also expresses soil loss per grid cell in tons/ha/year, in the direction of the steepest slope angles. In the case of the aqueduct this is in general also the direction of ploughing activity. In contrast with the water erosion model the tillage model does not take into account connectivity between parcels. Every parcel is thus modelled separately. The high erosion rates visible on the parcel edges are subsequently to be considered as an artefact of the model, rather than reflecting real erosion rates. Considering the aqueduct, highest erosion rates are predicted on the crest of the aqueduct, while minimal erosion rates are modelled on the flank of the aqueduct (fig. 14).

The combination of both models (fig. 15), expressing the (indicative) total net erosion rate per grid cell, demonstrates a dominance of the current impact of tillage erosion over water erosion on the aqueduct earthwork. This results in erosion rates on the crest of the aqueduct to be 2 to 4 times higher than those predicted on the flanks.

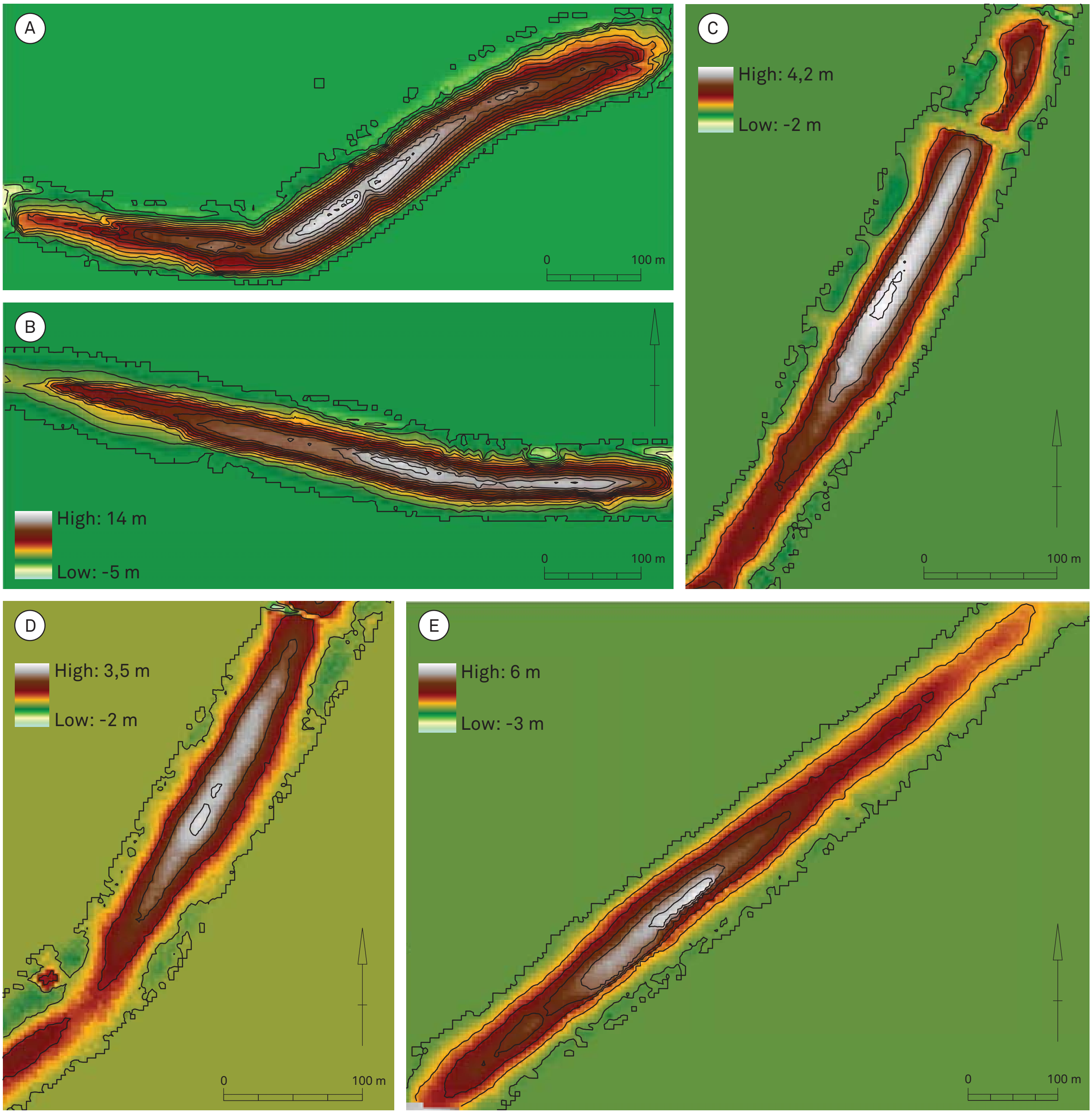


FIG. 11 **Isolated DEM's of the different parts of the aqueduct.**

36 *Idem*, 43-46.

When compared to recent aerial photographs a striking resemblance between the combined erosion model and the presence of lighter soil colourations can be observed. These lighter soil colourations, evidently originating from 'fresh' soil surfacing through erosion, are visible throughout the area, and a.o. mark very distinctly the rim of the aqueduct.

The presented erosion models do not, in contrast with the WATeM/SEDEM modelling used for the *Ottenburg* site (*supra*), predict sedimentation rates. To present an insight in sediment transport and sedimentation dynamics of the area we therefore produced a flow accumulation model of the area, and compared this with colluvium as presented on the available soil maps (fig. 16). This predicts a flow pattern in part flanking the aqueduct, in part corresponding with mapped colluvium, and demonstrates partial direct flow connectivity between the aqueduct and dry valleys to the NW of the aqueduct, also characterised

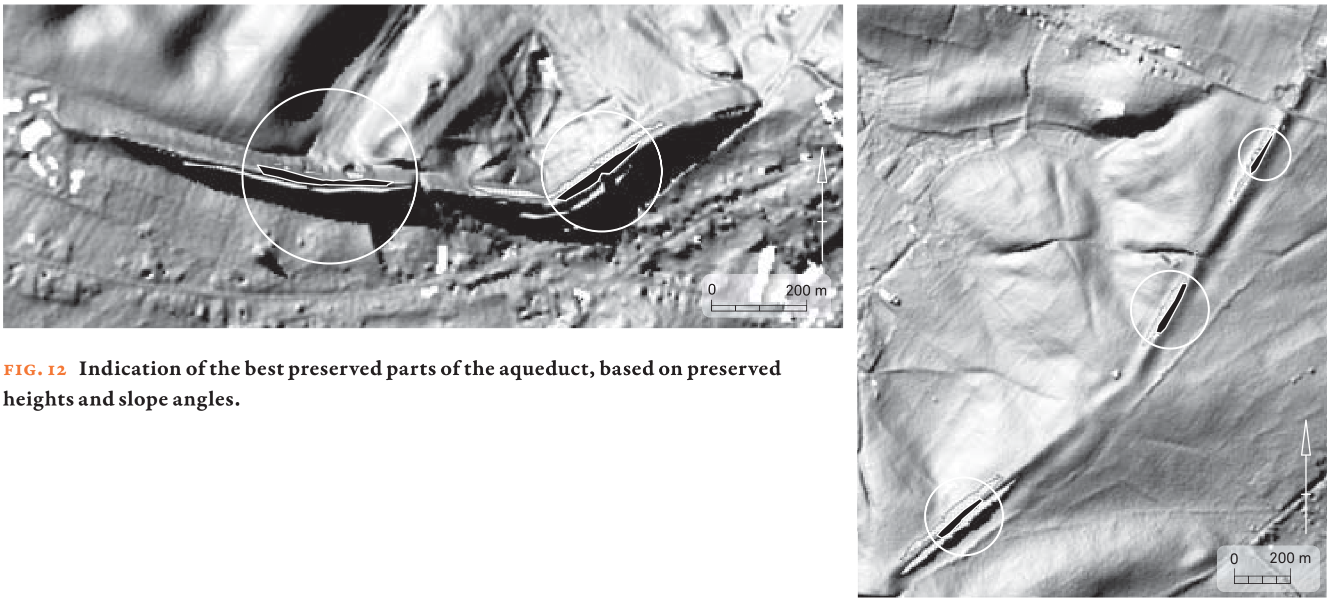
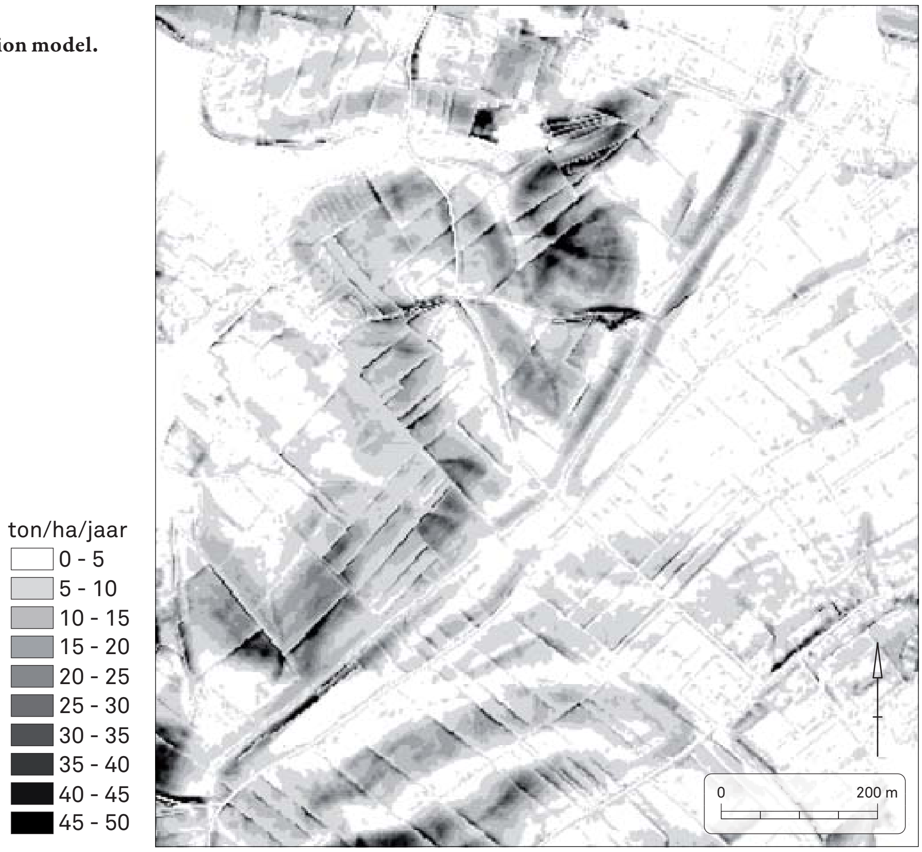


FIG. 12 Indication of the best preserved parts of the aqueduct, based on preserved heights and slope angles.

FIG. 13 Water erosion model.



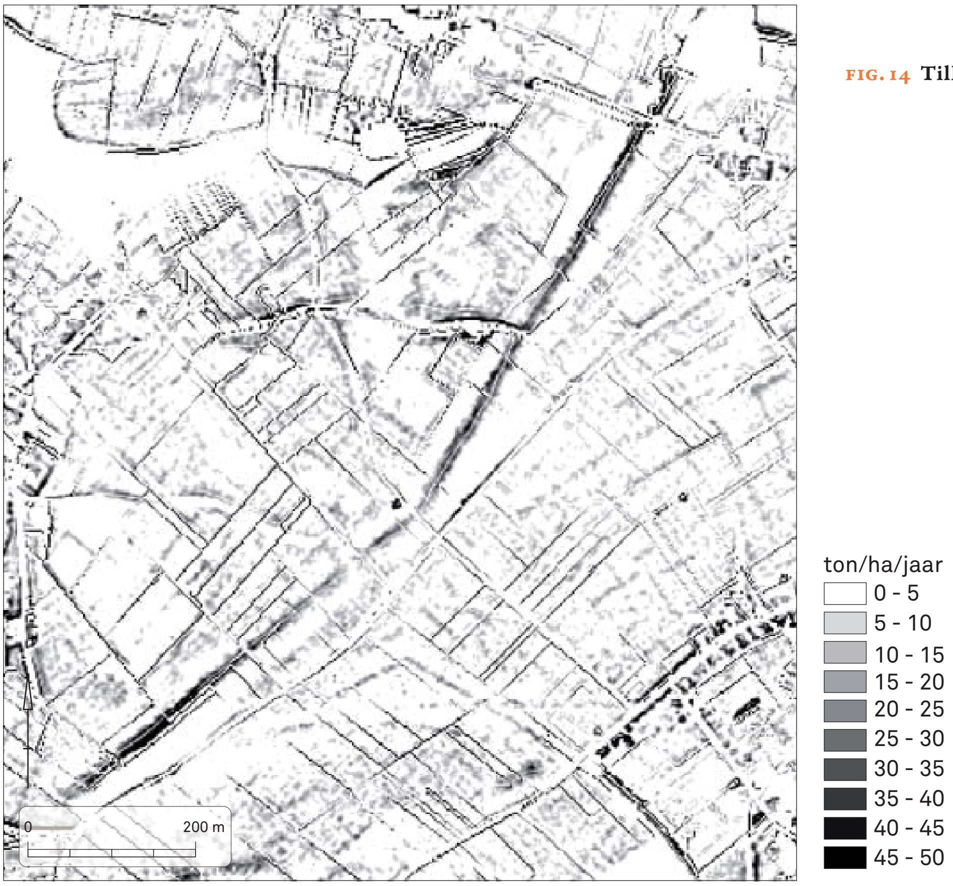


FIG. 14 Tillage erosion model.

FIG. 15 Cumulated erosion model, with topographical measurements from 2006 (blue lines) and indication of the areas where the differences in height between DTM and new measurements indicate a trend of 'flattening' (circled in red).

by colluvial fans on the soil map. This connectivity possibly explains the poor preservation state of the earthwork there. Considering the soil map data we must however keep in mind that this data was collected in the 1970s, thus before large scale reallotments from the 1990s, and thus before the large impact of tillage erosion in this area.

3.4 Conclusions

The use of the DHMV LIDAR data, as was the case for the *Ottenburg* site, proves itself to be extremely useful for an assessment of the preservation state of the Roman aqueduct. The high resolution data allow to take very precise measurements of the monument, which subsequently can be used to hypothetically reconstruct the original dimensions of the parts of the aqueduct situated in agricultural land. By comparing this 'original' with its current state we can presume that the earthwork has been decreased in height by up to 4 m, i.e. *ca* half of its original height.

By comparing current erosion models with aerial photographs it is clear that the preservation of the monument is currently heavily threatened by tillage erosion, foremost affecting the convex crest of the ridge.

4 Discussion and conclusions

Both the *Ottenburg* and aqueduct project demonstrated the merits of the DHMV LIDAR data both for archaeological surveying and mapping of archaeological sites with earthwork structures[37], and for the construction of 'derivative' products for landscape analysis.

Through the construction of erosion and sedimentation models and their comparison with other data it proved possible to demonstrate the impact of erosion, and to map in a fairly detailed manner the current preservation of both sites. This in turn allows us to construct management schemes for both sites.

In general both these test cases show the possibilities of the available erosion models for a broad scale assessment of the threats posed on the archaeological heritage of the loess area. One of the main conclusions we can already draw from these models is that the impact of tillage erosion on the archaeological heritage is to be regarded as enormous, in this loess area probably far more intense than the total impact of large infrastructural works.

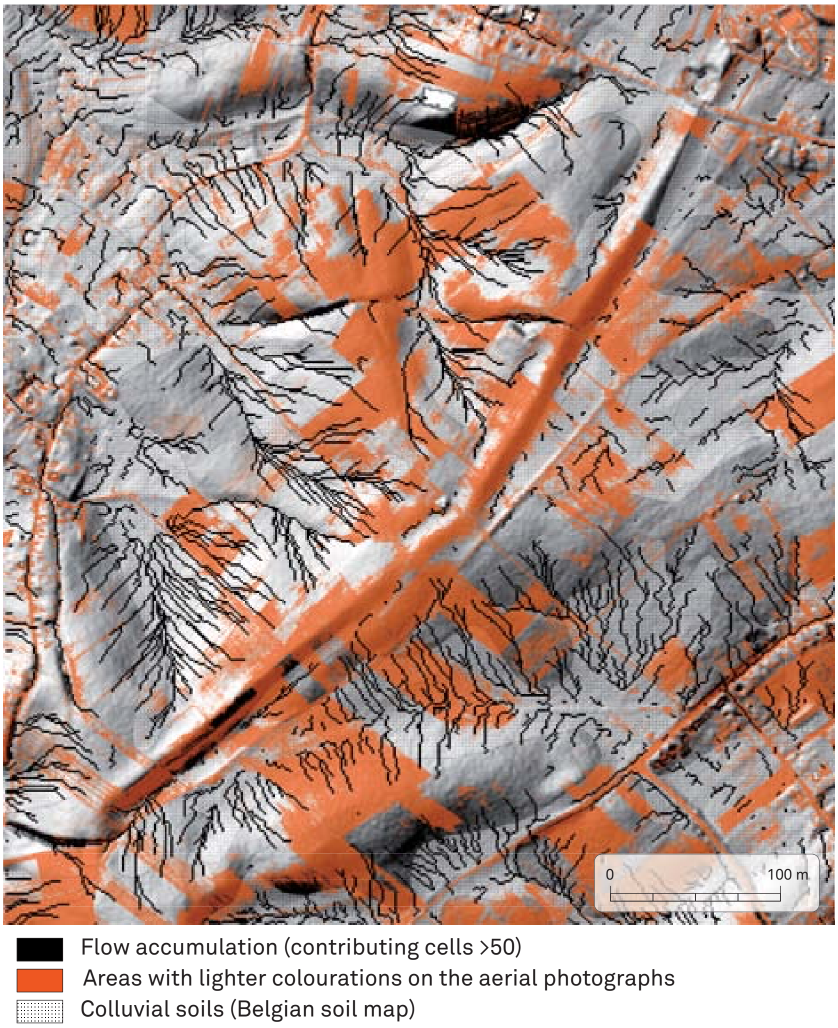


FIG. 16 Flow accumulation patterns, colluvium on the soil map, and indication of zones with lighter colourations based on Maximum Likelihood Classification Analysis (MLC).

37 See also Creemers *et al.* 2011.

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A pain in the plough zone. On the value and decline of Final Palaeolithic and Mesolithic sites in the Campine region (Belgium)

Marc De Bie[1], Marijn Van Gils[2] & David De Wilde[3]

Abstract

Since the start of the Holocene, the sandy area in the Northeast of Flanders known as the Campine region has experienced little natural erosion. Displacement of sediment and archaeological artefacts by wind, water, or gravity, has been rather limited. Many Final Palaeolithic and Mesolithic artefacts and sites are therefore still preserved near their initial location of deposition. At present, agricultural practices are the main cause for degradation of this archaeological record. This paper discusses the erosive impact of cultivation on stone-age sites in this Pleistocene region and argues that these contexts deserve more consideration, both in archaeological research programmes and in heritage management procedures.

Keywords

Plough zone, lithic scatters, site evaluation, Final Palaeolithic, Mesolithic, Campine region

1 Introduction

In the Campine region, water erosion had a rather small impact due to the scarcity of distinct slopes and the presence of coarse sands. This contrasts strongly with the southern hilly loess region, where the interplay with agriculture instigated substantial erosion and removal of archaeological evidence[4]. Wind erosion, although important during glacial periods, occurred much less frequently from the end of the Last Glacial onwards, when the increasingly dense vegetation started stabilising the soil. Only during the colder Younger Dryas, wind had a significant impact on the archaeological record, as could be attested at the *Federmesser* site of Lommel *Maatheide*[5]. Wind erosion was, more recently, also induced by vegetation removal through human activity, including pollution (e.g. at the site-complex of Lommel *Maatheide* as well).

Does this general scarcity of superficial erosion imply that Final Palaeolithic and Mesolithic sites in this region are perfectly preserved? Unfortunately it does not. Degradation of preservation quality started shortly after deposition with natural processes affecting virtually every site. Firstly, almost all organic remains disintegrated in the acidic sandy soils. Lithic assemblages and their spatial context virtually remain our only source of information. The preservation quality of the lithic artefacts and the spatial integrity of the scatters are therefore major criteria for the valuation of the archaeological value of these sites. Bioturbation was the second important taphonomic factor. A combination of various processes of flora- and faunaturbation affected every known site in this area[6]. The systematic large vertical dispersion of the artefacts is one of the most obvious results.

A third, but primeval, cause for site degradation is human activity, especially agricultural practice. In the loess region, as mentioned, this invigorated water erosion and the removal of a major part of the archaeological record. In relatively flat sandy areas such as the Campine region, the impact of agricultural activities is rather confined to direct local disturbance. Variation in the local history of land-use, such as the type of cultivation and the amount of ploughing, causes significant variance in preservation conditions of Final Palaeolithic and Mesolithic

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4 Vanmontfort *et al.* 2006.

5 De Bie *et al.* 2009; Van Gils & De Bie 2005a; 2005b.

6 Bubel 2003a; Vermeersch 2006.

sites. In fact, some sites in arable land are better preserved than generally thought. In the Campine region, large parts of land have remained unfarmed until recently. This region therefore potentially contains sites in cropland with relatively minor disturbances, more so than the rest of Flanders.

This variation of preservation conditions in agricultural land has, unfortunately, hardly been considered and recognised so far. This paper therefore aims to open the debate on the value and availability of prehistoric assemblages in these increasingly 'eroded' contexts, ranging from very well preserved buried sites, over sites only affected by Holocene bioturbation and soil formation, down to assemblages that are partly or completely incorporated in various types of plough zones. Analyses of excavation results of the last two decades serve to discuss the conservation of content, extent and structure of these sites, as well as their potential for intra- and inter-site spatial analysis.

The paper concludes with some recommendations for heritage management, as ongoing agricultural practices are further degrading or even destroying the residual archaeological value of these sites.

2 Sites from different contexts and their values

2.1 Sites in deeply buried palaeosols

In Flanders, stone-age sites of which the artefacts remained completely immobile since deposition have not been discovered yet, as every known site has at least been slightly affected by

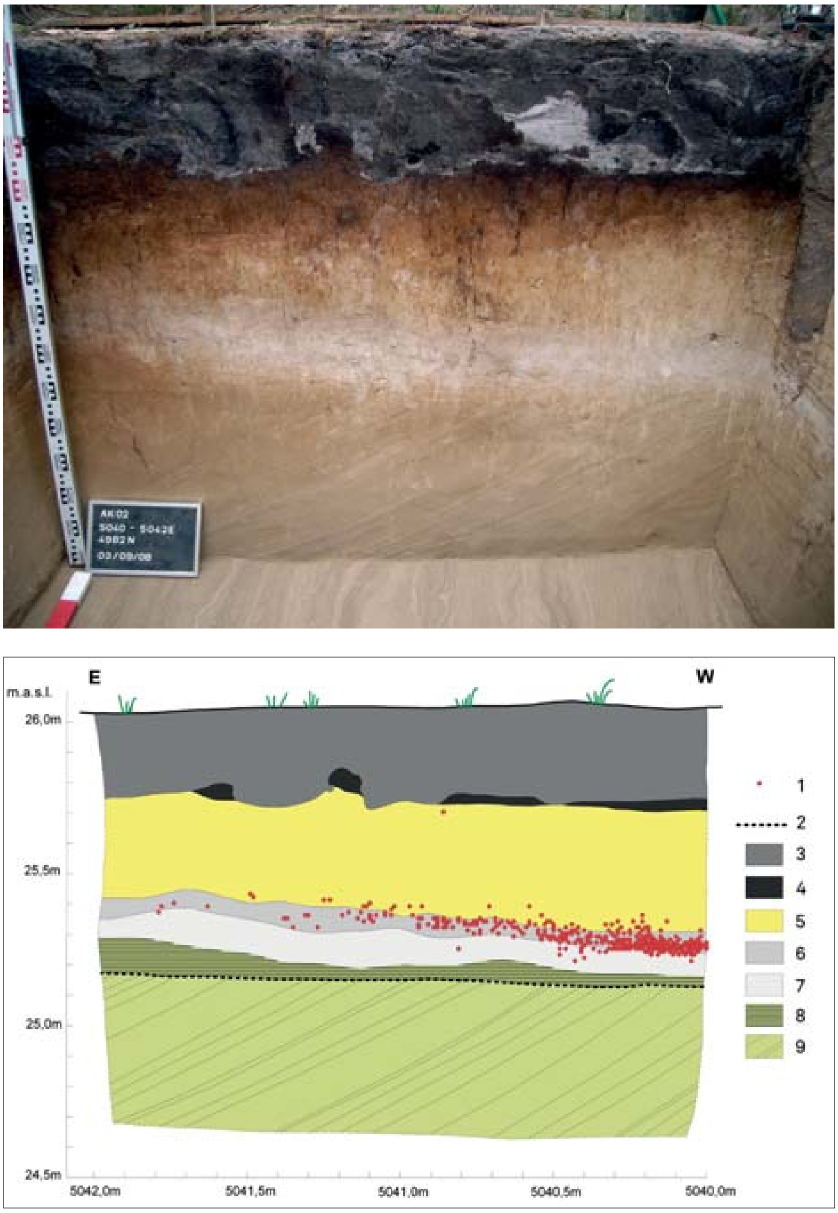

FIG. 1 **Top: buried and well-preserved Late Glacial Usselo soil at Landschap De Liereman *Duinengordel*. Bottom: artefact distribution of a 4 m² test excavation on the same profile. Note how this is strongly concentrated in the top of the Usselo soil, with only limited vertical displacement (Meirsman *et al.* 2008a; Meirsman *et al.* 2008b). The Podsol near the surface has been disturbed by singular ploughing but contained Mesolithic artefacts in another test excavation, only 25 m from this findspot (Van Gils *et al.* 2009).**
Legend:
1: lithic artefact
2: erosion level with small pebbles
3: disturbed Podsol
4: Podsol B-horizon
5: Podsol C-horizon
6: top of the Usselo soil
7: base of the Usselo soil
8: horizontally layered sands
9: obliquely layered sands

bioturbation. Artefact scatters preserved in a buried palaeosol, such as Final Palaeolithic *Federmesser* artefacts in a Late Glacial Usselo soil, represent the best conservation context encountered so far. Bioturbation did affect the spatial integrity of such sites, but only to a minor extent. The Allerød surface was soon covered by aeolian sands during the Younger Dryas, halting bioturbation in the now buried soil.

In the Campine region such contexts have, thus far, been recognised at three sites: Lommel *Maatheide*[7], Landschap De Liereman *Duinengordel*[8], and Lommel *Molse Nete*[9]. At these sites, Mesolithic occupation was attested in the Holocene Podsolic soil at the top of the sands covering the Usselo soil. This indicates that the Usselo soil was covered before the Early Holocene, most likely by aeolian activity during the Younger Dryas. The older scatters have thus only been affected by bioturbation for a relatively short period of time. As a result, the spatial integrity of these sites is excellent. The vertical artefact distribution is limited to some 10 cm, which more or less equals the thickness of the Usselo soil (fig. 1). The horizontal distribution is very discrete and seems very well preserved (fig. 2). Furthermore, the artefacts themselves are extremely sharp and 'fresh', which is important for microwear analysis and detailed technological studies. Without any doubt, preservation conditions in this type of context are exceptional. They offer unique possibilities for detailed intra-site spatial analysis and for the study of Final Palaeolithic cultural behaviour. The few known sites, however, can not provide sufficient information to examine themes like hunter-gatherer mobility, demography, land-use, etc.

2.2 Sites buried in palaeosols but also affected by Holocene soil formation

If not buried deep enough, covered Final Palaeolithic flint scatters can be affected by posterior Holocene bioturbation and soil formation. One *Federmesser* scatter at Lommel *Maatheide* for example, was preserved in an Usselo soil which was obliterated by Podsol formation. Figure 3 shows how the accumulation horizon of the podsol formed directly above the Late Glacial soil, rendering the latter invisible to the naked eye. The presence of the Usselo soil at the archaeological level could however be positively confirmed by palaeotopographical study over a larger area, by means of drillings and trenches. Preservation conditions, both in terms of vertical distribution and in terms of conservation of the artefacts, are obviously worse than those of deeply buried palaeosols, but generally better than those of Podsols[10].

The *Federmesser* site of Rekem was preserved in similar conditions (fig. 4). An elaborate functional and spatial analysis of this settlement clearly proved that the post-depositional processes did not systematically blur the fine-grained spatial patterns connected with past human activities[11].

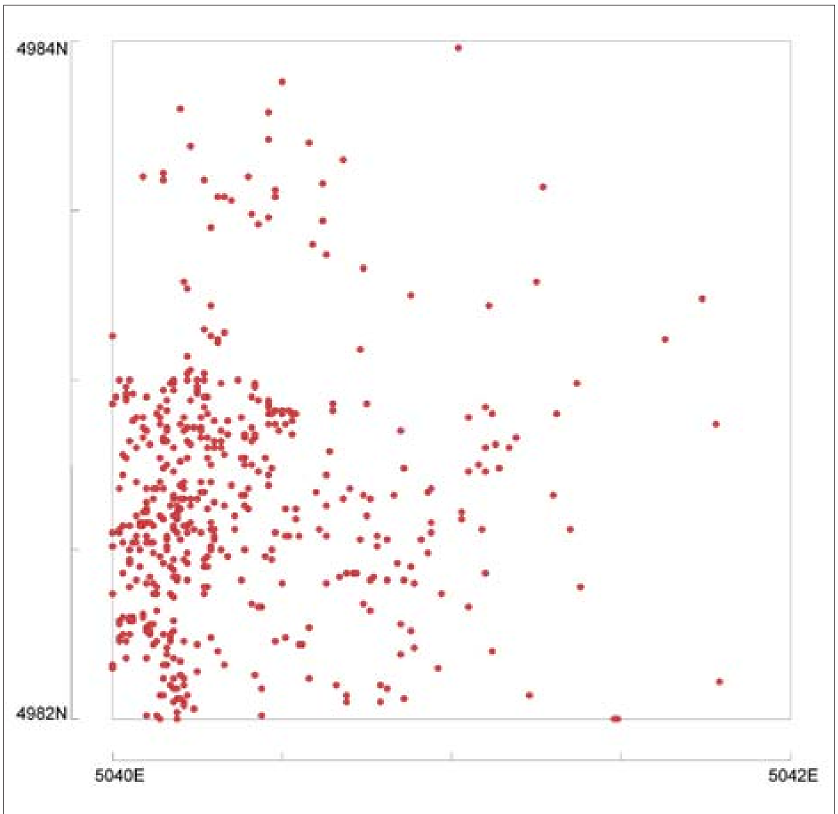

FIG. 2 Horizontal artefact distribution of the same test excavation at Landschap De Liereman *Duinengordel*. Note how the artefacts are densely concentrated near the south-western corner (Meirsman *et al.* 2008a en b).

7 De Bie *et al.* 2003; De Bie *et al.* 2009; Van Gils & De Bie 2005a; 2005b.

8 Meirsman *et al.* 2008a; Meirsman *et al.* 2008b; Vanmontfort *et al.* 2010.

9 Van Neste *et al.* 2009.

10 De Bie *et al.* 2009; Palmans 2006; Van Gils & De Bie 2005a.

11 De Bie & Caspar 2000; De Bie *et al.* 2002.

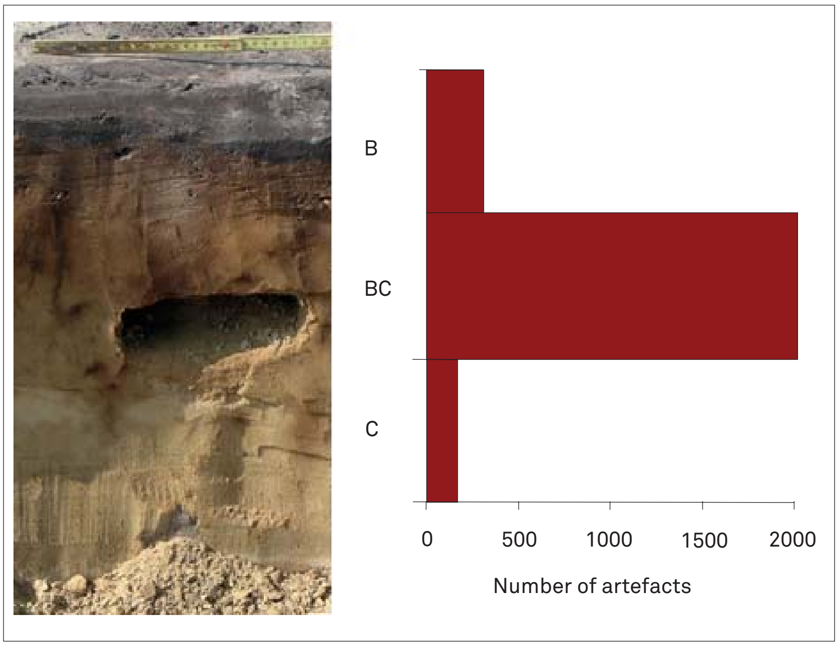

FIG. 3 Vertical artefact distribution at LB57A (Lommel *Maatheide*). The majority of artefacts were found under the B-horizon of the Podsol, in a buried Usselo soil. Podsol illuviation processes (BC-horizon) have blurred the visibility of the Usselo soil (Van Gils & De Bie 2005b).

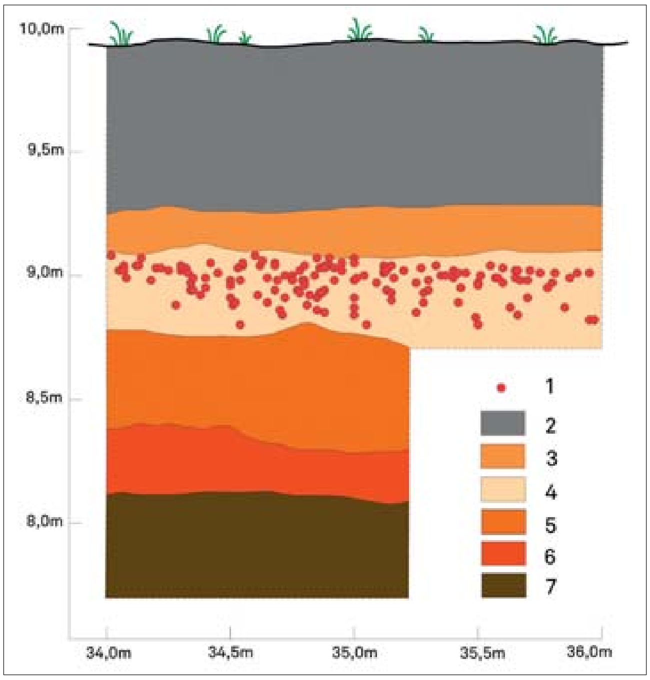

FIG. 4 Vertical distribution at Rekem. Although the artefacts were preserved in a buried context, later bioturbation and soil formation reached deep enough to cause significant vertical displacement (De Bie & Caspar 2000, 37-40).
1: lithic artefact
2: plough zone
3: heavily bioturbated cultural layer
4: bleached horizon, obliterated by recent soil formation processes
5: homogeneous aeolian sands
6: distinctly layered cover sands
7: gravels of Meuse river terrace

2.3 Sites in a Holocene soil (Podsol)

Most Holocene sites, as well as the majority of known Final Palaeolithic sites have been fully incorporated in the Holocene Podsolic soil.

Again, bioturbation is the main factor of degradation. But, as these post-depositional processes have been active for a much longer period, they had a far greater impact than in a covered Usselo soil[12] (fig. 5). Biological activity in these poor soils may be low at present, but was much more intense before the Podsol had fully developed. The impact is most visible in the vertical artefact distribution, which often spans the entire thickness of the Podsol, reaching 30 cm to 50 cm or even more (fig. 6). Most importantly, this seems to have intermixed all possible occupational phases present at these sites, Final Palaeolithic as well as Mesolithic. All attempts at stratigraphical separation of occupation phases have indeed, to date, failed. As a result, isolating distinct episodes of occupation and dating these events are often problematic[13]. However, the horizontal distribution seems to be affected less and spatial integrity by itself is usually sufficient to allow for some degree of spatial analysis, as was for example conducted at Meer *Meirberg* II[14].

12 Bubel 2003a.

13 Bubel 2003a; Vermeersch 2006.

14 Van Noten (éd.) 1978.

FIG. 5 **Excavation in progress at Brecht *Moordenaarsven*, showing the impact of large tree roots on the soil (Verbeek *et al.* (eds) 2004). This constitutes only part of flora-induced bioturbation and one moment in time (one generation of trees). Faunaturbation may have been even more disruptive (Bubel 2003b).**

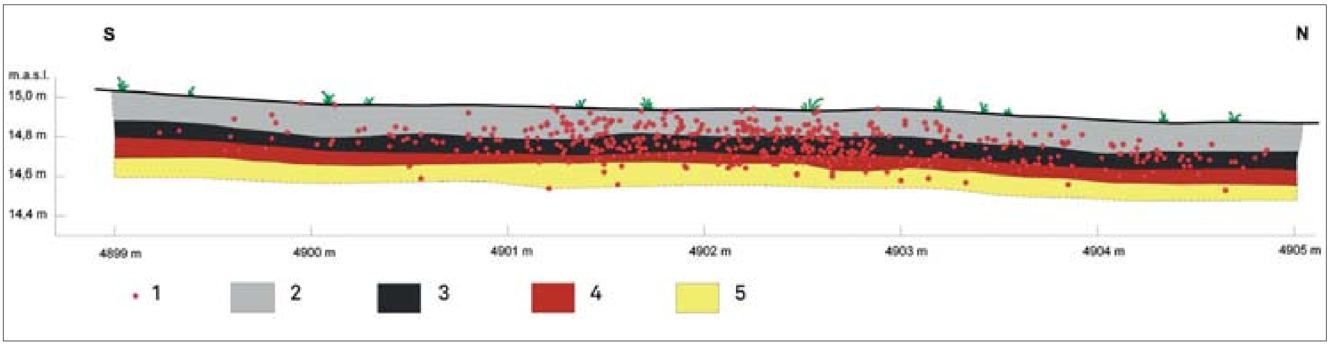

FIG. 6 **Vertical distribution of lithic artefacts at the Early Mesolithic locus of Meer 6. Although abandoned at the current surface, they are dispersed over 40 cm throughout the Podsol (De Bie 2000a).**
Legend:
1: lithic artefact
2: eluviation horizon (E)
3: humic illuviation horizon (Bh)
4: iron illuviation horizon (Bir)
5: yellow sands (C-horizon)

At isolated loci, such as Meer 6 and Meer 7, that presumably represent single and short-term occupation episodes[15], significant spatial patterning emerges. The most obvious pattern is the diagonal separation of the work space, with a concentration of hunting-related artefacts (microliths and microburins) at one side and 'domestic' tools (scrapers and burins) at the other side (fig. 7-8). This pattern has recurrently been observed at Mesolithic sites with far better preservation conditions (including organic materials) for example in Southern Scandinavia, where this patterning is thought to reflect male- and female-related activities[16].

Even though the artefacts have obviously somewhat moved from their original position, preservation conditions of lithic assemblages in podsolic soils are generally considered satisfying. Microwear analysis can usually be executed with success, offering further opportunities to test the observed spatial organization.

Some sites have been covered by aeolian sands of historic age, as for example Meer *Meirberg* II[17] and part of Lommel *Molse Nete*[18] (fig. 9). Unfortunately, this local sedimentation postdated Podsol development and the associated bioturbation and therefore hardly generated better preservation conditions. It did, however, protect these sites from recent human impact.

As Holocene soils generally have not been covered in the Campine region, most sites are indeed further affected by recent anthropogenic disturbances. Most present-day forested areas, for example, were ploughed at least once when they were planted in former heathland in the 19th and early 20th centuries. This can be observed in the upper part of the Podsol, as Bocholt *Smeetshof* clearly illustrates[19] (fig. 10). Most sites in Podsol soils in forests

15 De Bie 2000a; Depraetere *et al.* 2007.
16 Grøn 2003.
17 Van Noten (éd.) 1978.
18 Van Gils & De Bie 2003.
19 De Bie 2000b.

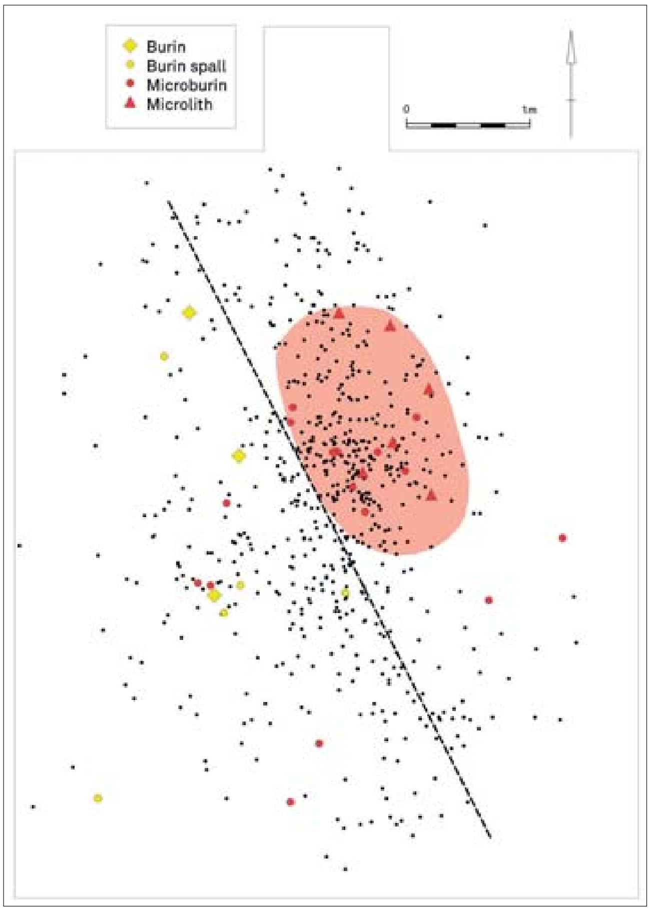

FIG. 7 Artefact distribution at Meer *Meirberg* 6. Artefacts were piece-plotted individually. Projectile-related pieces (microliths and microburins) are predominantly discarded in the north-eastern sector (reddish area), while 'domestic' tools (burins) and tool waste (burin spalls) are exclusively present in the south-western sector (After Nakken 2006).

FIG. 9 Profile of Lommel *Molse Nete*, showing historic aeolian sands covering an intact Podsol. All artefacts were found in the Podsol, while the sands above remained sterile (© Flanders Heritage Agency).

FIG. 8 Artefact distribution at Meer *Meirberg* 7. Artefacts were piece-plotted individually. Projectile-related pieces (microliths and microburins) are here predominantly discarded in the south-western sector (reddish area), while 'domestic' tools (burins and a scraper) are exclusively present in the north-eastern sector (After Nakken 2006).

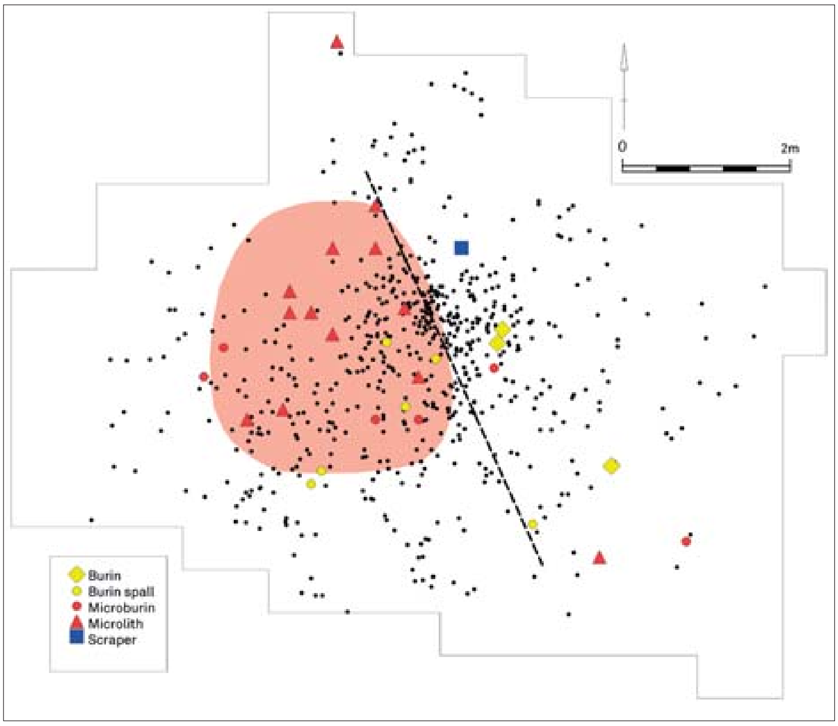

FIG. 10 One time ploughing at Bocholt *Smeetshof*, visible in a 4 m² excavation pit (top: surface; bottom: profile) by the singular row of plough lines in the top half of the eluviation horizon (E) of the Podsol (De Bie 2000b).

seem to have been affected by this. However, the impact of this kind of singular ploughing is probably less substantial than the natural bioturbation and therefore constitutes only a minor element of site degradation.

Sites in Holocene soils are more easily discovered and therefore better known than sites in buried palaeosols. Due to the poorness of the Campine soils, relatively large areas of the region have never been subjected to agriculture but were regarded as wasteland (so called '*woeste gronden*'). Many of these areas are now preserved as forest or heathland and some of them are part of protected nature reserves or military property[20]. These areas yield a good number of sites in Holocene soils, but this number is certainly limited and the policy should be to conserve these sites *in situ* for the future. Moreover, the distribution of these areas across the region is quite irregular, leaving large areas without any such site. In these areas, sites in plough zones are the only remaining archaeological sources for these periods.

2.4 Sites in plough zones

Agricultural activities can take many forms. The impact they have on archaeological sites can be as diverse as the activities themselves. As mentioned above, a single ploughing event only modestly reduces the quality of a site in this region. This section will discuss the sites that were more strongly influenced by agricultural activities. The value of these plough zone sites is mainly determined by the research potential they offer. Key aspects are the homogeneity and spatial integrity of a concentration. Three main factors related to the history of land-use determine the degree of degradation.

The first factor concerns the different types of cultivation. The impact on archaeological remains depends on which part of the crop is 'profitable' and thus harvested. For crops like potatoes and sugar beets, that need to be extracted from the soil, the agricultural practice involves major displacement of soil and removal of the larger artefacts (e.g. cores) by sieving of the sediment. If, on the contrary, the profitable part grows above the soil

20 Van Gils & De Bie 2002; Verdurmen & Tys 2007.

(e.g. corn) the impact on the archaeological record is limited to the depth of the roots and the depth of ploughing[21].

This brings us to the second factor: the depth of ploughing. Evidently, deeper ploughing implies more vertical disturbance and less hope for part of the assemblage to remain unaffected. Stratigraphically separated concentrations may be mixed, which evidently implies important loss of information.

The third factor is the amount of ploughing. This depends on the length of the period during which parcels have been ploughed, and on how frequently this was done. For example, cropland is usually ploughed much more often than grassland, resulting in a greater disturbance over the same time-span. The more a parcel has been ploughed, the greater the degradation of the spatial context. This also increases the chance and intensity of damage to pieces by direct contact with the plough, which causes edge damage to the artefacts and has a negative influence on the potential for microwear analysis.

Modelling studies have shown that the slope of a surface has an influence too, causing artefacts to slowly move downhill by repeated ploughing, but slope gradients are negligible in most of the Campine region.

The same studies show that the amount of ploughing is by far the main factor for the degradation of a spatial context. More importantly, they also indicate that this is a very gradual process over time[22]. In the Campine region, where the sandy soils were rather poor during historical times, large areas remained uncultivated heathland for a long time. This means there is good reason to conjecture a significant variation between land that was used for a long period of time, known to be 'historical' agricultural land, and areas taken into cultivation much more recently. The latter might show far better preservation conditions.

2.4.1 'Normally' ploughed sites

Some sites containing a substantial amount of plough zone finds can still be of genuine value for spatial analysis. Examples of such sites were excavated at Weelde in the 1990s[23] (fig. 11). The loci Weelde *Eindegoorheide* 12, 13, 16, 18 and 21 are aggregations of lithic artefacts from both the Final Palaeolithic and the Mesolithic, discovered on parcels which have only been in agriculture since the early 1960s.

At Weelde *Eindegoorheide* 16 and 18, about 90% of the finds were retrieved from the plough zone. Still, analysis of the horizontal artefact distribution clearly revealed several distinct concentrations, and significant patterns could still be perceived in plots of the plough zone finds. The same features appear when only the 'in situ' finds (10% of the artefacts) are displayed (fig. 12). As the spatial integrity of the material in the plough zone can in these cases be compared with the unaffected part of the assemblage, the impact of ploughing on the preservation can be assessed. Weelde *Eindegoorheide* 12 (18% in situ finds) and 13 (12% in situ finds) are heterogeneous concentrations, containing both Final Palaeolithic and Early Mesolithic artefacts. Both findspots are palimpsests where artefacts from various periods are intermixed due to natural and human postdepositional processes. However, when diagnostic artefacts, i.e. microliths, microburins and pieces of Wommersom quartzite, are registered and visualised on a distribution map, these Mesolithic artefacts reveal a distinct distribution (fig. 13). Weelde *Eindegoorheide* 13, for instance, shows a clear concentration of microburins and Wommersom quartzite in the northern part of the lithic scatter.

Even concentrations, such as Weelde *Eindegoorheide* 21, with an extremely limited amount of artefacts preserved under the plough zone (in situ finds are in this case limited to 1% or 31 artefacts), can present clear patterning (fig. 14). Spatial analysis revealed the preservation of two distinct concentrations and a significant distribution of several artefact types within the eastern concentration, presumably linked to different activities[24]. The arrangement is clearly analogous to the observations described above for the 'in situ' loci Meer 6 and Meer 7. Evidently, this unmistaken and meaningful patterning would not have been discerned if the plough zone at Weelde *Eindegoorheide* 21 would have been removed without systematic sieving and recording in spatial units[25].

Sites that have been ploughed for a much longer period of time are less suitable for in-depth spatial analysis. This type of sites, as for example Weelde *Voorheide* 2[26], can only retain a

FIG. 11 Typical profile at Weelde *Eindegoorheide*, showing a plough soil directly on top of yellow sands. Artefacts were retrieved from both levels, but the majority came from the plough zone (© Prehistoric Archaeology Unit, KULeuven).

21 Nakken 2006, 19-20.
22 Boismier 1997.
23 Verbeek 1999.
24 Nakken 2006, 54-55; 2008, 109-111.
25 De Wilde 2007.
26 Verbeek & Vermeersch 1995, 63.

certain degree of structural integrity in the plough zone, such as recognisable circular concentrations. Lower artefact densities (max. 46 items per m^2 at Weelde *Voorheide* 2) and diffuse boundaries indicate that these scatters are more spread out and reworked by ploughing. Any human induced patterning within the scatters is most likely lost in these conditions[27].

It should be clear that the value of a plough zone site should be assessed case by case. Not only the remaining 'in situ' fraction, affected by the depth of ploughing, but especially the amount of ploughing events determine the state of the horizontal and vertical integrity of the concentrations. Continued and repetitive ploughing on these sites causes gradual deterioration of the spatial integrity over time[28]. This does, however, not imply a complete destruction of all patterning. Sites which have been farmed for a long period of time can still contain structural evidence (i.e. recognisable spatial features), while sites that have only been ploughed for a few decades still retain clear potential for relevant intra-site and intra-locus spatial analysis.

2.4.2 Tuberous plant cultivation

Cultivation of potatoes (quite common in the Campine region), sugar beets, flower bulbs, etc. necessitates more preparation of the land after ploughing. First, a tiller crumbles the top soil. Then, after planting the tubers, part of the soil is raised to form

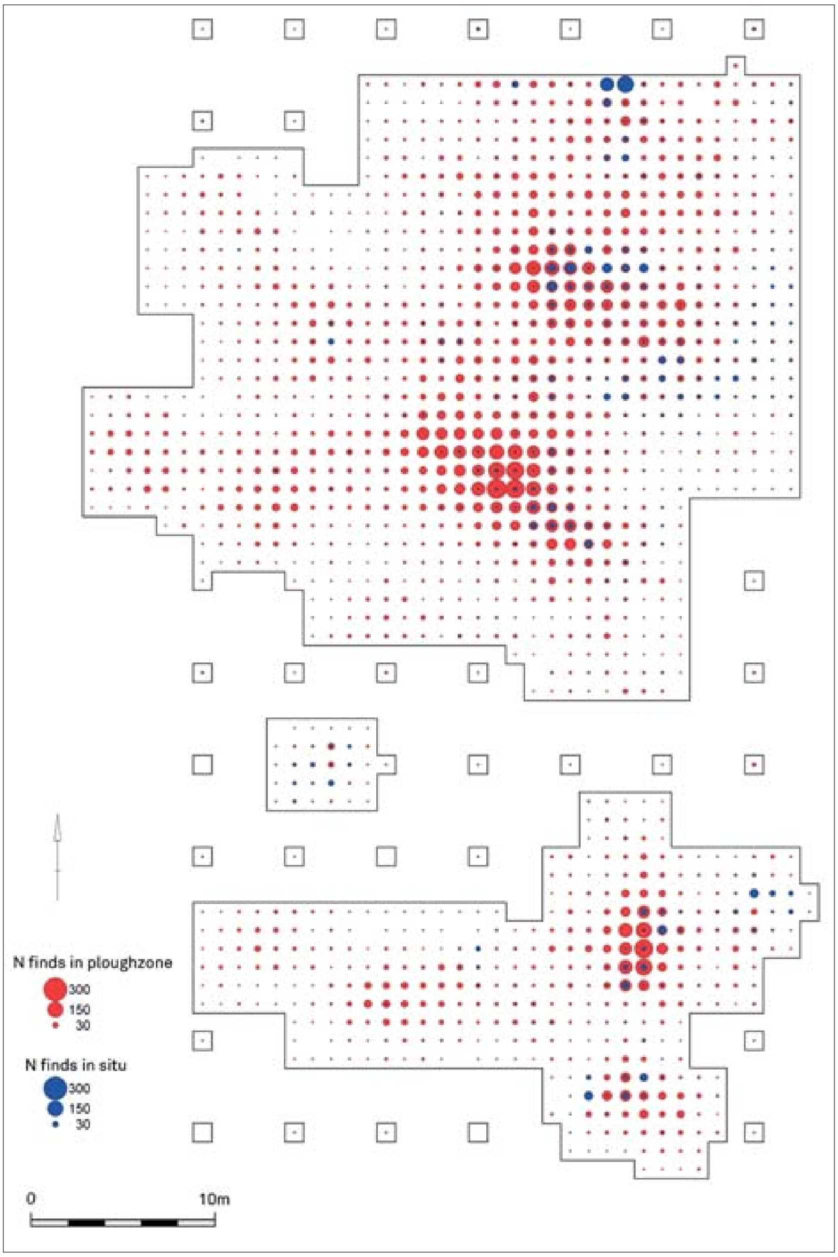

FIG. 12 Artefact distribution at Weelde *Eindegoorheide* 16, 17 and 18. Every dot represents the amount of artefacts from 1 m^2. Note how the presence of concentrations in both stratigraphical units largely correlates.

27 Boismier 1997.

28 Boismier 1997.

rows to facilitate extraction later on. Finally, when machine-lifting the crops, the soil is disturbed for a fourth time. The earth is sieved, displacing the soil and removing all big elements like flower bulbs, potatoes, beets and large lithic artefacts[29]. Evidently, the sum of these activities has a much greater impact on site conservation than ploughing alone.

Weelde *Flaesheide* is an example of a site affected by these techniques of planting and harvesting. Potatoe cultivation caused a greater horizontal displacement, spreading the scatter, which resulted in a much lower density of finds per m². In Weelde *Flaesheide* no more than 12 artefacts/m² were registered, while at Weelde *Eindegoorheide* 16 a square meter sometimes contained more than 200 artefacts. Some patterning remained at Weelde *Flaesheide* but in-depth spatial analysis seems difficult or even impossible[30] (fig. 15). However, as only spatial integrity and the largest artefacts are affected, these sites undoubtedly retain a value for inter-site comparisons and land-use analysis of prehistoric societies.

As the type of cultivation is often alternated on many parcels, further research on the precise impact of potato or beet cultivation is definitely needed.

2.4.3 Levelled sites

As former land consolidation projects in the region often implied a complete levelling of the land, sites located in these areas are generally destroyed (fig. 16). The integrity of these sites is seriously damaged and no spatial patterning whatsoever remains. The site of Weelde *Brouwersgoor* for example, which was levelled around 1960, does no longer show concentrations but instead a rather uniform finds distribution, with a maximal density of 60 artefacts/m²[31] (fig. 17). The informative potential of such sites for spatial analysis seems negligible. These assemblages retain a certain value, however, for typo- and technological research, study of major historical processes, etc.

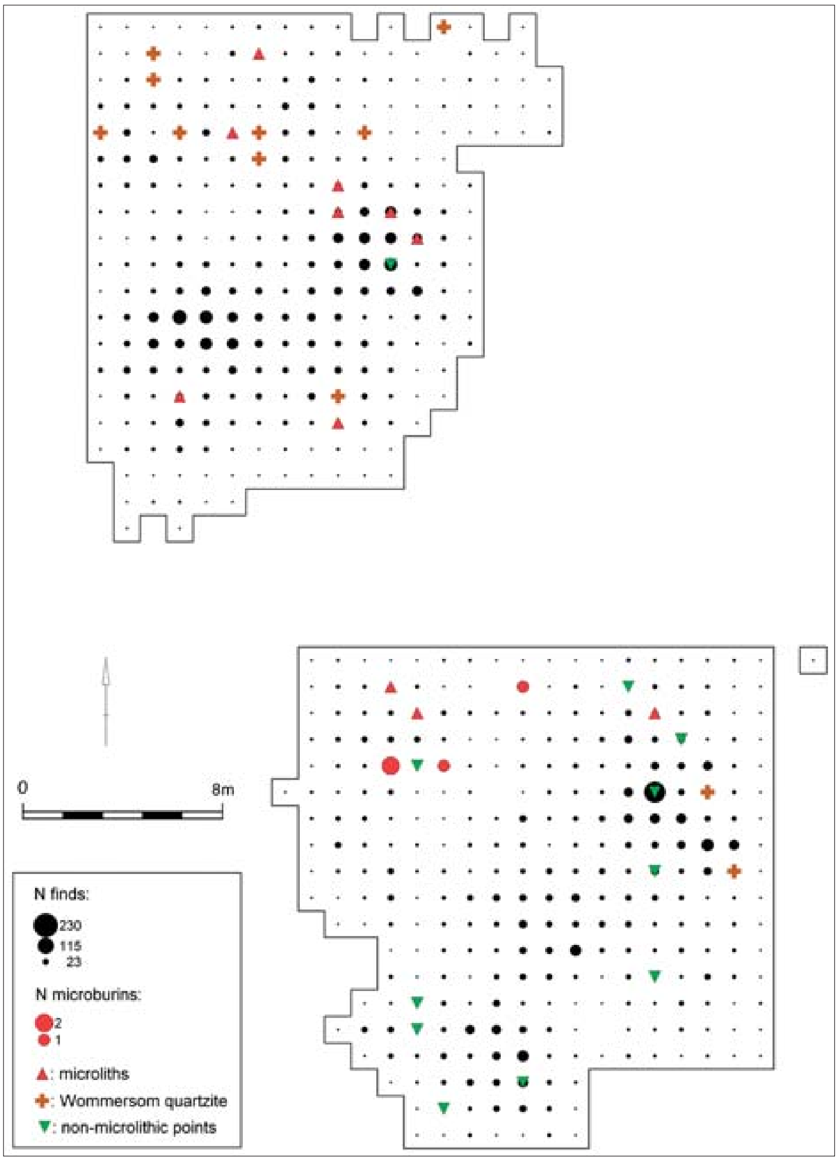

FIG. 13 Artefact distribution at Weelde *Eindegoorheide* 12 (bottom) and 13 (top). Black dots represent the amount of artefacts from 1 m², while the other symbols show the location of specific artefact types and of Wommersom quartzite. Note how Mesolithic tools (microliths), tooling waste (microburins) and Wommersom quartzite (also typical for the Mesolithic) were found in the northern parts of Weelde *Eindegoorheide* 13. A very different pattern emerges for the non-microlithic Final Palaeolithic points.

29 Nakken 2008, 104.

30 Verbeek 1997, 82; 1999, 25.

31 Verbeek 1999, 22-23.

2.4.4 A peculiar situation: sites covered by anthropogenic soils

Whereas all the activities mentioned above have a negative impact on the conservation of prehistoric sites, a historical type of agricultural activity existed which can actually protect sites. Plaggen soils are built up by continuous fertilisation of cropland with dung-soaked heath sods. The resulting thick anthropogenic humic horizon can cover the natural topography, including the Podsol and any lithic scatter it contains[32].

So far this has only been observed at Merksplas *Hoekeinde*[33] (fig. 18), where the conservation can best be compared to the sites discussed in 2.3 (sites in a Holocene soil). This context might not be as uncommon as it seems, however, as the covering plaggen soil itself may obscure sites, making them virtually invisible at the surface[34]. More research on this type of soil needs to be carried out in the form of in-depth survey and evaluation projects.

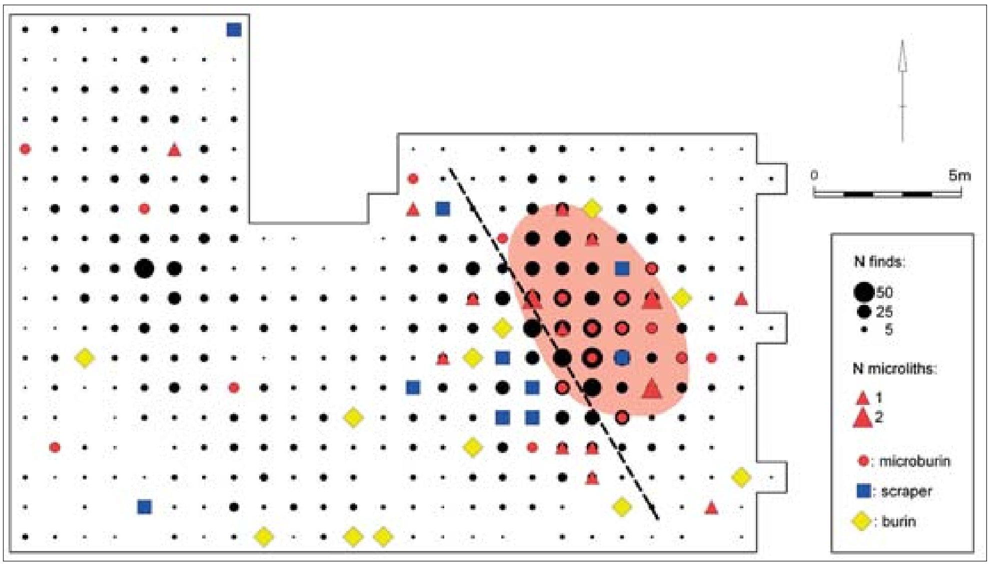

FIG. 14 Artefact distribution at Weelde *Eindegoorheide* 21, a scatter that was excavated in units of 1 m². In the eastern concentration, projectile-related artefacts (microliths and microburins) clearly dominate the north-eastern sector (reddish area), while 'domestic' tools are better represented in the south-western sector (After Nakken 2006).

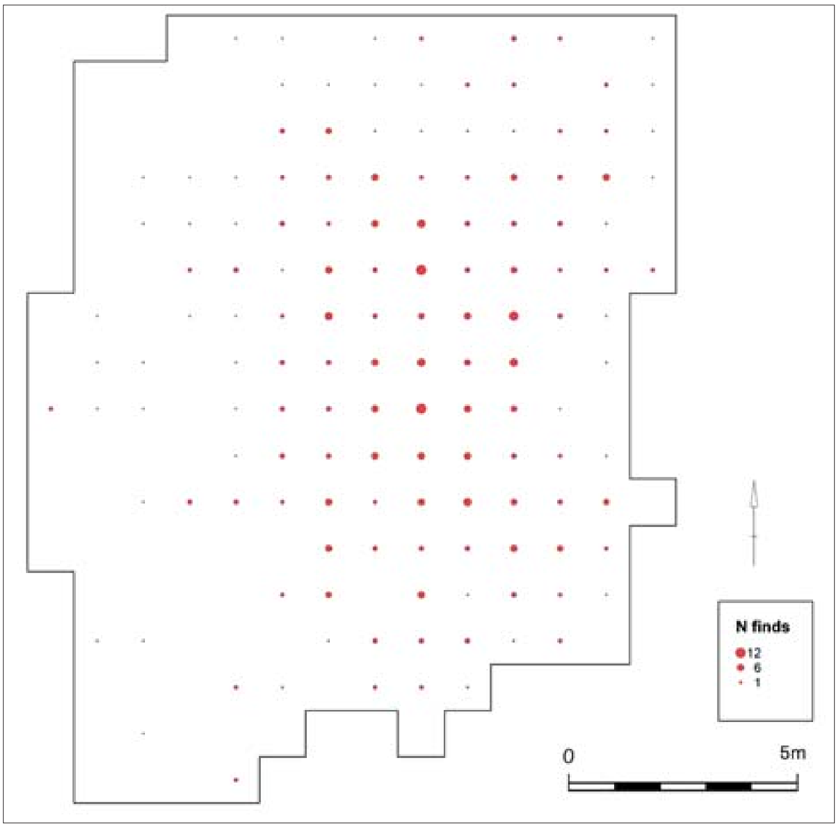

FIG. 15 Artefact distribution at Weelde *Flaesheide*. Red dots represent the amount of artefacts from 1 m².

32 Deeben & Groenewoudt 1999.

33 Depraetere *et al.* 2006b.

34 Deeben & Groenewoudt 1999.

FIG. 16 The effects and scale of land levelling in the Campine region. Top: the more or less original topography, typical for the region, at Merksplas *Hoekeinde*. Bottom: an intensely levelled landscape in Weelde (photographs: Kris Vandevorst, © Flanders Heritage Agency).

3 Discussion

3.1 Research potential

Hunter-gatherer plough zone sites have significant research potential to offer. Even completely displaced or levelled sites can still be useful for comparative inter-site, typo- and technological studies (fig. 19). Moreover, for general regional comparisons or the study of evolutions through time of demography, technology, etc., every known assemblage may be relevant.

When sites, due to long-term agricultural practices, do no longer represent any recognisable features, they still relate to the local topography - at least when they are not displaced in their entirety. For large scale landscape approaches, focussing on topics like settlement patterning, land-use histories, and inter-site comparisons, plough zone sites offer virtually the same data as better preserved sites.

Evidently, the better preservation conditions are, the more useful and significant spatial information plough zone finds can contain. Whereas intensively farmed parcels can at best yield recognisable scatters, less frequently ploughed sites are potentially still suitable for intra-site spatial analysis. In fact, only detailed intra-locus spatial analyses can rarely be achieved on plough zone sites. This indeed demands sites in buried palaeosols or well-preserved Holocene soils. These better preserved contexts, however, deserve protection for the future. They should only be excavated when necessary or inevitable, and with all necessary care (see below). From this perspective, plough zone sites offer opportunities in all respect and are, at least, complementary with less disturbed contexts.

3.2 Excavation strategies

As illustrated above, plough zone sites are to be assessed in a wide range of conservation conditions, from relevant preservation of the spatial context to complete displacement and blurring of the artefact scatters. In order to minimise both unnecessary cost and loss of relevant data, varying conservation conditions require different excavation strategies. Care should be taken when selecting the best performing field methods for each site.

It is obvious that very well conserved sites, like the ones preserved in buried palaeosols, demand precise excavation methods and detailed spatial registration to enable all possible detailed

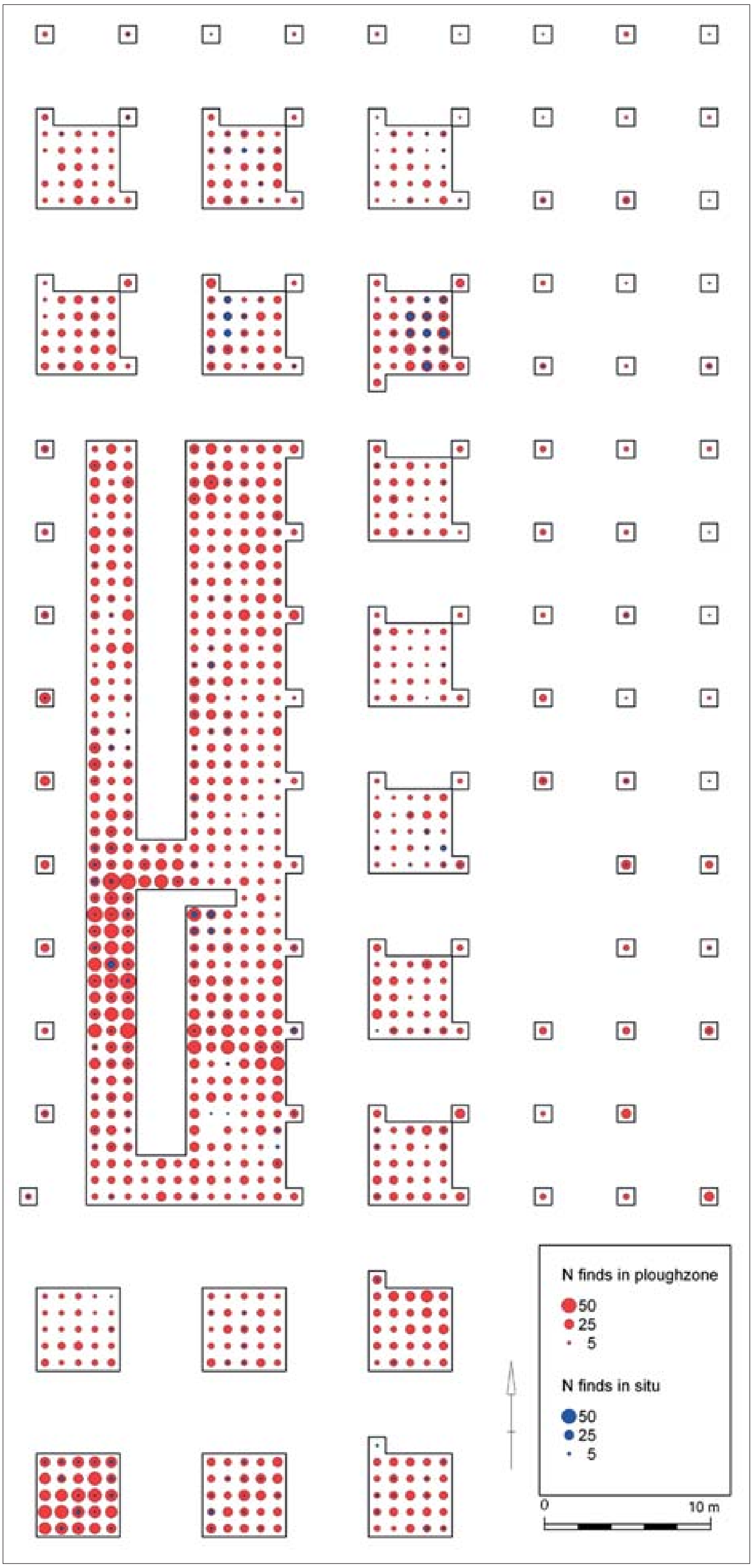

FIG. 17 **Artefact distribution at Weelde *Brouwersgoor*. Every dot represents the amount of artefacts from 1 m².**

FIG. 18 A test-pit at Merksplas *Hoekeinde* showing a thick ploughsoil covering a well preserved Podsol. A flint blade (red circle) is still visible in the eluviation horizon (E) of the podsol (Depraetere *et al.* 2006a).

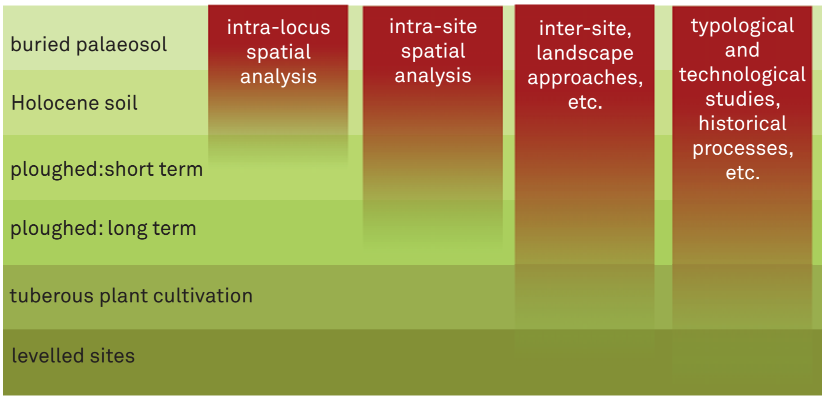

FIG. 19 The correlation of different preservation contexts encountered in the Campine region and their research potential.

post-excavation studies, e.g. part of Lommel *Maatheide*[35] and Landschap De Liereman *Duinengordel*[36]. Sites buried in Holocene soils have been excavated with the same degree of detail in the past, e.g. Weelde *Paardsdrank*[37], Opglabbeek *Ruiterskuilen*[38] and Meer *Meirberg*[39]. For some of them, however, finds were collected by shovelling and sieving the sediment retrieved from a vertical level (e.g. statigraphical units, soil horizons or fixed intervals) in horizontal units of one 1/4 m^2 (50x50 cm squares), e.g. Lommel *Maatheide*[40] and Lommel *Molse Nete*[41]. This method is, indeed, much more time- and cost-effective. It remains hard to assess whether this causes a noticeable loss in useful information for sites in a bioturbated Podsol.

Plough zone assemblages have generally been excavated by shovel and sieved per m^2 (e.g. Weelde *Eindegoorheide*[42]). When the entire plough zone constitutes one stratigraphical unit, it can be processed as such, making these excavations less time consuming and therefore less costly. The spatial data recorded by this technique seem to be sufficient, as the m^2-grid still allows for a relevant degree of spatial analysis[43].

At sites with completely destroyed spatial contexts, e.g. levelled sites, an even faster and cheaper approach can be justified. Collecting the assemblage by sieving the sediment in much larger units, or even without recording intra-site spatial data at all, could be considered an appropriate option. Development of new excavating and sieving machinery would be necessary however to cope with the large amounts of sediment. Documenting and sampling a site by only partly excavating it might be a valid alternative as well.

Before any excavation, however, in-depth evaluation of the preservation condition is necessary. For this, archaeological surveys are often not sufficient and need to be complemented by studies of historical geography, geomorphology, pedology, landuse, etc. Since this has received little attention in the past, new research on evaluation methodology for prehistoric plough zone sites is urgently needed.

35 De Bie *et al.* 2003.
36 Meirsman *et al.* 2008a; Vanmontfort *et al.* 2010.
37 Huyge & Vermeersch 1982.
38 Vermeersch *et al.* 1974.
39 Van Noten (éd.) 1978.
40 Van Gils & De Bie 2005a; 2005b.
41 Van Gils & De Bie 2003.
42 Verbeek 1999.
43 De Wilde 2009; De Wilde *et al.* 2007; Nakken 2006; 2008.

3.3 Heritage valuation

Flint scatters from a plough zone are at present often underrated since they score low in terms of standard valuation criteria such as visibility, physical quality, or rarity. The main value of stone-age sites, however, lies in their research potential, for which excellent physical quality or rarity is not always a prerequisite, as shown above.

Plough zone sites rarely survive selection procedures when brought into competition with sites that potentially contain 'structural evidence'. Here, however, structural evidence lies in the spatial patterning of the artefacts. This is sometimes sufficiently preserved in the plough zone, as illustrated above. Their research potential, and thus a main factor of their value, is clearly underestimated.

Moreover, as arable land is nowadays quite important in the Campine Region, a great majority of prehistoric sites, both known and unknown, are situated in a plough zone context. As better preserved sites are rare in large parts of this region, but also in many other regions, assemblages situated in the plough zone are often virtually the sole type of evidence left. To neglect these sites would mean to neglect a major part of the archaeological record of this period. In heritage management procedures, plough zone sites therefore always need to be surveyed and thoroughly evaluated, and excavation with appropriate methods seriously considered.

4 Conclusion

The scientific value of prehistoric sites in the plough zone depends largely on their research potential. As research on prehistoric societies over the years has shifted from site-oriented analyses to large-scale landscape approaches, focussing on settlement patterning, land-use histories and historical processes in general, just this type of sites can have a crucial role to play. Regarding intra-site studies, our analysis has shown that the better preserved plough zone sites can still provide useful spatial information.

In heritage management, these sites urgently deserve more attention. Survey, monitoring and salvation programs are recommended, as further surface levelling and deep ploughing is obviously destroying their residual value. Further assessment of the impact and scale of different agricultural activities demands new research, including the use of new, but not necessarily complicated, procedures such as collecting artefacts from potato harvesting machines, studying past and present land-use, etc.

It is vital to recognize the variability in conservation quality of plough zone sites. This needs to be taken into account in heritage valuation procedures, but also when choosing excavation strategies. No choices can be made without thorough assessment of these sites and their conservation condition. This topic deserves more methodological research.

Most importantly, the general mentality towards plough zone sites, as an inferior data-source, needs to change. These sites should be considered as full-fledged sites, of which the scientific value can only be estimated after thorough assessment. Just like any other type of site, they need adapted methodology and an integrated multi-disciplinary approach, including for instance historical geography studies. When reconstructing a comprehensive image of the past, the plough zone holds a vast amount of indispensable information. Every time these sites are ploughed, their value erodes further. There is no time to lose.

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The erosion of archaeology: the impact of ploughing in England

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Abstract

This paper documents the history of concern amongst archaeologists in England about the impacts of cultivation on the archaeological record. It examines recent initiatives to address some aspects of this impact, not least as part of the wider process to reform the Common Agricultural Policy and in the context of a new statutory framework for heritage management proposed for England and Wales. It concludes by reviewing in detail two related research projects, examining the impact of cultivation on archaeology, jointly funded by English Heritage and England's Department for Food, Environment and Rural Affairs.

Keywords

Common agricultural policy, heritage management

1 From Dorchester to Danebury

One third of the land area of England, some 40,000 km^2, is cultivated and cropped, with a heavy geographical bias towards the east and south of the country. In 1995 it was calculated that 35% of all inventorised archaeological sites (covering a total area of 12,270 ha) lie within these arable landscapes[3]. These archaeological sites include 3808 that are considered to be of national importance and are statutorily designated in order to offer them protection. Of these designated sites, 2209 are partly or wholly under cultivation: the remainder are unploughed but isolated within wider arable landscapes. It is unsurprising, therefore, that the impact of agricultural intensification - and cultivation in particular - has been a major concern of UK archaeologists for many years.

Indeed, concern about the impact of cultivation on archaeology pre-dates - and contributed towards - the introduction of the first ancient monuments legislation in England. In the 2nd July 1870 edition of the *Saturday Review*, Colonel Lane-Fox (later to become General Pitt-Rivers, England's first Inspector of Ancient Monuments) wrote of his concern over the conversion of grassland to arable within the important Iron Age enclosed settlement at Dyke Hills, near Dorchester on Thames in Oxfordshire (fig. 1). This case was one of several *cause célèbres* that stimulated the introduction of Sir John Lubbock's Ancient Monument Bill in 1872 and the eventual passing into legislation of the first British Ancient Monuments Act, ten years later.

A century later, concern over the impacts of ploughing re-emerged as a significant theme in UK archaeology, as the modern archaeological profession began to establish itself during the 1970s. Philip Barker, in the seminal publication *Rescue Archaeology*[4], wrote:

"The most destructive of all processes, however, is the least obvious. Ploughing, especially deep ploughing.... poses the major threat to the continued existence of our sites".

The issue continued to receive particularly high profile attention throughout the decade, with the Ancient Monument Directorate of England's Department of the Environment commissioning two regional-scale plough damage surveys, which began to quantify the considerable scale of the problem, and publishing the proceedings of a landmark conference (held in 1977) *The Past Under the Plough*[5].

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3 Darvill & Fulton 1998.

4 Barker 1974.

5 Hinchliffe & Schladla-Hall 1980.

FIG. 1 Dyke Hills, an Iron Age *oppidum* near Dorchester on Thames, in Oxfordshire. Agricultural improvements, including ploughing, in 1870 contributed to the development of the United Kingdom's ancient monuments legislation. The site continues to be cultivated today. © English Heritage.

In 1979 the Ancient Monuments and Archaeological Areas Act established the statutory framework for protecting and managing archaeology in England that persists to the present day. While the Act introduced many positive measures, including a requirement for a statutory consent (licensing) before most works affecting designated sites could be undertaken, it did little to address the impacts of agriculture. Continuing cultivation at the same depth is exempted from the licensing regime and refusal to grant a license to carry out other potentially damaging agricultural activities may require that significant compensation be awarded to farmers.

Despite the upsurge of professional interest in the issue of plough damage in the 1970s, in the years which followed the attention of the state archaeology service (henceforth embodied within English Heritage) shifted to other equally pressing demands. These included the pressures on wetland archaeology and the rather more resolvable challenge of development-led impacts, which eventually culminated in the successful application of the "polluter pays" principle to archaeology within the UK's spatial planning system. Cultivation impacts were largely set to one side in terms of high level priorities. As a result, while significant funding continued to be made available for the "rescue excavation" of key sites threatened by ploughing - most notably the landscape-scale recording exercises centred on Danebury Hillfort[6] - no significant investment was made in long-term and strategic research on approaches to managing the problem. With the benefit of hindsight, this appears to be a missed opportunity that now hinders current attempts to address the problem.

2 Understanding the scale of the challenge

In the mid 1990s, the scale of the challenge invoked by Philip Barker and *The Past Under the Plough*, was quantified for the first time as a result of the England-wide 'Monuments at Risk Survey'. This project, carried out from 1995, examined a 5% sample of England's inventorised archaeological sites in the field, reporting on their condition and vulnerabilities[7]. The results of the survey demonstrated that agricultural impacts were the single greatest agency of gradual destruction of archaeology over the last 50 years. This information revived professional interest in the issue of plough damage and, from 2000 onwards, provided the platform for a new English Heritage strategy relating to archaeology and agriculture. This strategy comprises a number of separate but interlined strands including: further data enhancement; advocacy and awareness raising; lobbying for changes to statute; greater emphasis on management through environmental farming (agri-environment) schemes; greater emphasis on advice to land managers and research on impacts and mitigation (a subject examined in detail in the second half of the paper).

Data Enhancement: The 'Monuments at Risk Survey'[8] had shown that in the fifty years since 1945, an average of one archaeological site had been destroyed every day. These losses had included Scheduled Monuments as well as undesignated sites. In the light of this statistic and the basis for the Monuments at Risk survey - the generation of statistically representative data at a national level rather than data on individual monuments – it was decided to pilot an assessment of all Scheduled Monuments in the East Midlands, methodically examining in more detail the processes affecting each and every site.

6 Cunliffe (ed.) 2000.

7 Darvill & Fulton 1998.

8 *Ibidem*.

The study had three main aims: to evaluate the current condition and amenity value of scheduled monuments, to assess the extent to which they are at risk (their vulnerability), and to help to establish priorities for management action. The East Midlands pilot project was completed in 2005[9], and established a methodology which was rolled out across the remainder of the regions in the period 2005-2008. The completed national study represented the first systematic assessment of all 19709 Scheduled Monuments in England and its methodology now forms the Monuments at Risk strand of English Heritage's ongoing Heritage at Risk initiative, launched in 2008[10] and subject to an annual report.

Advocacy: The first element of the strategy was provided by the 'Ripping up History' campaign document (2003). Distributed to over 200 parliamentarians with expressed interest in rural and environmental issues, to Agriculture and Culture Ministers, senior civil servants, to the European Commission Directorate General Agriculture, and to farming interests, the document coincided with both a major review of England's environmental farming (agri-envionment) schemes and initial proposals for a new statutory framework for archaeological conservation.

Legislation: As part of its recent review of heritage legislation in England, and influenced by *Ripping up History*, the UK Government announced that it would deliver statutory reform to better protect archaeological sites under cultivation. A new Heritage Protection Bill for England and Wales was published in April 2008 in draft for consultation before parliamentary scrutiny. Unfortunately, at the time of writing there is no agreed timetable for its parliamentary passage and the proposed new Class Consent order for cultivated sites is not yet published.

Land management: Given the shortcomings of the current legislative system, the need to facilitate positive management under any new system and the large numbers of archaeological sites that will never be designated, financial incentives aimed at farmers and designed to encourage them to care for sites on their land is – and will continue to be - a vital tool for archaeologists in the UK. Management of historic landscape features has been an objective of England's environmental farming schemes since 1987 but never a major priority and archaeological sites under cultivation were particularly poorly served. Following lobbying by English Heritage, including the publication of *Ripping Up History* in 2003, archaeological sites and historic buildings and landscapes were made one of five core objectives of a new England-wide environmental farming scheme, the Environmental Stewardship Scheme. This was launched in 2005 and, amongst the measures available to land managers, are options to remove sites from cultivation, for minimum tillage, managing sites in grassland, to remove scrub and to maintain or restore historic buildings. By the autumn of 2008, Environmental Stewardship had already delivered 36 million Euros worth of agreements to manage historic features, including 3444 ha of archaeologically sensitive land removed from cultivation and 10265 ha of reduced depth ploughing on archaeologically sensitive land.

Advice to farmers: While popular with many farmers, environmental farming schemes cover only a proportion of farmland. In order to attract farmers into these schemes and to address areas which lie outside them, English Heritage has been addressing the need to provide advice to land managers. Alongside devoting an element of our own staff resource to this, we have successfully lobbied for the appointment of 15 historic environment specialists in Natural England, the national nature conservation agency which administers environmental farming schemes within England. We have also successfully lobbied for the appointment of 3 archaeologists in the Environment Agency, which is responsible for soil and water policy. At the same time, we have grant-aided the appointment of some 20 local authority based archaeologists specialising in rural development and land management. These archaeologists have proved the key to the much greater emphasis placed upon the historic environment in the new schemes, by providing advice on the most appropriate features to be managed through agri-environment schemes and through face-to-face advocacy with farmers and land managers. They have been supported in their work by a suite of 'Farming the Historic Landscape' guidance literature (http//:www.helm.org.uk/farmadvice), some of which has been aimed directly at land managers, some at historic environment professionals. In addition, responding to a real demand from farmers to know more about designated and undesignated historic environment assets on their holdings, English Heritage has worked with local authority archaeologists to make specially-formatted data available to land managers through the Selected National Heritage Dataset and, more recently, the Selected Heritage Inventory for Natural England (or 'SHINE') database (http//:www.myshinedata.org.uk). SHINE is a regularly updated and curated national dataset of undesignated rural archaeological sites that is used to illustrate the maps of environmental assets provided to farmers entering into environmental farming schemes.

Research on risk and mitigation: As already noted, within the UK concerns around the issue of cultivation damage to archaeological sites are nothing new, and have been raised by successive generations of archaeologists over the course of the last century. In 2001 the English Government ministry responsible for farming, rural communities and environment - the Department for the Environment, Food and Rural Affairs (Defra) - commissioned Oxford Archaeology to undertake the Management of Archaeological Sites in Arable Landscapes project[11]. The research began by synthesising existing literature on standard cultivation practices, and using this to model the likely effects upon the archaeological resource. In addition to this synthesis of existing data, it had two other main outputs. The first was a national plough damage risk map, which used a basic assessment of crop regimes and soil types to identify those areas where archaeology was deemed to be most under threat from cultivation. The second were two desk top models for predicting risk at the level of individual sites, consisting respectively of a flow chart and a scoring method. However, whilst these models were a useful starting point for predicting risk, they were purely conceptual.

In addition to the need to rigorously test the methodologies in the field and review their accuracy, there was also a need to look at the models in relation to a greater number of variables than those considered in the original work. These variables included localised topography (more specifically the topographic location

9 Cooper 2006.

10 English Heritage 2008.

11 Oxford Archaeology 2002.

of the sites), the soil type and the specific crop and cultivation regime being employed on an individual site. In cases where an archaeological site spreads across several fields and crops, the capacity for multiple risk scenarios also needed to be incorporated, as did the nature of the archaeology itself (specifically whether the presence or absence of surface archaeological features made a significant difference to risk). Finally, assessing risk accurately was only half of the story and needed to be balanced by recommendations for mitigation.

The result of all these needs was the Conservation of Scheduled Monuments in Cultivation (COSMIC) project, run jointly by English Heritage and Defra between 2003 and 2005 with Oxford Archaeology as the contractors[12]. Having already undertaken the 'Scheduled Monuments at Risk' pilot project in the East Midlands region, and identified all of the scheduled monuments under cultivation there, this area made an obvious test bed for the work. The East Midlands region brought the added benefit of a range of geology, land forms and soil types. It also had a similarly broad range of crop types and cultivation regimes. In total 159 assessments were carried out covering 77 Scheduled Monuments and 39 non scheduled sites. In each case farmers were also asked a series of questions about how they cultivated their monument, a field visit and risk assessment was carried out, and then the accuracy of the initial desktop assessment was checked using either test-pits, augering or a combination of both.

The comparison of plough depths recorded during the fieldwork and those reported by the farmers indicated a significant difference between the two.

Two-thirds of farmers on scheduled sites underestimated the depth of their ploughing, with only 27% getting within 5 cm accuracy. For non-scheduled sites 40% of farmers were getting within the 5 cm accuracy and just under two thirds underestimated the depth by between 10 cm and 20 cm. The most likely cause of the discrepancy between the two sets of figures is that farmers on Scheduled Monuments were concerned about giving true cultivation depths because of worries about whether they had breached the terms of their 'class consent' (that is, their automatic consent to continue established agricultural operations) to cultivate. It is also interesting to note that the non-scheduled sites were being consistently cultivated to a shallower depth than Scheduled sites. The deeper ploughing over Scheduled Monuments was primarily explained by the higher incidence of root and tuber crops being cultivated on these sites, as opposed to non-scheduled ones.

Slopes and buffer deposits were observed to be a major factor in the preservation and survival of archaeological deposits in the field. The non-scheduled sites had a slightly higher number of sites with buffer zones (39%) compared to the Scheduled sites (32%). The depth of buffer deposits in general tended to be deeper over non-scheduled sites than scheduled sites.

The buffer deposits present were found to consist mostly either of older plough soils or colluvium. The locations of these buffer deposits were not just confined to the bottom of a slope, as assumed in the pre-fieldwork stage, but were found in a number of different locations throughout the slope profile, in response to changes in micro-topography. The pre-fieldwork assumptions were found to be overly simplistic therefore, and the risk to many sites was underestimated in the pre-fieldwork stage, compared to the reality recorded during the fieldwork.

The assessment methodology developed by COSMIC saw risk determined by three main factors; site intrinsic variables (such as micro-topography and soils); site management (such as the cultivation regime, depth and drainage) and archaeological (including the significance, type and vulnerability of the deposits). The importance of each factor depends on the area and individual circumstances of each site and cannot be studied in isolation as one factor will ultimately have an effect on another.

Site intrinsic factors are part of the natural aspect of a site and are important because they determine the rate at which erosion is likely to occur within a cultivated field. The movement of soil can be a key mechanism by which the level of archaeological protection decreases over time and risk increases as the soil protecting a site gradually thins, and archaeological horizons are increasingly brought into the cultivation zone. Any effective model therefore needs to include an assessment of the likelihood of erosion and the rate at which it is likely to occur.

The site management factors considered encompassed the past, current and future crop regime on a site, specifically the type of cultivation, the depth of ploughing, drainage measures and type of crop rotation. As with soil erosion, these directly determine the likelihood of cultivation coming into contact with the archaeological horizon. For example, root and tuber crops are more likely to require deeper ploughing and more frequent drainage than combinable crops, resulting in increased risk levels. In contrast, cultivation associated with long term grass land (such as scarification and re-seeding) is significantly less likely to come into contact with archaeological horizon than combinable crops, and these sites therefore are likely to be at much lower risk.

The survival and vulnerability of archaeological deposits are also factors in assessing risk as they help to determine how susceptible a site will be to damage. For example, a well preserved site like a Roman villa with walls and floor surfaces is classed as being at higher risk then a small Romano-British farmstead, more commonly characterised by truncated cut features.

The COSMIC project enabled the identification of the variables which most often resulted in sites being at serious risk from cultivation. These variables were:

- The survival of earthworks (which will be actively degraded by every cultivation episode) or the likely presence of vulnerable sub-surface archaeological deposits such as mosaics or burials (where only one episode of slightly deeper cultivation could destroy the last significant remains of that site);
- Sites that are under root and tuber crops (because of the depth of cultivation);
- Sites that are particularly vulnerable to soil erosion (such as those on moderate to steep slopes, those with lighter soils or those being harvested for root and tuber crops, often during wet conditions);

12 Oxford Archaeology 2006.

In light of the above, where possible, the aim of each proposed mitigation strategy was to allow the site to remain in cultivation but also provide a sustainable level of protection to the archaeology. This was achieved either by limiting agricultural disturbance depths or, where this was likely to provide insufficient protection, taking part or the whole of the field out of cultivation. Where cultivation was allowed at a reduced depth or otherwise, the aim was to create a sufficient buffer deposit to provide a minimal, but sustainable level of protection to the archaeological resource.

Given that archaeologists had long believed that the only effective mitigation for sites under cultivation was to place them under permanent grassland, the recommendations for mitigation generated by COSMIC were a surprise. No action was deemed necessary to reduce risk on 11% of sites, and it was recommended that subsoiling should be prevented on a further 5%. It was suggested that cultivation should be limited to between 10cm and 20cm in depth on 50% of sites, and on 16% it should be limited to 10cm depth. Most importantly of all, it was deemed necessary to cease cultivation entirely on only 18% of monuments. In policy and farm business terms this latter was a crucial message, because reversion to grassland is expensive, and given the extent to which mixed farming in England has declined, and arable and pastoral systems have become geographically polarised, the creation of grassland in otherwise arable areas has little practical value in farm business terms and is unpopular with farmers.

3 Cranfield Trials Project

COSMIC had brought us to a stage where we had what was considered an 80% accurate desktop risk assessment model for archaeology under cultivation, and this accuracy could be improved still further by site visits and test pitting. However, this work was based upon some assumptions about how cultivation actually affects archaeology, assumptions which archaeologists have been making for many years but never actually tested empirically. There was a need to gather this empirical data, and see how it might affect the mitigation proposed for sites. If we could better understand what was most damaging, and why, this might open the way to suggesting fundamental changes to cultivation practices which could deliver general as opposed to site specific mitigation. COSMIC had also proposed reduced depth cultivation as a means of mitigating risk. However, there was no simple or reliable method for farmers or curators to monitor depth and ensure compliance. This aspect also required further work.

In 2005 English Heritage and Defra therefore commissioned a four year project called 'The Effects of Arable Cultivation on Archaeology' with the Department of Soil Sciences, Cranfield University and Oxford Archaeology as the contractors, with several research aims.

English Heritage's Centre for Archaeology had already done some initial work on two possible methods of depth-compliance monitoring using electrical transponders and coloured glass beads (fig. 2). Both transponders and glass beads can be put in place using a GPS. A series of monitoring stations were put in place on the Scheduled Monument of Little Woodbury, the Iron Age site near Salisbury excavated by Gerhard Bersu in 1938. The transponders were buried at the base of the plough zone on the surface of the layer containing chalk-cut archaeological features. The transponders give off a signal, and if cultivation goes too deep, and displaces the transponder, this can be detected using a combination of a GPS and a transponder reader. Transponders come in a range of sizes and are inexpensive, although monitoring requires expertise and specialist equipment and has other cost implications. For the beads a 1m square pit was excavated immediately above the archaeological horizon and filled to predetermined depths with varying colours of glass. Where cultivation goes too deep the beads are displaced into the cultivation horizon.

Following this initial work at Little Woodbury, the Cranfield University and Oxford Archaeology research project therefore evaluated the most effective transponders to use in terms of signal strength and longevity, and the simplest method of

FIG. 2 Constructing one of the glass bead depth-compliance monitoring station test sites as part of the Trials project. © Oxford Archaeology.

FIG. 3 A 'facsimile archaeological site' created as part of the Trials project which was subjected to tillage and other cultivation practices to better understand the impacts on sub-surface archaeology. © Oxford Archaeology.

monitoring their location. Although initially more time consuming to put in place, glass bead monitoring stations have the advantage of providing a very simple visual indication for both the farmer and specialists that cultivation has gone deeper than it should. The project reviewed what colour of beads might be the most effective, whether (in the light of the cost of beads) coloured sand would be equally as effective, what size of monitoring station was required, and how the methods stood up over 30 years of accelerated cultivation.

In order to better understand the physical impacts of cultivation on archaeology, Cranfield University and Oxford archaeology also constructed a series of replica surface and sub-surface features which were then subjected to accelerated and real time cultivation using a range of common equipment and cultivation regimes (fig. 3). The 'false archaeological sites' comprised both a series of sub-surface features (including walls, pits and ditches) and earthworks (mimicking medieval ridge and furrow and prehistoric barrows; fig. 4). The four 10 m by 20 m test plots, each of which contained six false archaeological sites, also contained various configurations of monitoring stations, including transponders, glass beads and sand and were subjected cultivation using respectively a mouldboard plough, shallow inversion, non inversion and direct drilling. In each case one half of the plot was first subsoiled, whilst the other half was not.

One of the reasons that the Soils Science department of Cranfield University was chosen as contractor was not only their agronomic expertise, but also their laboratory facilities. These included a soil bin which could be filled with any soil, and then using hydraulic equipment, have any tillage implement or combination of wheel or track loadings ran across it. A series of pressure sensors buried within the soil could then be used to measure the forces exerted. This aspect of the laboratory work looked at several areas of interest, first of which was the relationship between depth and the transmission of pressure. A penetrologger was also used to look at compaction. From this initial laboratory work it was intended to identify the least and most damaging combinations in terms of tillage operations and wheel loading, and then use these combinations for the accelerated and real time field trials on the false archaeological sites. However, clay soils could not be used in the soil bin, so work on this soil type was carried out only in the field. The final aspect of the work on soil pressure and compaction looked at the effects of tillage implements and cultivation systems on buried artefacts. The initial trials used plant pots in order to develop a workable methodology. The pots had a simple electrical circuit painted on to them, they were wired up and buried, and a pressure plate exerted pressure upon them. Once the circuit was broken, so too was the pot. This methodology was then transferred from plant pots to specially made replicas, and then onto human bones. The latter proved more problematic because they were found to flex rather than break cleanly.

Without empirical data to show otherwise, it had always been assumed that, in addition to the effects of the tillage implements physically ripping through archaeological deposits, the pressure they exerted as they dragged through the soil was primarily what led to soil compaction. However, Cranfield University's work using pressure sensors showed that in fact the tyre or track loads on farm vehicles produced much greater peak pressures than the tillage implements, ranging from 0.5 bar to 7.5 bar, depending on load, inflation pressure and carcase stiffness. The work also showed how these peak pressures could be massively reduced simply by decreasing inflation pressure, carcase rigidity, or in the case of tracked vehicles, by fitting additional idler wheels. The clear message was that the weight of the vehicle or tillage implement is much less important than the manner in which this weight is transferred onto the surface.

The aim of all of this laboratory and field work was to examine pressure and physical damage to artefacts buried under the soil, the implications for any buried soils underneath earthworks being cultivated using minimum tillage, ploughing and direct drilling, the thinning of plough soils, and the physical damage to features. Therefore, after each episode of cultivation on the

FIG. 4 A section of the simulated earthworks (in this case medieval ridge and furrow) undergoing cultivation as part of the Trials project. © Oxford Archaeology.

false earthworks a GPS survey was undertaken to show changes in profile. The surprising result was that the profile of the medieval ridge and furrow earthworks had changed much more than that of the barrows, even using minimum tillage. This appeared to have been due to the frequency of the earthworks, and the rigidity of the minimum tillage rig. Unable to pivot adequately, the rig simply planed the surface of the features. For each cultivation technique the work also looked not just at the surface changes in profile, but also at soil movement (using transponders) and the depth of disturbance (using glass beads). Together with the work on profiles, this gave some data on the rates of erosion, and the implications for buried soil and archaeological features below or within earthworks.

4 Lessons from the management and mitigation projects

We were confident of the utility and accuracy of the COSMIC risk assessment model, which in terms of the mitigation required to significantly reduce the risk for archaeology under cultivation had suggested – possibly for the first time – that with some notable exceptions, the majority of archaeological sites could remain in cultivation, if conditions were imposed on the way they were cultivated. To make this work however we needed to know whether the mitigation measures really worked. The trials project undertaken by Cranfield University and Oxford Archaeology was an attempt to get around that problem, by providing a scientific rather than just intuitive understanding of what the specific problems are for archaeology, and how they might be mitigated by changing farming practices generally, rather than just at the level of individual sites. In doing so, it highlighted some issues we had not previously considered or known. Standard mouldboard ploughs are ineffectual for depth-limited cultivation because they are designed to 'dig in' and always go more deeply than is intended. Another issue is that of pressure. Vehicle or tillage implement weight appears far less important than the loading placed upon wheels, and therefore the soil, which increases compaction. The greater the compaction the greater the necessity to sub-soil, which means the greater the depth of disturbance, often going far deeper than normal tillage. So wheel loading can be potentially more damaging than the direct physical impact of tillage implements.

There is also scope for multiple benefits. If we can help farmers to cultivate more efficiently - such as by reducing accidental compaction - this will also reduce the need to subsoil, but more than that, they will save time and fuel costs. This will make the recommendations more attractive to farmers and will surely be more persuasive than any other arguments that we might deploy.

5 Future prospects

As a result of the 'Ripping up History' campaign and work to enhance our understanding of the scale, pace and mechanics of plough damage, we have achieved significant progress in the last decade. England's environmental farming schemes are now delivering enhanced management on many archaeological sites, including removing or reducing the threat of plough damage to many, and the UK government has expressed a willingness to reform the relevant statute as part of a planned wider overhaul of heritage legislation. Nevertheless, at the time of writing (December 2009) the prospect of new legislation remains uncertain and the future of the environmental farming agenda is unclear, given competing demands on a declining Common Agricultural Policy budget. At the same time, rising commodity prices, a revival of interest in "food security" and a requirement for land to produce energy crops, continues to maximise demand for arable cultivation.

It is clear that the impacts of cultivation on archaeology will be a challenge that future generations of archaeologists, in England and beyond, must continue to address. The key question for our profession is whether we can develop an audible and respected voice amongst those who will determine the impact of agriculture on our resource, or whether we will simply be passive onlookers, whose role is to sort through the fragments that survive.

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The conservation of Gallo-Roman tumuli in Limburg (Belgium): problems and possibilities

Vicky Wuyts[1]

Abstract

In the province of Limburg (Belgium) 15 tumuli still remain, spread over 12 sites in 5 municipalities. All tumuli are protected as monuments and should therefore be preserved. This article focuses on the threats to the conservation of the tumuli: intensive agricultural use of the surroundings, afforestation of the hills, physical neglect or lack of maintenance, inadequate records and inspections and damage inflicted by man or by animals are known to be important threats to the conservation of the burial mounds. Some examples of problems in the conservation of the tumuli will illustrate the seriousness of the situation.

The Flanders Heritage Agency set up an extensive survey of the tumuli to enable an evaluation of the physical condition of the mounds. The results of the campaign can help to identify the problems in conservation and can give an idea of the weathering process. A clear view on the actual problems in conservation can help to determine the best approach in maintenance and restoration.

Keywords

Tumuli, Conservation Management

1 Introduction

Tumuli, Gallo-Roman burial mounds, have been present in the Belgian landscape for many centuries. The majority of these mounds has disappeared in the course of time. In the province of Limburg, 15 tumuli remain, spread over 12 sites in 5 municipalities[2] (fig. 1). Limburg is the province with the highest number of remaining tumuli in Flanders. The sites are all concentrated in the south of Limburg. This can be explained by the intensive agricultural exploitation of this region in the Roman period, organised in large villa domains.

All remaining tumuli are protected as monuments since the late 1970s-early 1980s. The surroundings were protected as town sites or as landscapes. This article will focus on the factors that can cause problems in the conservation of the mounds. As explained later in the article, the situation of the 15 tumuli is quite diverse, both in ownership and location as in the state of conservation. This diversity results in different approaches in maintenance and conservation measurements. This article attempts to identify the problems in conservation and makes some suggestions for future management.

2 The major threats to the conservation of tumuli

The tumuli are designated as protected monuments. However, their nature and characteristics (earthworks) are different from most other protected monuments (historic buildings). To understand how we can preserve the tumuli in the best possible way, we first need to get a clear view on the major threats to their conservation.

In 1969, the Report of the Committee of Enquiry into the Arrangements for the protection of Field Monuments was published[3] in the United Kingdom. A total of 640 field monuments were included in an extensive survey with an analysis of their condition and conservation problems. The Committee was able to determine 4 major threats to the conservation of field monuments: (1) economic developments such as agriculture, afforestation and land development, (2) widespread ignorance of

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2 Massart 1994; Schuermans 1862, 1863, 1864, 1865.

3 *S.n.* 1969.

their existence, (3) physical neglect and (4) inadequate records and inspections. Van Ginkel and Groenewoudt (1990) add in their research another important threat: vandalism and damage done by man and animals, including archaeological research[4].

This chapter intends to give an overview of the nature of the problems and threats to conservation as seen at the sites in Limburg, using some obvious examples.

FIG. 1 **The 12 remaining tumuli-sites in Limburg, spread over 5 municipalities.**

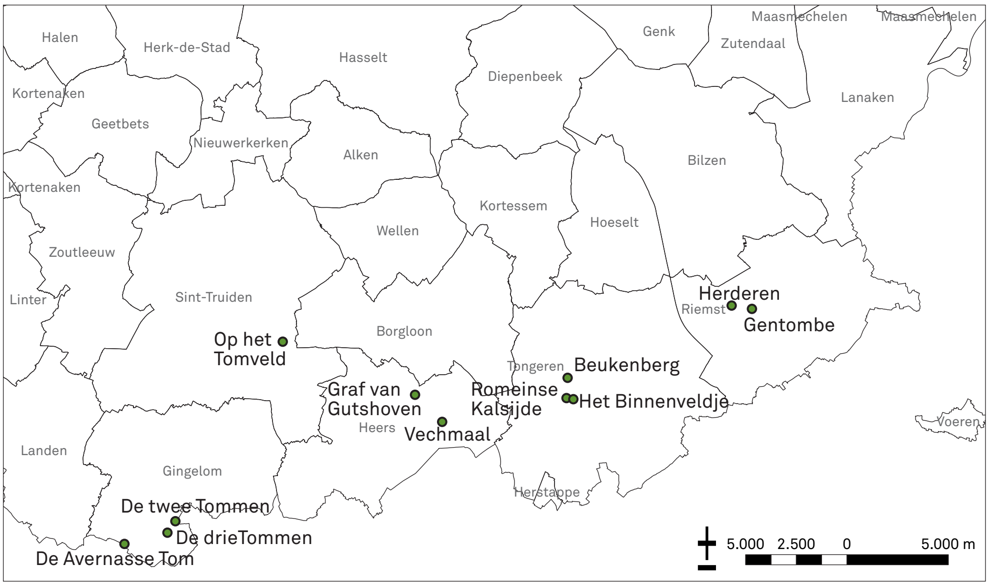

FIG. 2 **The tumulus of Lauw (Tongeren). The mound is protected as a monument, the surroundings as a landscape.**

4 Van Ginkel & Groenewoudt 1990.

2.1 Agriculture

The mounds situated in farmland are located on small parcels. The shapes of these parcels were defined in land consolidation projects in the 1960s and 1970s. These parcels are in many cases too small. Often, the foot of the mounds still suffers from ploughing. This is clearly visible in Lauw, Tongeren, where the tumulus is situated on a small and narrow parcel (fig. 2). The northwest slope of the hill is very steep and the foot of the slope is degrading (fig. 3).

FIG. 3 The tumulus of Lauw (Tongeren). The parcel on the northwest side of the hill.

At the '*Drie Tommen*' in Gingelom, large agricultural machines damaged the central mound (fig 4). The road is very narrow and the hill suffers from the passage of machinery.

Another example is the tumulus '*Aan het Binnenveldje*' in Tongeren (fig. 5). Although this mound is located in the immediate vicinity of a housing area, the south-western part of the hill is being affected by ploughing (fig. 6). In this case, no physical boundary or marker defines the limits of the tumulus. The ploughing is a threat to the stability of the slope.

2.2 Natural reforestation

Appropriate vegetation protecting the mounds from erosion, is an important factor in the safeguarding of these monuments. The presence of trees on the mound is an important threat, as tree wind throws can cause severe damage to the hills. The

FIG. 5 The tumulus '*Aan het Binnenveldje*' in Koninksem (Tongeren), as seen from the southwest. © Oswald Pauwels.

FIG. 4 The central tumulus of the '*Drie Tommen*' (Gingelom). The hill is being damaged by agricultural machines.

FIG. 6 Southwest slope of the tumulus. The traces of ploughing are clearly visible.

weight of trees can also cause stability problems by overloading the slope of the mound. Furthermore, trees cannot provide sufficient soil cover preventing erosion. A grass cover serves this purpose better.

An example is the tumulus of *Genoelselderen*, which lies in a forested area and is covered with trees (fig. 7). The surface of the tumulus is uncovered, and especially vulnerable for water erosion.

2.3 Physical neglect and lack of maintenance

The lack of maintenance is an important threat to any kind of monument. For earthen monuments the maintenance of the vegetation cover is the most important aspect as this can prevent erosion and stability problems. Grass covers should be mown twice a year, and trees should be prevented from growing on the tumulus.

Within the group of remaining tumuli, there is a diversity in ownership. Tumuli are owned by private owners, local administrations, the Provincial administration and the Flemish administration. This results in different approaches towards the management of the mounds.

The local administrations of Gingelom and Tongeren have a management program, but the aims of the programs are different. The tumuli of Gingelom (fig. 8) are mown twice a year, in order to maintain a rich grass vegetation on the mounds. Bushes and shrubbery are removed. Some remaining trees will in term be removed.

In Tongeren, three out of four tumuli are mown once or twice a year. One tumulus, at the Beukenberg, is covered with large bushes (fig. 9). The shrubbery is cut down every 3 or 4 years. This results in a woody vegetation. After maintenance, it is clearly visible that the soil is uncovered.

The two tumuli owned by the Provincial Administration of Limburg are only sporadically maintained. This results in a woody vegetation of large bushes and even small trees (fig. 10).

The tumulus owned by the Flemish Administration in Riemst is being treated in the same way as the forest it is located in (fig. 7).

The private owner of the tumulus of Herderen recently started with a maintenance program in order to obtain a grass cover on the tumulus. Some large trees are still present on top of the mound (fig. 11).

The private owner of the tumulus of Brustem, on the other hand, does not maintain the hill at all. Large bushes and trees

FIG. 7 Tumulus of Genoelselderen (Riemst). The mound is covered with trees. © Oswald Pauwels.

FIG. 9 Tumulus at the '*Beukenberg*' after cutting down the vegetation. The soil is uncovered.

FIG. 8 The '*Twee Tommen*' in Gingelom. © Regionaal Landschap Haspengouw.

FIG. 10 Tumulus of Vechmaal (Heers). The tumulus is covered with bushes and trees. © Oswald Pauwels.

FIG. 11 Tumulus of Herderen (Riemst). The grass cover is being restored. © Oswald Pauwels.

FIG. 12 The tumulus of Brustem (Sint-Truiden). The tumulus is covered with bushes and large trees. © Oswald Pauwels.

have overtaken the hill (fig. 12). In summertime, it is almost impossible to discover the shape of the tumulus through the dense foliage.

2.4 Inadequate records and inspections

The tumuli of Limburg are protected, but the administration was lacking objective records of their condition. After the legal protection, the tumuli were never recorded or measured in any way. Hence it was not possible to evaluate their physical condition or to take specific measures when a problem occurred. Recently the Flanders Heritage Agency set up a monitoring program in order to measure and document the mounds. This program will be discussed in the following chapter.

2.5 Damage inflicted by man or by animals

Finally, damage inflicted by man or by animals is an important threat to the conservation of the tumuli. The *Avernassetom* in Gingelom, for example, was intentionally damaged: a large pit was dug in the surface of the hill. This pit was refilled, in order to prevent further washing out of material.

Most tumuli were excavated during the 19th century. By digging galleries - a technique used in mining - archaeologists tried to reach the centre of the mound and to recover the burial content. Sometimes, they discovered traces of earlier galleries or pits. The documentation on this 19th century research is often very poor, mostly restricted to short descriptions focussing on the presence or absence of a grave. In some cases, drawings were included. The quality of these varies: the drawing of the excavation of the '*3 Tommen*' by Schuermans is schematic (fig. 13). Schuermans started the excavation in 1862. He published his report[5] on the campaign and added a drawing.

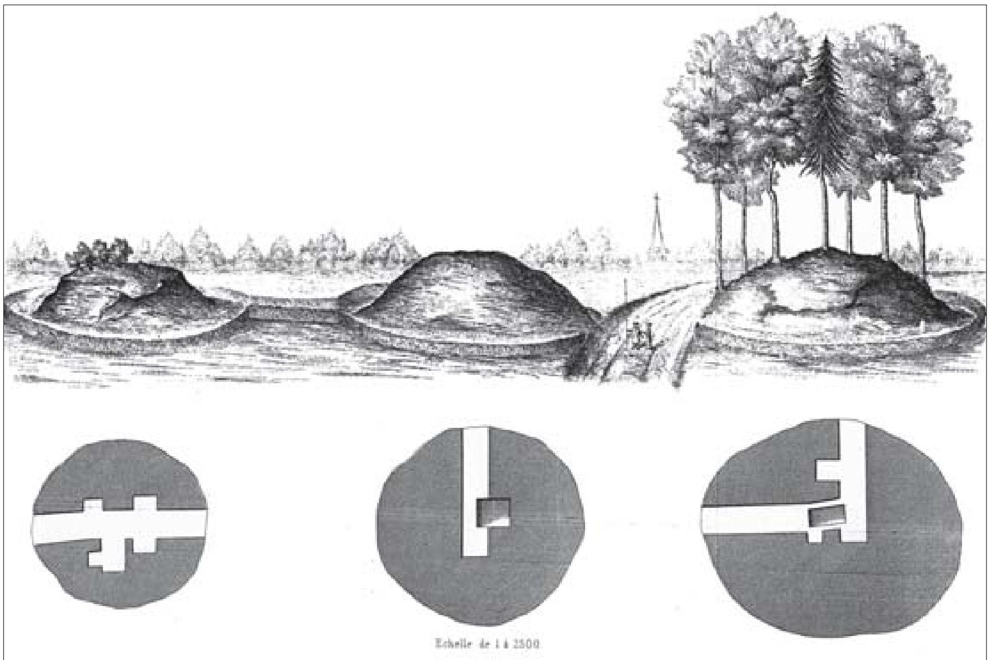

FIG. 13 Drawing of the excavation of the '*Drie Tommen*' in Gingelom by Schuermans (19th century).

5 Schuermans 1863.

Another drawing, from Guioth who excavated the tumulus of Brustem near Sint-Truiden in 1846, is of a better quality (fig. 14). Guioth was an engineer, and included measurements in the drawing. The tumulus of Brustem is often believed to consist in fact of two mounds, melted together in the course of time. The drawing of Guioth clearly shows one tumulus, with a round and elevated mound. Guioth didn't publish his report of the excavation.

The most recent archaeological excavation was conducted on the tumulus of Gutschoven in Heers by Vanvinckenroye in 1985[6]. The largest part of the hill was dug away; only two small parts of the original mound were kept standing. The hill was later on reconstructed. This tumulus was not included in our recording program, since the mound is a reconstruction.

Damage caused by animals can be quite severe. This is the case in the tumulus of Lauw (Tongeren). A badger has dug out a large amount of earth (fig. 15). This is clearly damaging the mound.

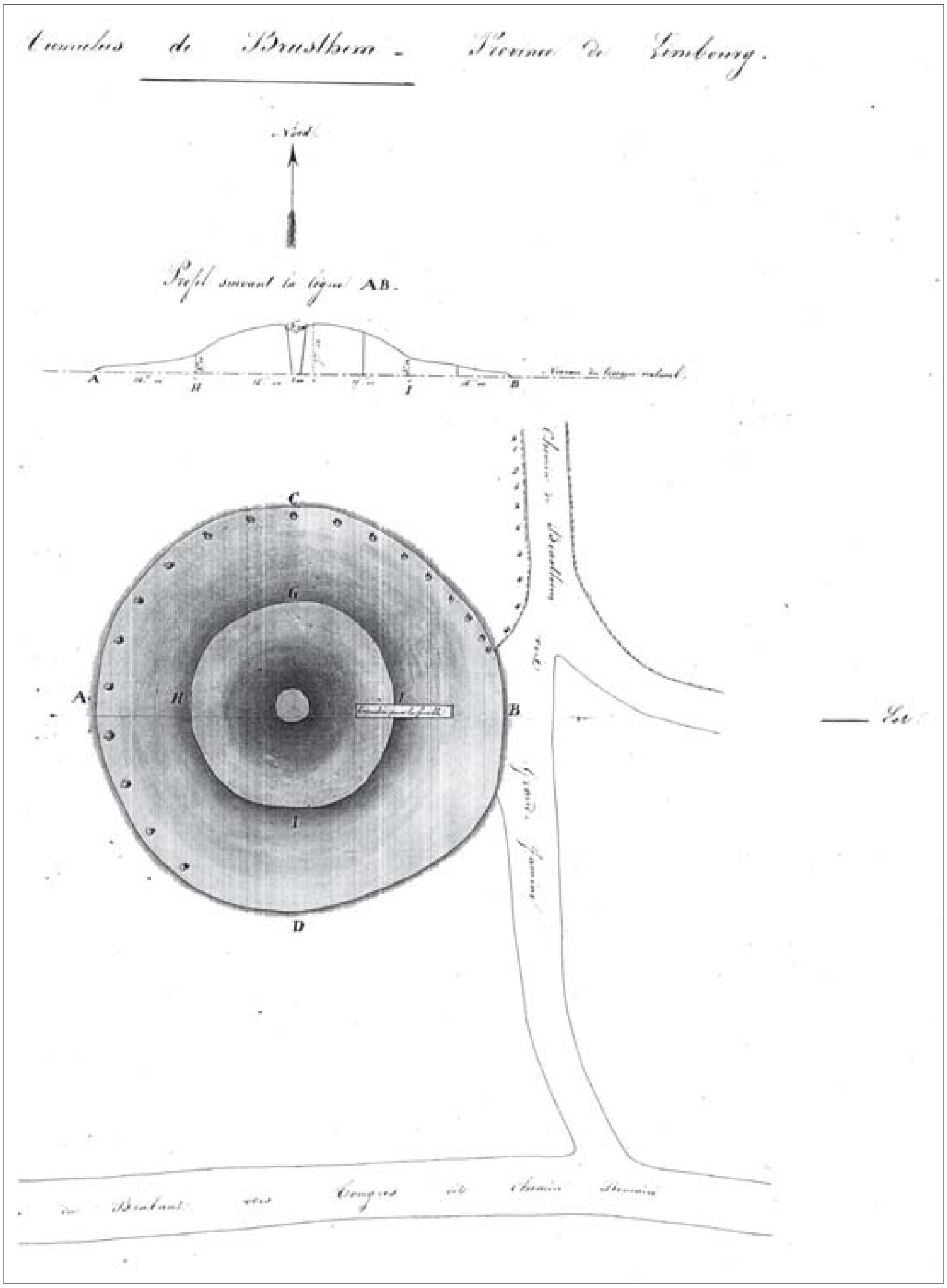

FIG. 14 **Drawing of the excavation of the tumulus of Brustem (Sint-Truiden) by Guioth (19th century). Source: Archives de l'Académie royale des Sciences, des lettres et des beaux-arts de Belgique, n°10354.**

6 Vanvinckenroye 1987.

3 Towards a general approach in monitoring and maintenance

To evaluate the physical condition of the mounds on a long term base a recording program was started in 2005. This included detailed topographic recording of the mounds using a total station. On the tumulus 10.000 to 15.000 points were recorded, depending on the condition of the surface. The measuring took about 4 to 5 weeks, the processing of the data 1 to 2 weeks. Two tumuli could not be recorded due to the density of the vegetation with bushes and trees.

The results of these measurings are an important tool for the evaluation of the conservation of the mounds. The data result in a 3D-model of the surface of the mound. On these models, the damaged surfaces are clearly visible (fig. 16).

In the case of the tumulus '*Aan het Binnenveldje*' (Tongeren), the results of the ploughing are clearly visible on the render image, as seen from the southwest (fig. 17).

The results of the measurings are only the start of a larger monitoring campaign: repeated measurements are planned in the future.

The results of the measurings are combined with historical research on previous archaeological campaigns. In some cases, old archaeological excavations can provide an explanation for the damage visible today. The tumulus of Lauw is an interesting example. A gully appears in the eastern side of the tumulus (fig. 18).

The tumulus was excavated in 1895 by Huybrigts[7]. He examined the centre of the tumulus by means of two galleries in the eastern side of the hill, one 2,50 m above the other (fig. 19). When the

FIG. 15 Tumulus of Lauw (Tongeren). The holes made by the badger are clearly visible. © Oswald Pauwels.

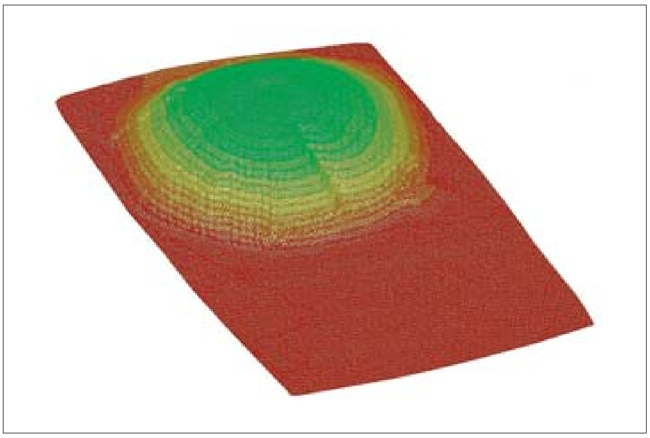

FIG. 16 3D-model of the southwest side of the tumulus of Lauw (Tongeren). A gully is clearly visible.

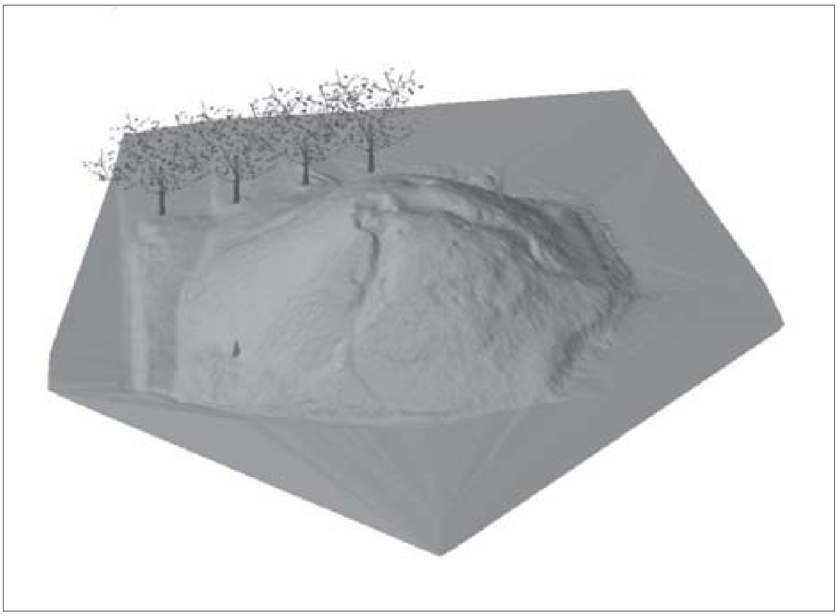

FIG. 17 Tumulus '*Aan het Binnenveldje*' (Koninksem). Render image of the southwest side.

7 Huybrigts 1897.

FIG. 18 **Tumulus of Lauw (Tongeren). The gully in the eastern flank.**

results of the measuring campaign and the data from the report Huybrigts published are combined, it becomes clear that the gully we see today can very well be related to these excavations.

4 Conclusion

Each individual tumulus should receive a 'best fit' approach for its management. For example, stability problems of the hills ask for different approaches than problems due to water erosion. An effective and continuous maintenance programme will be the first step towards better conservation practices. This can only be possible in close collaboration with the owners of the tumuli, who have to deal with the problems of the conservation of the mounds on a daily basis. The results of the measuring campaign will be the basis for this evaluation of present maintenance practices. Through this evaluation it should be possible in the future to develop fitting conservation schemes, or improve existing ones, for these valuable monuments

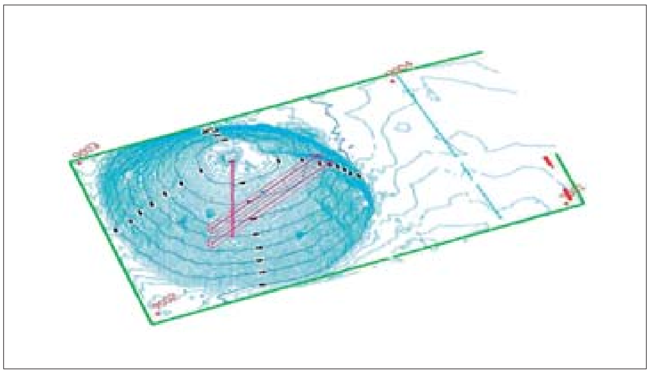

FIG. 19 **Southwest view on the tumulus of Lauw (Tongeren). The galleries of Huybrigts are indicated.**

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Erosion of the defensive system of the 'princely' site of Vix (France): a geoarchaeological approach

Frédéric Cruz[1], Christophe Petit[2], Thomas Pertlwieser[3], Bruno Chaume[4], Claude Mordant[5] & Carmela Chateau[6]

Abstract

Through the sedimentary analysis of a cross section of the fortifications at the 'princely' Iron Age site of Vix, insights on the taphonomic processes (erosion, sedimentation) influencing the preservation state of the site are gained. This analysis provides a chronological framework for these processes, as well as allows an assessment of human impact during the long occupation history of the site.

The approach identifies anthropogenic activities such as destruction of structures and road management works, as well as erosion induced by agriculture, as major disturbing aspects. Colluvial sedimentation at the foot of the slope contrastingly results in burying and thus a better preservation of archaeological structures.

These insights provide a framework for the assessment of the preservation state of archaeological structures on the slopes of the site at Vix.

Keywords

Hillslope erosion, colluvium, site evaluation, earthworks

1 Introduction

The transformation of landscapes by humanity during the last millennia has been widely demonstrated by the analysis of the sedimentary dynamics of river catchment basins (erosion and filling)[7]. The intensity of geomorphological processes (erosion, sediment transport, sedimentation) can be modified by human activity either directly, for example with the construction and destruction of monumental buildings (such as fortifications and barrows), or indirectly, for example through agricultural practices (deforestation, parcelling)[8].

From the Neolithic onwards, monumental fortifications (walls and associated ditches) were built on the surrounding slopes of hilltop sites (for example protohistorical fortified houses, Iron Age hill-forts)[9]. Excavations of sites in Burgundy over the past twenty years have brought to light a complex stratigraphic record, which is used to establish a chronological reference system for pre- and protohistoric societies[10]. Through hillside cross-sections a millennia-spanning sediment budget is presented with recorded phases of construction (defensive ramparts, ditches, roads, etc.) and phases of sediment deposition or erosion (colluvial processes, often through anthropogenic influences)[11]. Sedimentlogical interpretation involves the recognition of ancient anthropogenic structures, but also the identification of the taphonomic processes which partially destroyed (voluntary destruction, tillage erosion and hillside erosion) or masked them (filling in of hollow structures)[12].

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7 Bichet *et al.* 2002; Campy & Macaire 2003; Petit *et al.* 2006.

8 Goudie 2006.

9 Buchsenschutz 1984; Fichtl 2000.

10 Nicolardot 2003; Thévenot (ed.) 2005; Buchsenschutz *et al.* 1999; Guichard *et al.* (2002); Chaume 2001.

11 Petit & Ollive 2005.

12 Petit 2001.

Previous, poorly documented excavations of Mont Lassois[13], in conjunction with the topography of the site, helped to identify the most propitious area for further investigation. A sedimentological cross-section of the fortifications on the eastern slope of the site was analysed in order to achieve a more global understanding of the defensive systems of the "princely" Hallstattian site at Vix (Cote d'Or)[14]. The objective of this article is not to present in detail the defensive Iron Age structure brought to light[15], but to understand the chronology and intensity of the various sedimentary processes that have modified the slope morphology of this hilltop site, which has been occupied from the end of the Bronze Age until the present.

2 Geomorphological and archaeological context

The Hallstattian housing environment at Vix occupies the upper plateau of Mont Lassois, which dominates the valley of the Seine. The main necropolises, including the famous "princely" grave discovered in 1952[16], lie between the alluvial plain and the mountain (fig. 1).

Mont Lassois is a *butte témoin* which culminates at 307 m. It is an isolated hill directly south of the Oxfordian cuesta of the Châtillonnais, on the outer rim of the Paris Basin (fig. 2). The "Calcaires Argileux et Marne de Bouix" (clayey limestone and Bouix marls), which form the main geologic constituents of the outcrop, are protected at the summit by a "Calcaire de Stigny" limestone slab (fig. 3). The slopes are relatively steep, on average 17°, and are covered with a mass of fallen cryoclastic rocks dating from the last glaciation. The "Calcaires d'Etrochey" limestone, which crops out in the plain, was amongst other things used for the construction of the protohistoric ramparts[17].

International excavations of this site are currently seeking to understand the organization of the Hallstattian housing environment and the main defensive arrangements. Defensive systems can be found on the upper plateau and on the surrounding slopes. Levée 1, the object of the geoarcheological analysis presented here, is situated on the slope. The archaeological inventory has identified various phases of site occupation, from the Neolithic to the present.

The oldest traces of occupation on Mont Lassois are Burgundian Middle Neolithic sherds collected at the base of the rampart encircling the upperplateau[18]. The Bronze Age is illustrated by some isolated finds of bronze objects (knives and axes). A large tumulus with central cremation grave, dated of Late Bronze Age, marks the installation of the aristocratic necropolis at the base of Mont Lassois[19]. The Early Iron Age is the most important period of human occupation on Mont Lassois and its immediate surroundings. Housing environments, fortifications,

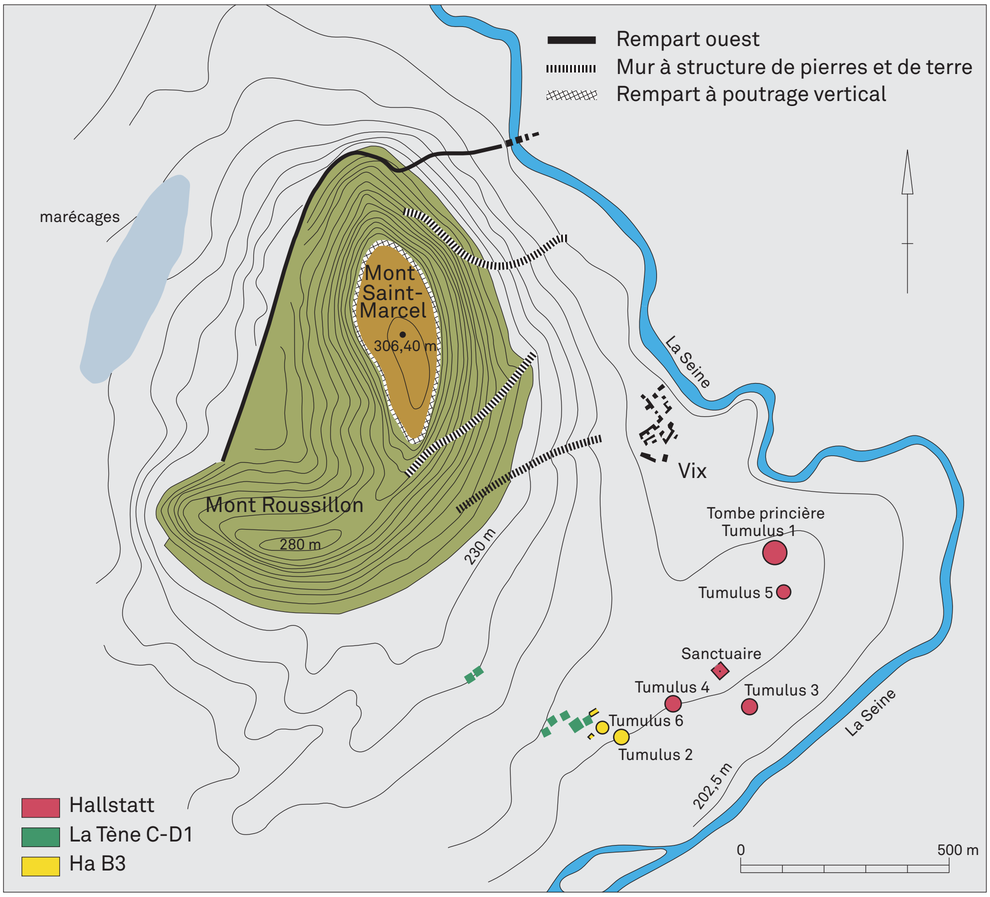


FIG. 1 Archaeological map of Mont Lassois (Chaume 2003).

13 Joffroy 1960; Chaume 2001.
14 Chaume 2001.
15 Pertlwieser & Ott 2004.
16 Joffroy 1962; Chaume 2001.
17 Joffroy 1960; Cruz 2007.
18 Urban & Pertlwieser 2007.
19 Joffroy 1962; Chaume 1997.

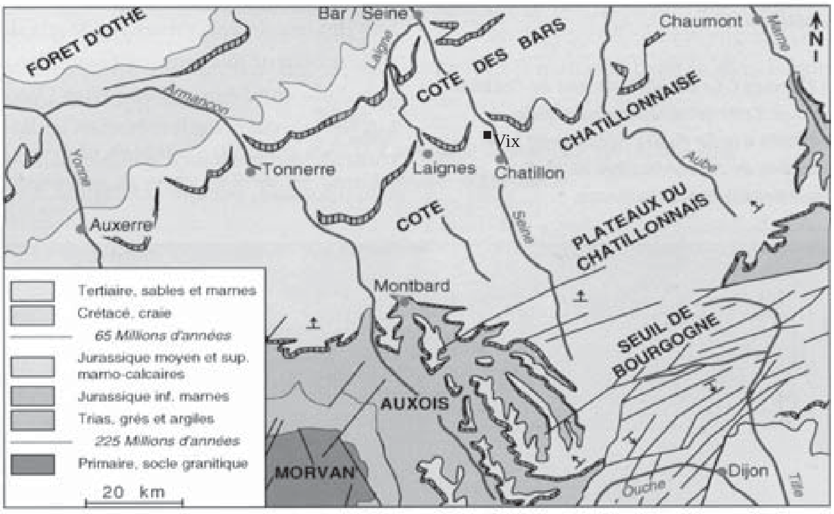


FIG. 2 **Situation map of Vix (Rat 1986).**

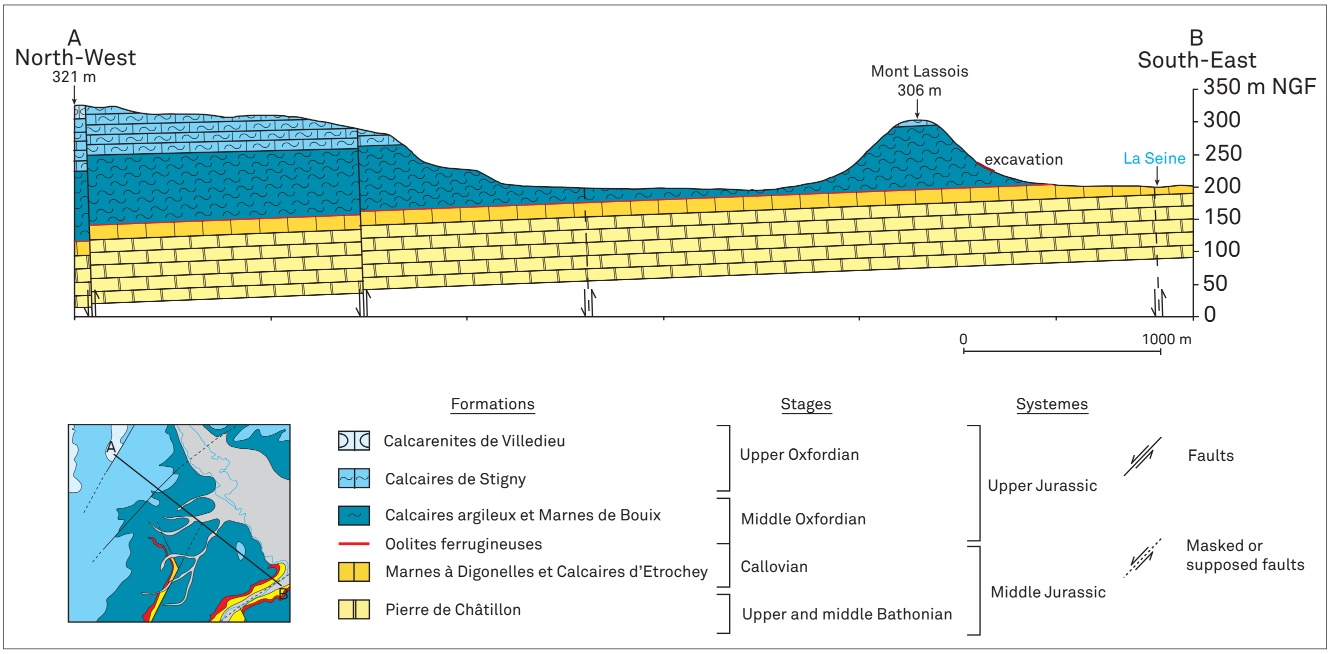


FIG. 3 **Geological cut of the cuesta of Châtillonnais (Cruz 2005).**

and burial sites provide evidence of the privileged status of this "princely residence"[20]. At the beginning of the La Tène period, the socio-economic status of this sector started to decline. However, graves with incineration found in the plain indicate that occupation continued from 400 to 200 BC. After 200 BC, Mont Lassois seems to have been completely abandoned, because the next vestiges of occupation are found from the first century BC onward[21]. The Gallo-Roman period is represented only by the presence of modest agricultural installations, on the plateau and in the plain[22]. Occupation in the Early Middle Ages is attested by a necropolis on mont-Roussillon (the lower plateau) and a palisade on the edge of Saint-Marcel, the upper plateau[23]. The importance of the site is also referred to in texts about Girard de Roussillon's castle[24]. In the High Middle Ages, in the twelfth century, only one new building was constructed on the lower plateau, the church of Saint-Marcel. During this period, the plateau was the site of regional fairs and its slopes were cultivated, particularly as vineyards.

Geomorphological and pedological modifications of Burgundian hillsides by viticulture were already clearly in evidence from Medieval times[25]. Vineyards may have made their first appearance on Mont Lassois towards AD 858-859, after the installation of the Pothières abbey, whose lands included the territory of Mont Lassois. Yet the earliest written mention of

20 Joffroy 1962; Chaume 2001.
21 Joffroy 1962.
22 Chaume *et al.* 2003; Haffner & Grübel 2003.
23 Urban & Pertlwieser 2007.
24 Thomas & Zink 1990; Belotte 1997.
25 Garcia *et al.* 2003; Brenot *et al.* 2008.

wine-growing on Mont Lassois dates from AD 1297[26]. From the end of the Middle Ages up to 1879 - the date of the greatest expansion of vineyards in the region - wine-growing developed continuously on the hillsides of the Châtillonnais cuesta. From the beginning of the nineteenth century, considerable effort was made to ameliorate viticulture in Côte-d'Or, in particular by adding earth to create soils favourable to the enhancement of wine quality. In the Châtillonnais, Marshal Marmont is known for his major investment in the improvement of his vineyards, notably at Vix[27]. After the phylloxera crisis, which affected the Châtillonnais region at the end of the nineteenth century, the vineyard of Mont Lassois was quickly replanted, because it produced one of the best white wines in the Châtillonnais[28]. However, the First World War was fatal to wine-growing in the region[29]. Although vines have never been totally absent from the Châtillonnais cuesta, they were often replaced by fallow lands and forest. Recently, wine-growing in the Châtillonnais vineyard has regained importance. Vines have been replanted on the upper slopes, while the base of the hillside remains occupied by mechanized cereal agriculture.

Within the context of this prolonged occupation, the objective of recent excavations is to identify protohistoric structures situated on the slopes of Mont Lassois and evaluate their preservation.

3 Excavation of the hillside

The excavation led by T. Pertlwieser in 2004, at «la-Mériotte», sought to understand the stratigraphy and architecture of the fortification system on the eastern slope of Mont Lassois identified and named «Levée 1» by R. Joffroy[30]. A rampart in the form of a ledge connects the plain to the lower plateau, cutting obliquely across the main slope (fig. 4 and 5).

The slope at the excavation site has a maximum difference in elevation of 12 m. Mechanical stripping created a trench 4 m wide and 71 m long, cutting through the hillside and the defensive ditch. The ramparts were then manually excavated. The sedimentary units visible in cross section were recorded from the north face of the trench, using georeferenced and rectified digital photographs (fig. 6). In the field, these units were the object of a precise sedimentological description, completed by laboratory analyses (magnetic susceptibility, colour according to the Munsell code, and petrographic determination of the origin of the limestone found in various layers). Granulometric sampling was completed by taking block samples along transects located on the cross-section. The various sedimentary units (archaeological structures, waste layers, agricultural structures, and slope colluviums) were identified on the cross-section, and then resituated on a chronostratigraphic diagram, also taking into account data from the analysis of the archaeological material.

The cross-section allows clear identification of the main stratigraphic sets: the geological substratum, the defensive system composed of a rampart and ditch, and later installations (roads, plantation trenches, etc.) (fig. 6, 7, 8, 9 and 10).

The substratum: "Marnes de Bouix" (bluish grey and yellowish marls) are visible at both ends of the excavation trench (US 8). On the internal slope of the ditch (side wall), indurate layers with conchoïdal break are inserted between looser marls. They are covered by masses of fallen rocks, composed of angular and subangular gravels and calcareous or calcareo-clayey sands, mixed with a yellow-red or brown clayey material (US 9). These deposits, where clayey mudslides alternate with cryoclastic fragments from the limestone plateau, are more thanone metre thick. These slope deposits of Würmian age[31] were protected from recent erosion by the rampart.

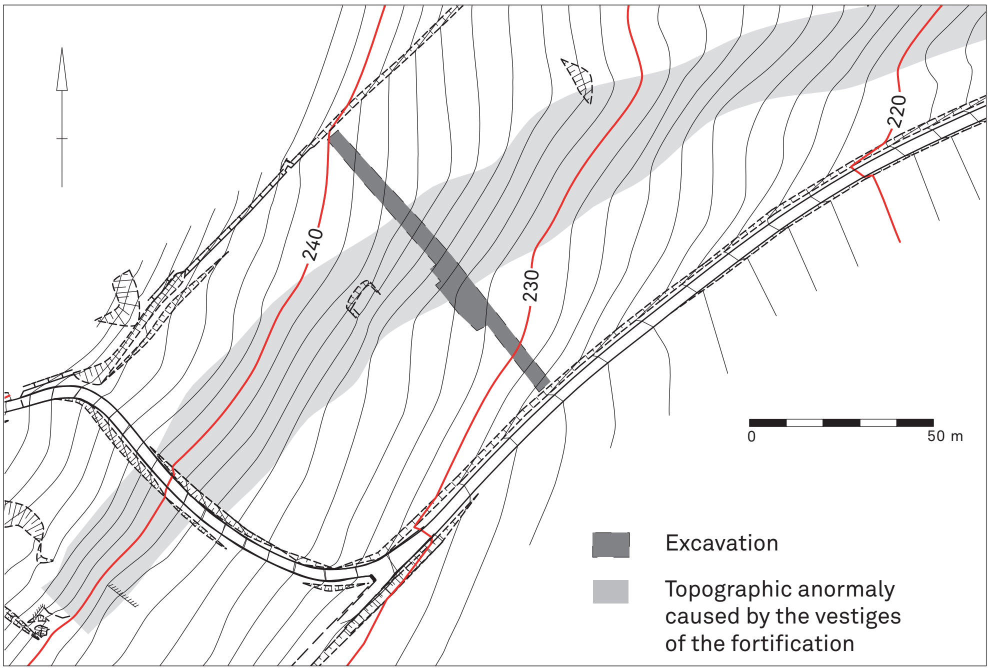


FIG. 4 Situation plan of the excavation; the grey strip corresponds to the visible remains in topography (Pertlwieser & Ott 2004).

26 Bellotte 1997.
27 Courtois 1933.
28 Drouard 1888.
29 Belotte 1997.
30 Joffroy 1960.
31 Thierry 1975.

The excavation of the fortification brought to light traces of two phases of rampart development, with which two types of ditches are associated[32].

Rampart Phase 1: this composite anthropogenic structure is represented by (fig. 6 and 9):

- a compact layer of red-brown clayey silt (US 79) 20 metres long and 15 to 50 cm thick overlying fallen cryoclastic rocks. The base and top are well identified. This layer of red silt, in which the presence of archaeological material is very rare, does not correspond to a normal horizon of alteration of the underlying marls, but constitutes a first anthropogenic input of Quaternary superficial formation;
- a fine black layer of some centimetres in thickness (US 61) covering the whole surface of US 79. It presents little archaeological material (bones and ceramics) dated to the Late Bronze Age[33];
- a composite set of layers (US 43, 74 and 76) of bluish marls up to 70 cm thick, measuring approximately 13 m long. No archaeological material was found in here. These layers form a prism prograding eastward.

FIG. 5 **From above the excavation of the rampart (Pertlwieser & Ott 2004).**

Ditch Filling Phase 1: a layer of bluish silt (US 80) with a maximal thickness of 40 cm lies on the internal wall of the ditch (side wall) (fig. 6 and 10). It presents an upper truncated surface and fine particle size. This layer is interpreted as being the only trace of the probably colluvial filling of the first ditch remaining in place, before the ditch-clearing associated with the repair of the defensive system in its second phase.

Rampart Phase 2: a second, very badly preserved phase of rampart development can be identified above the first (fig. 6 and 9). It consists of:

- a fine black layer rich in archaeological material (US 53);
- a layer (US 33) composed of limestone blocks which come from the "Calcaires d'Etrochey" at the base of the cuesta. This unit is 1.5 m wide and 25 cm high.

Six post-holes distributed according to a precise meshing (2.15 m by 2.75 m) are probably connected with this rampart phase. The depth of the post-holes decreases as the slope descends. Uphill, four post-holes cut through all the layers of both ramparts, whereas the two most downhill post-holes only cut through the first rampart phase.

The archaeological material found in this stratigraphic set is dated partly from the Late Bronze Age and partly from the Late Hallstatt[34].

Ditch Filling Phase 2: the second ditch phase is 6 m wide at the base and 20 m wide at the top (fig. 6 and 10). The ditch wall slope is interrupted by a ledge on the rampart side, whereas the opposite slope is much steeper. The maximum depth of the ditch is 4 m. Its filling from base to top is as follows:

- a silty-clayey, bluish-brown layer at the bottom (US 88) and a similar layer situated on the internal ditch wall (US 41). These stratigraphic units were deposited during the period of ditch functioning, but no archaeological material was collected there;

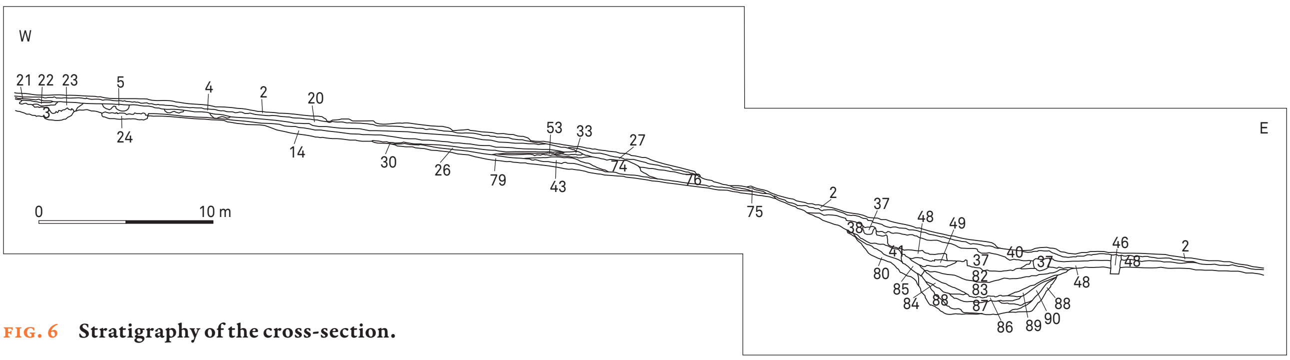


FIG. 6 **Stratigraphy of the cross-section.**

32 Pertlwieser & Ott 2004.

33 Pertlwieser & Ott 2004.

34 Pertlwieser & Ott 2004.

FIG. 7 **View of the drainage system and a pit with stones (Pertlwieser & Ott 2004).**

- a layer of blocks and pebbles (US 87);
- a layer of brown colluviums (US 90);
- a second layer of rejected pebbles (US 86) left in the middle of the ditch;
- two layers of brown colluviums (US 84 and US 89) situated on all sides of the ditch;
- thick brown layers of agricultural colluviums (US 40, US 48, US 38, US 82 and US 83), with few pebbles, at the top of the ditch.

This ditch filling is recut by later agricultural structures (US 49 and US 37).

Stone pits: three rectangular shallow pits (US 24, 49 and 85) contain blocks and pebbles of "Calcaires d'Etrochey" (fig. 6, 7 and 10). They correspond to pits of stones from agricultural clearing of land scattered with limestone pebbles. They very probably come from the ruins of the protohistoric rampart in this sector.

Plantation trenches: uphill from the rampart lies a first series of structures dug in a U-shape and filled with brown earth (US 4+5) (fig. 6). They are increasingly less preserved in instalments as the slope descends. A second series of U structures recuts the top of the ditch filling (US 37) (fig. 6 and 10). They are 10 cm to 50 cm deep with widths of 60 cm to 1 m. Their filling consists of a mixture of bluish "Marnes de Bouix" and brown earth. Several generations of digging seem to succeed one another, but it is difficult to distinguish stratigraphic boundaries between them. These successive diggings can be interpreted as trenches of vineyard plantation or layering.

Agricultural drainage: at the upper end of the cross-section, a wide structure recuts the whole extend of the hillside colluviums and part of the substratum (Marnes de Bouix). Its filling consists of stones with concretions without matrix (US 3), covered with layers of soil containing pebbles and blocks in varying amounts (US 21, US 22 and US 23) (fig. 6 and 7). This set of layers could correspond to a drainage system for runoff.

FIG. 8 **View of the excavation of the road (Pertlwieser & Ott 2004).**

Road: a layer (US 30) composed of well-calibrated round stones and pebbles, 1.20 m wide and 10 cm thick, situated 6 m uphill from the rampart (fig. 6 and 8). In stratigraphy, this structure is posterior to the remains of the second rampart phase and predates the formation of the thick colluviums layer (US 14). This modest structure can be interpreted as a Gallo-Roman road to Mont Lassois.

Pipe: a trench 65 cm wide and 1 m deep was dug out in the downhill part of the cross-section. Its filling (US 46) consists of a mixture of marl and earth (fig. 6). At the bottom, there is a water main about 20 cm in diameter which supplies the present-day cemetery of Vix with water.

4 Reconstitution of the hillside sedimentary history

A reconstruction for each major phase of hillside morphological evolution of Mont Lassois can be proposed (fig. 11). The volumes of materials (m^3 by linear metre of structure) extracted or accumulated on this hillside were estimated by calculating surfaces (m^2) of sections of the excavated and constructed structures, cut through by this cross-section.

FIG. 9 View of the cross-section of the vestiges of the rampart (Pertlwieser & Ott 2004).

FIG. 10 View of the cross-section of the filling of the ditch (Pertlwieser & Ott 2004).

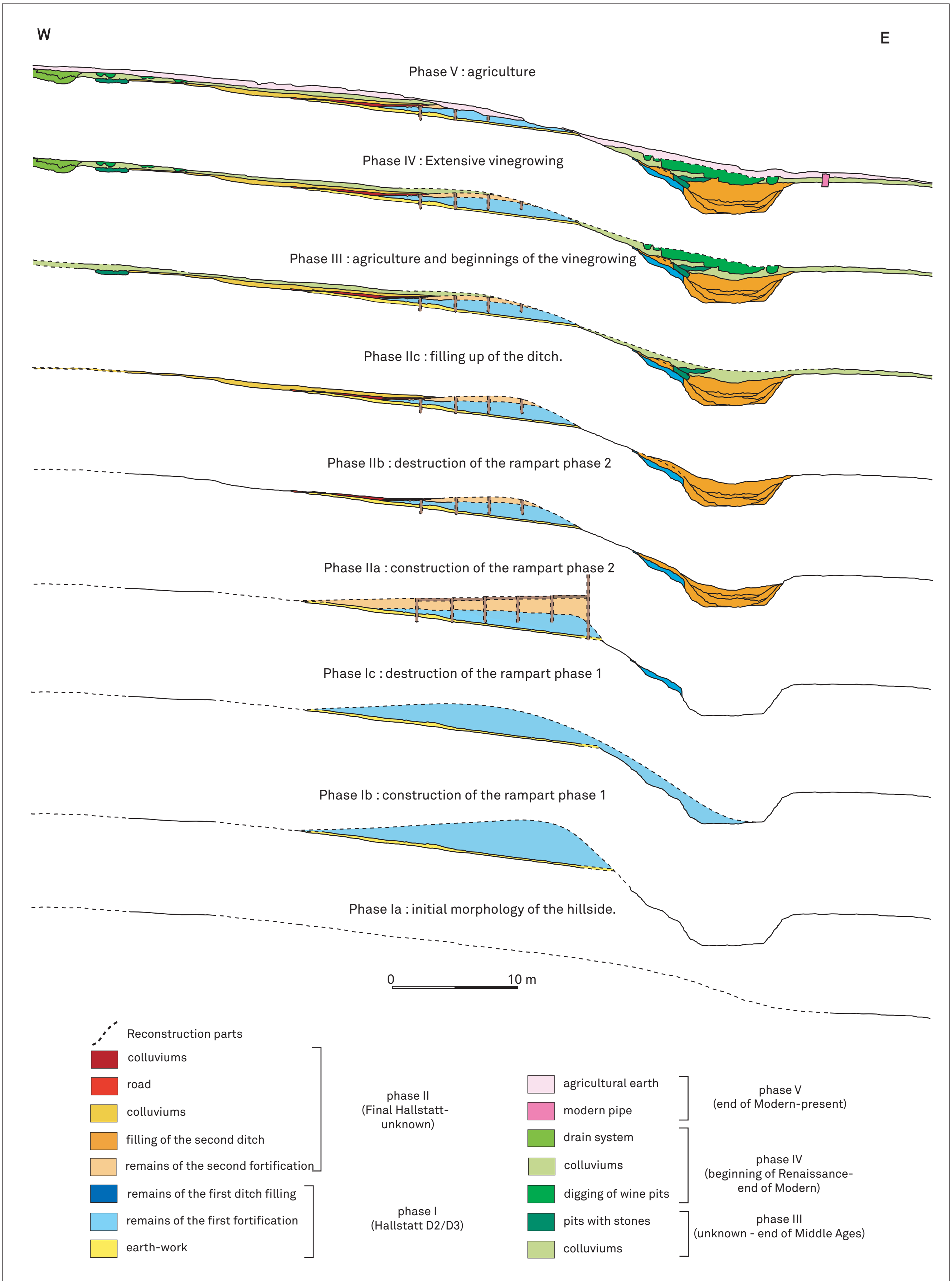


FIG. 11 The major phases of the Mont Lassois slopes.

Before the construction of the first rampart phase, the Mont Lassois hillside presented a steep slope with a morphological ledge due to the presence of hardened layers of "Marne de Bouix" (Marls). In this sector of excavation, the rampart is installed on the ledge, and the digging of a ditch below accentuates the monumental character of this defensive system.

The construction of the first rampart phase begins with the installation of an earth-work base (US 79; 4.9 m^3) before the construction of an earth embankment composed of marls extracted with the digging of the defensive ditch. The morphology of the flared ditch with a flat bottom allows a large quantity of earth to be extracted, while also improving the efficiency of the defensive system. The archaeological material found in the embankment suggests a construction date at the end of the Late Bronze Age or at the Hallstatt period. The volume of materials extracted from the ditch (41 m^3) is compatible with a rampart of terrace type with a flat summit, and triangular section. It was at least 25 m wide at the base and must have had a wall facing (palisade?) approximately 4 m high.

There are few traces of the first ditch filling (US 80; 1.4 m^3). The first rampart phase was an earthen structure which gradually collapsed, filling the ditch below. The main destruction of this fortification is caused by the construction of the second rampart phase.

This second rampart phase required the levelling of the embankment and the extension of the wall facing to construct a new type of rampart with which is associated a quasi-complete cleaning out of the ditch situated at its base. This rampart had a framework of vertical wooden posts probably strengthened by a horizontal framework at the top, although no trace of this was found. The vertical framework has a foundation consisting of a layer of stones. Limestone pebbles of "Calcaire d'Etrochey" found in the ditch filling probably come from the dry-stone wall on the outer side of this rampart. The wall dimensions are probably comparable to those of the first phase, on which it lies. The archaeological material found in the wall suggests construction in the Late Hallstatt period.

The colluviums (US 88; 3.6 m^3) which laterally fill the ditch show an absence of fortification maintenance preceding phases of voluntary destruction or more simply recuperation of rampart materials. During the successive dismantling phases of the wall facing, some of the stones were discarded at the ditch bottom (US 86; 2.8 m^3 and US 87; 1 m^3). Throughout this phase (La Tène and Gallo-Roman periods), the ditch remains empty with only a thin layer of colluviums (US 26; 0,9 m^3) deposited uphill from the rampart. The Hallstattian fortification morphology (rampart and ditch) was thus still clearly visible during the installation of the Gallo-Roman road (US 30; 0.25 m^3).

The history of this site from the Gallo-Roman to the Medieval period is clearly of an agricultural nature as shown by the presence of agricultural colluviums (and wine growing?) along the hillside (US 14; 5.3 m^3 and US 17=20; 10.9 m^3). The rampart no longer impedes this and colluviums fill the ditch in this period (US 82; 4.9 m^3 and US 83; 3.6 m^3). Numerous stone pits bear witness to agricultural practices which removed stones from the field surface by deeply burying stones. This agricultural practice continued until the twentieth century.

Throughout the cross-section vine cultivation is clearly recognized by the identification of the plantation pits and layering at the base of US 4=5 (0.7 m^3) and US 37 (6.7 m^3), and of the drainage system at the edge of the plot (US 3, 21, 22, 23; 3 m^3). This intensification of agricultural activity on the hillside probably goes back to the nineteenth century, during which Marshal Marmont brought about considerable changes on the Mont Lassois slopes (importation of earth).

After the abandonment of wine growing on the hillside from the First World War onward, the land returned to its natural moorland state, displaying only weak sedimentary dynamism. At the end of the 1990s, deep ploughing and mechanical agriculture partially destroyed the final remains of the rampart.

5 Sedimentary budgetting

Sediment volumes (m^3 per linear metre of structure) are estimated from the reconstructed cross-section of the hillsides. This gives some idea of the impact of anthropogenic activity (digging, destruction, etc.) and natural phenomena (colluviation, etc.) on the sedimentary budget, for the Mont Lassois hillside, in the locality "la-Mériotte", during the last 2,500 years.

First of all, the greatest phase of sedimentation associated with digging is the first rampart construction phase which required the removal of 41 m^3/m of hillside substratum for wall mass, and of 4.9 m^3/m for the establishment of a foundation layer (fig. 12). During the second rampart construction phase, the cleaning out of the ditch and levelling of the first rampart phase removed 25 m^3/m, whereas earth and stones (stones of blocking and facing) replaced 22 m^3/m. The anthropogenic destruction phase of the second rampart is strongly erosive (14 m^3/m). During this destructive phase, recuperation of materials and colluviation of sediments at the bottom of the ditch provoked the loss of 2.3 m^3/m. Also, earth-moving for road establishment (0.3 m^3/m) at the back of the fortification is characterised by a loss of 5.5 m^3/m of materials. The agricultural activities of stone clearing (2 m^3/m) and of plantation or vine layering (10 m^3/m) present balanced sedimentary budgets. Considerable volumes of reworked materials, during the phase of extensive vine-growing, underline the considerable efforts of winegrowers to improve the quality of their wine, because the volume of earth involved represents a quarter of the volume used in the construction of the first rampart phase at the excavation site.

During natural destruction of rampart phases, estimation of lost volume by reconstruction is 17 m^3/m for the first phase and 15 m^3/m for the second phase (fig. 13). The volume accumulated in the ditch is much lower than the eroded volume (12 m^3/m for the first rampart phase and 5.5 m^3/m for the second phase). This phenomenon is explained by a natural transport of sediment in the defensive ditch in the direction of the Seine. Concerning the contemporary erosion through agricultural activities, it cannot be estimated in the absence of topographic marks on cultivated land. The volumes of 30 m^3/m deposited during the phase of agriculture/vine-growing and of 32 m^3/m deposited during the extensive vine-growing period represent a positive terminal sedimentary budget, which reveals major erosion uphill from the study sector.

The distribution of eroded or deposited material according to the length of the chrono-cultural periods considered (m^3/century/metre of linear structure) brings to light two major phases of sedimentary dynamics: the construction of the defensive system (rampart and ditch) during the Hallstatt period, and extensive agriculture during the recent times (fig. 14). The sedimentary budget of the Hallstattian hillside is slightly positive (0.4 m^3/century/m), then decreases until the Gallo-Roman period (-2.5 m^3/century/m). After an increase during the Early Middle Ages (1.8 m^3/century/m), it remains stable until the end of the Modern period. The current period is marked by a very big increase in the sedimentary budget (11.7 m^3/century/m). In this period, only a low volume of rampart remains (14m^3/m) is buried by sedimentary activity on the hillside (fig. 15). The volume of defensive wall remains decreases very quickly after the construction of the second rampart phase (37m^3/m).

The construction of fortifications has spectacularly modified the hillside morphology and also strongly influenced its sedimentary dynamics. This phenomenon is revealed by a decrease in the sedimentary budget until the Gallo-Roman period, when the essentially anthropogenic rampart levelling prevented it from trapping any more sediment. In a more diffuse way, hillside agricultural practices are important factors in sedimentary dynamics. They provoke major erosion uphill and major sedimentation in hollow zones (defensive ditches) or on gentle slopes (uphill and downhill from the defensive system). The agriculturally induced sedimentary contributed more to the levelling of the hillside morphology by the burying of fortification remains, than by their erosion, except for recent mechanised agriculture with in-depth ploughing.

FIG. 12 Quantification of erosion and sedimentation directly related to human activity.

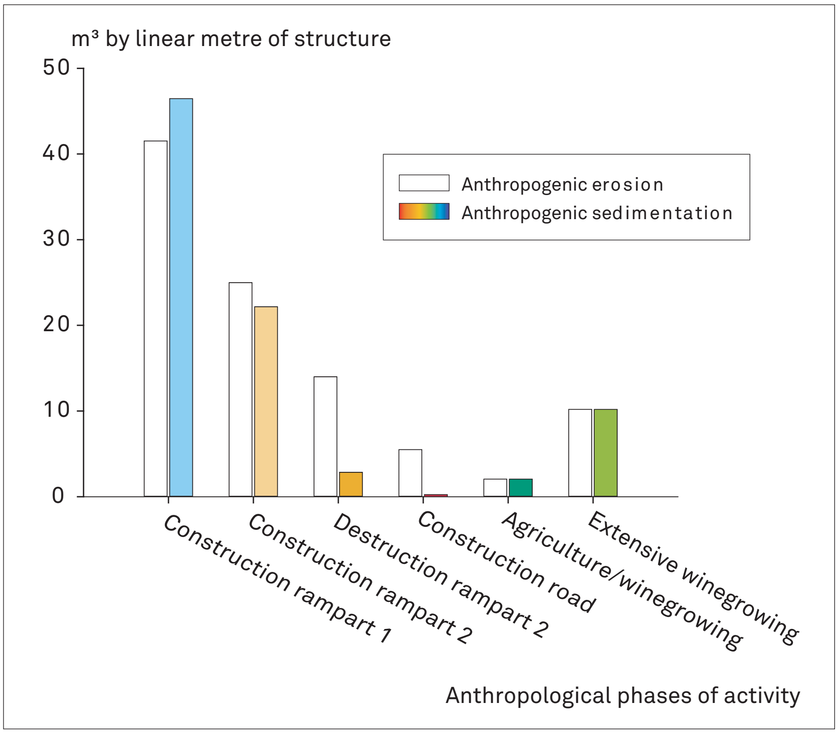
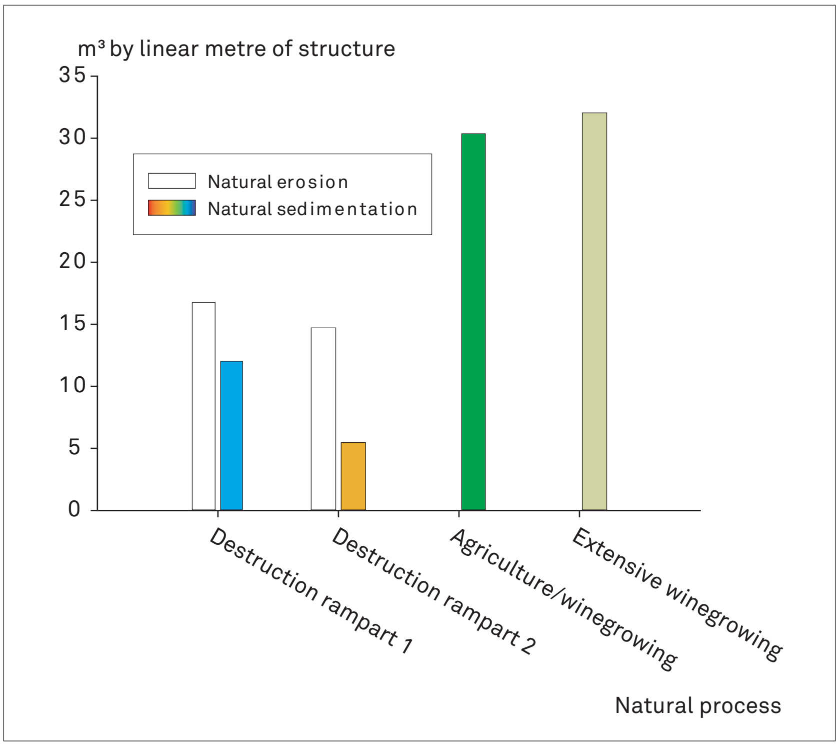


FIG. 13 Quantification of erosion and sedimentation whether natural or related to indirect human activity



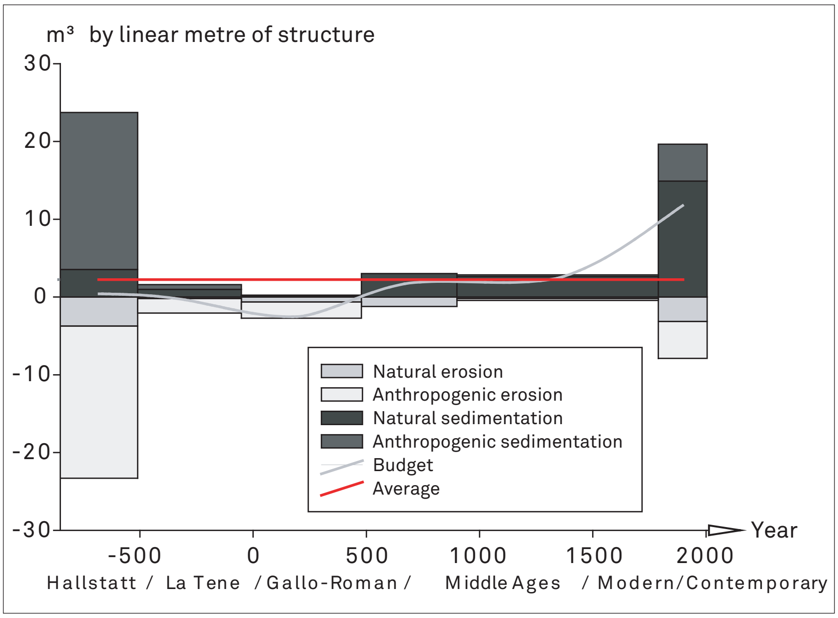


FIG. 14 Sedimentary budget of the major morphological phases of the Mont Lassois slopes.

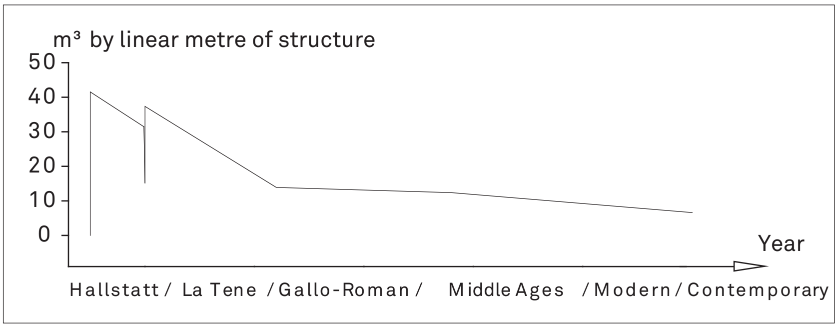


FIG. 15 Quantification of the rampart remains during the major morphological phases of the Mont Lassois slopes.

6 Conclusion

The archaeological remains of the Mont Lassois southern slope present two main phases of sedimentary activity after their abandonment. At first, they are quickly destroyed by anthropogenic activities (destruction, road management), but also in a lesser measure by slope erosion. Secondly, they are buried under agricultural colluviums, in particular during a major phase of vine-growing in the nineteenth century. From this, it is possible to make predictions as to the state of structure conservation on the slopes and at the base of Mont Lassois. On the hillside, archaeological remains are probably non-existent, because they are completely eroded, except for strong and deeply founded monumental buildings such as fortifications. At the base of the Mont Lassois, archaeological structures should be well preserved, but buried under thick layers of colluviums. This phenomenon is to be taken into account in archaeological research on the "princely" Vix site; in particular at the base of the Mont Lassois eastern slope. It is hypothesised that a Hallstattian housing environment was established between the two big levees which run down the Mont Lassois eastern slope, to the terrace of the alluvial plain of the Seine. The search for archaeological remains by relatively deep soundings with a mechanical digger will be preferred to campaigns of sub-surface geophysical prospection (electric, or magnetic).

Besides their defensive character, the monumental ramparts are often considered by archaeologists as markers of the wealth and power of Protohistoric populations[35]. They can be compared in terms of surface area surrounded by the defensive system, construction technicality and the volumes of materials used for the wall constructions. In view of the sometimes residual traces (levee 1 of the defensive system of Mont Lassois) excavated by archaeologists, it seems important to us that geoarcheaological studies should be carried out with the aim of making realistic estimations of the volume of materials involved.

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35 Colin 1998; Daubigney 2000.

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An exceptional landslide tongue near Alden Biesen (Limburg, Belgium): the relevance of temporary exposures of the subsoil for elucidating complex geological history

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Abstract

Valuable geological exposures often disappear without proper documentation. Unlike for archaeology, there is no organization responsible in Flanders for geological heritage management related to building construction permits or other licensed ground movement or transport.
It was a rare opportunity therefore that in the fall of 2007 a large excavation for a private house could be investigated in Rijkhoven (near the castle of Alden Biesen, Belgian province of Limburg). This temporary exposure provided new insights in the succession of geological strata and their rather unexpected evolution with respect to landscape genesis[7]. After comparing fieldwork results in the excavation with the LIDAR based Digital Terrain Model of the surrounding area, we propose the hypothesis that a large and complex landslide has affected the whole Alden Biesen area. This landslide could be responsible for the varying lithological succession and for the unusual topographic features in the vicinity of Alden Biesen.

Keywords

Outcrop, geological hazard, Digital Height Model, LiDAR, paleosols, Oligocene

1 Introduction

Because of the high population and building density in Flanders and as a result of the general obligation to re-cultivate exposed bedrock surfaces, temporary exposures are extremely useful as they provide valuable and often unique geological information. A number of locations, such as Alden Biesen (fig. 1), is especially cherished by the geoscientist community. In this area, natural outcrops with abundant fossil *Potamides*-type gastropods formerly occurred along the unpaved road leading from the Alden Biesen Castle to the *Apostelenhuis* (and beyond to Maastricht): these were recognized as the stratotype or type locality for the Sands and Marls of Alden Biesen[8] or "*sables et marnes des Vieux Joncs*" in older publications. On the new lithostratigraphical scale of the geological map of Flanders, this particular lithostratigraphical unit is referred to as the Member of Alden Biesen, a lower part of the Borgloon Formation[9]. The latter formation groups lithological units hitherto known as the "continental Tongrian".

The studied excavation near the castle of Alden Biesen offered a temporary but important geological window on the layered-cake like succession of colorful sedimentary strata from Early Oligocene age, complicated by a fossil paleosol and a spectacular landslide tongue disturbing the top layers of the succession[10]. Because of the scarcity of outcrops in the area, this temporary section was measured in great detail, photographed and sampled for further analysis. Besides a classical geological field survey of the exposed walls (measuring thicknesses and describing

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7 Dreesen & Dusar 2008.
8 Van den Broeck & Rutot 1883; Glibert & de Heinzelin 1954.
9 Maréchal & Laga (eds) 1988; Maréchal 1993.
10 Dreesen & Dusar 2008.

macroscopic lithologic features) additional augering has been performed and shallow pits haven been dug in the bottom of the excavation, in order to complete the section. Fossil assemblages have been photographed *in situ*, whereas *in situ* samples have been taken from the calcareous concretions, quartzarenitic sandstone, clays and palaeosoils.

This case study proves the urgent need for a regulation on the reporting of temporary geological exposures in Flanders. Further refining of the geological map of Flanders largely depends on the acquisition of new geological data, either by extra drilling campaigns or by such studies of temporary exposures. Because this information generally concerns the youngest geological strata present at each site, it also provides background information on geomorphological landscape development and the relation with human impact. The geological survey of a temporary exposure normally can be completed in a few hours or one day at most. Generally it consists of a detailed description and measurement of the pit walls, a representative sampling and a digital photographic survey. If the owner agrees, additional data can be gathered through extra augering and shallow test pitting, filled immediately after measuring and sampling.

2 Lithological succession observed in the excavation

The temporary exposure was located about 400 m south of the castle of Alden Biesen (fig. 1) along the *Kogelstraat* in Rijkhoven (Lambert-coordinates X: 230970 – Y:170450). The pit had a 6 m high and 20 m long backwall (oriented north-south) and two

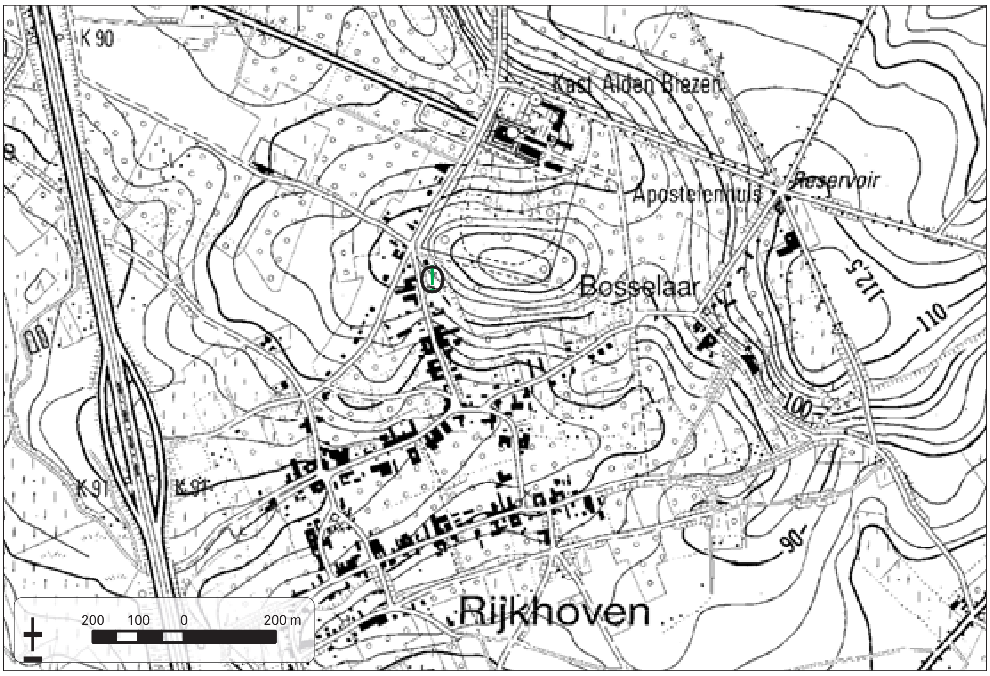

FIG. 1 Location map of the studied area, with location of the excavation in Rijkhoven (green dot).

FIG. 2 Alden Biesen castle. The Landcommandery Alden Biesen was built by the Teutonic Knights Order. Nowadays this castle is a cultural centre of the Flemish Community (© photo R. Dreesen).

east-west oriented side walls of about 4 m high and 8 m wide. This pit was dug in the slope of Winterberg hill south of the Alden Biesen Castle park (fig. 2).

Below a thin loam cover (1 or 2 m loam is supposed to have been removed earlier from the site), a colorful succession of geological strata was displayed. Additional augering in the bottom of the excavation and some extra hand-dug pits completed the following lithological succession, from top to bottom (fig. 3).

A. 0.00 - 0.80 m: heterogeneous, plastically deformed, orange brown (10YR 6/6, Munsell color code) loam, coarse and loamy sand with either dispersed or concentrated dark-grey flint pebbles, dark-green clay (5Y2/1), reworked pale orange yellow shell debris (including numerous *Potamides*-type gastropods) (fig. 4a) and reworked (rounded and perforated) large mollusc shells (*Glycimeris*) (fig.4b). The deformed strata display nice landslide tongues with overturned axes (figs 5 and 13).

B. 0.80 - 4.95 m: sequence of stiff green clays displaying internal stratification marked by color banding (organic carbon-rich layers), concentrations of white marly shell fragments, with rare limestone concretions and small septaria. The clay series can be subdivided into several subunits:

- 0.80 - 1.20 m: calcareous grayish olive-green clay (10Y4/2) with thin white marly layers, thin coquina levels and rare pale grey to white calcareous concretions (5 cm in diameter). Small flint pebbles are present at the top. This subunit has a disturbed contact with the overlying heterogeneous lithological complex.
- 1.20 - 2.00 m: dark olive-green clay with a banded aspect due to the occurrence of dark-colored zones (5Y2/1) rich in organic material (peat, oxidized wood debris).
- 2.00 - 3.20 m: pale-green, greyish-olive clay (10Y4/2) with pale brown oxidation spots, almost devoid of whitish shell fragments, with locally white to beige or greenish grey limestone concretions and flat septaria (up to 8-10 cm in diameter).
- 3.20 - 3.80 m: a concentration of white marly shell fragments (including fully conserved thin-shelled molluscs) in a clay matrix; the color of this clay becomes paler towards the top. Small septaria are present.
- 3.80 - 4.20 m: brownish green to olive black compact clay (5Y2/1) enriched with organic matter.
- 4.20 - 4.95 m: greyish olive-green clay (10Y4/2) with an orange oxidation layer (10YR8/6) near the base and some small white calcareous concretions (nodular gypsum, about 8 cm in diameter) in the middle of the clay bed. It has a knife-sharp contact with the underlying sand layer.

C. 4.95 - 5.85 m: white to light pinkish (5YR8/1 – 5YR6/1) fine, pure sand, showing more consolidated parts (not silicified however), enclosing a 25 cm thick lenticular ash-white quartzarenitic sandstone bed with slightly undulating (lobed) surfaces displaying rare small circular pits. The sandstones may cover at least several m² (fig. 6) The base of the sandstone is located about 20 cm above the base of the sand.

D. 5.85 - 6.70 m: predominantly chocolate-brown sand with various hues (5YR5/2-10R4/2-5YR2/2) displaying a strange marble-like (mottled) aspect and thin and oblique vertical black plant root traces. Several vertically stacked, sub-horizontal to locally bulging, anastomosed dark-brown to black humus layers and locally consolidated sand parts are present. In the upper chocolate-brown colored sands an unusual imbricated pattern of former cracks can be observed (fig. 7).

E. 6.70 - 7.55 m: olive-green clayey sands (5Y4/4). Near the top a gradual transition to the pale and brown-stained overlying sand was observed. It has a mottled aspect due to the presence of brown-yellow oxidation spots (fig. 8).

3 Stratigraphical interpretation

The stratiform deposit of white sands and green and black clays (units B to E) has been deposited during the Early Oligocene

FIG. 3 **Colorful succession of chocolate-brown & white sands (bottom), purple-black to green clays (middle) and orange-colored mixed lithologies (top), exposed in the eastern wall of the excavation. White stick measures 2 m (© photo R. Dreesen).**

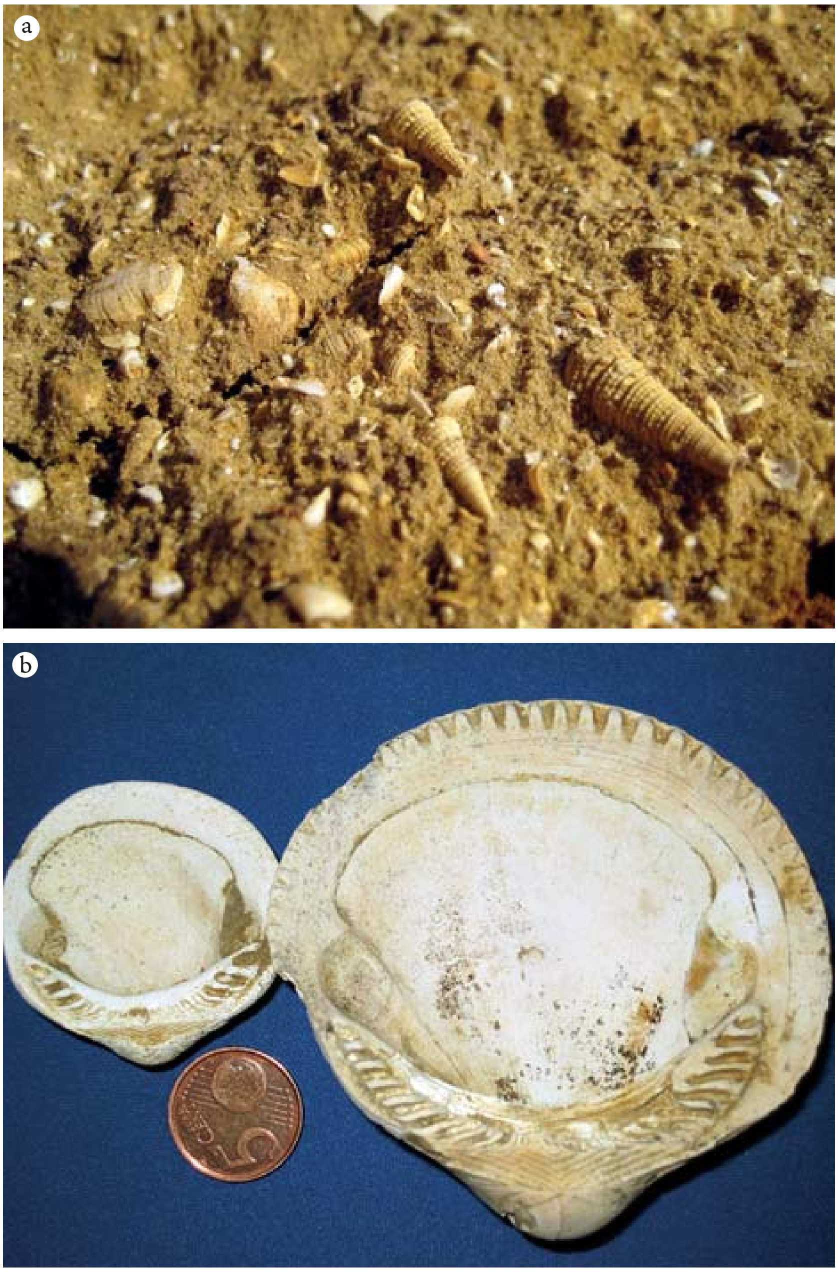

FIG. 4 a. Potamides-type gastropods in reworked sands of the Alden Biesen Member. b. Thick Glycimeris shells reworked from the Berg Sands (© photo R. Dreesen).

FIG. 5 Green clays, white marls, flint pebble layers and colluvial loam forming overturned landslide tongues in the top layer of the exposed strata. Eastern side of the excavation (© photo R. Dreesen).

FIG. 6 Quartzarenitic sandstone lens with conspicuous lobes at its surface. Large horizontal slab of a few m², displaced from the outcrop and vertically exposed near the entrance of the excavation (© photo R. Dreesen).

FIG. 7 Chocolate-brown humic concentrations below ash-white bleached sands. Note imbricated crack pattern in chocolate-brown sand and presence of quartzarenitic sandstone lens near top (© photo R. Dreesen).

(33,7 to 32,3 million years ago)[11]. It represents an upper continental and a lower marine cycle of the former "Tongrian" stage, currently assigned to the lithostratigraphic Tongeren Group. The Tongeren Group is formally subdivided in two geological formations: a lower marine Sint-Huibrechts-Hern Formation (with the Neerrepen and Grimmertingen Members) and an upper continental Borgloon Formation (including the Henis Clay and the Alden Biesen Sands and Marl Members) (see table 1). The exposed units C to E belong to the Neerrepen Member of the Sint-Huibrechts Formation. Unit B corresponds to the Henis Clay Member and forms the basal unit of the Borgloon Formation. Remnants of the overlying Bilzen Formation including shell-rich Berg Sand and greenish Kleine Spouwen Clay are incorporated in the fluidized landslide tongue (unit A).

At the boundary between the white fine sands (unit C) and the green clays (unit B), an important stratigraphical gap occurs, encompassing several hundred thousands of years. This gap apparently results from an important sea level drop that occurred in the area around 32,8 million years ago. Most interesting and consistent with the idea of the sea level drop, is the development of a conspicuous soil at the top of the Neerrepen Sand Member. This fossil soil is known from the literature as the Neerrepen paleosol[12]. The 1.50 to 1.75 m thick paleosol has been interpreted as a podzol or spodosol, with an upper bleached, white and locally indurated zone (the eluviation zone = unit C) and a lower humus-rich chocolate-brown illuviated zone (unit D). The indurated sands correspond to fragipans, where clay coatings and bridges between the sand grains act as cementing agents. According to the above authors, the podzol formation was superimposed on the fragipan formation. Moreover, after a drastic climate change event, another type of soil developed, a silica-rich duricrust (silcrete), forming extensive lenticular quartzarentic sandstone layers. This particular sandstone has locally been used as a building stone (so-called "zoetwaterkwartsiet"[13]). This is the first time that this Early Oligocene silcrete has been discovered within its original paleo-pedological context.

11 Vandenberghe *et al.* 1998; 2004.

12 Buurman & Jongmans 1975.

13 Dreesen *et al.* 2001; Dusar *et al.* 2009.

FIG. 8 Shallow pit dug in the bottom of the large excavation. Mottled transition from the chocolate brown and white sands (spodosol) with orange-yellow jarosite spots, to underlying green marine sands (Neerrepen Sands) (© photo R. Dreesen).

TABLE I
Lithostratigraphical scheme of the Oligocene deposits in the eastern part of Flanders (based on Maréchal 1993).

Group	Formation	Member
Rupel	Bilzen	Kerniel Sands
		Kleine Spouwen Clay
		Berg Sands
Tongeren	Borgloon	Alden Biesen Sands & Marls
		Henis Clay
	St.Huibrechts-Hern	Neerrepen Sands
		Grimmertingen Sands

4 Depositional environment

Thanks to the geological observations made on the freshly cut walls of the excavation (figs. 3,7-8), subsequent laboratory investigations on samples taken from the excavation (paleontological and petrographical analyses) and an extensive literature study, a better understanding of the depositional environments of the exposed geological strata can be formulated.

The oldest strata exposed in the excavation are the well-sorted (100-200 microns), glauconite-bearing fine-grained sands of the Neerrepen Member (unit E) They have been deposited in a shallow sea, close to the coast[14]. Sedimentary structures observed in time-equivalent deposits formerly exposed near Valkenburg (the Netherlands) displayed a tidal signature. The Neerrepen Sands together with the underlying Grimmertingen Sands form the Sint-Huibrechts-Hern Formation, the thickness of which reaches on average 20 m in the investigation area. The occurrence of a mottled zone near their top and the transition to a soil, clearly point to an emersion (sea level drop) and a subsequent stop of sand deposition.

The ash-white fine sands (unit C) with chocolate-brown humic enrichments (unit D) correspond to a podzol that developed in a coastal area under subtropical conditions. This paleosol marks the onset of a continental episode in the region. The soil is complex and has been formed over a time span of several millennia, with locally fragipan (duripan) formation. According to P. Buurman (2008, written communication) actual tropical coastal podzols formed in (old) coastal plains of southern and western Brasil most probably represent the best recent analogues for the Neerrepen paleosol.

The conspicuous sharp contact between the white sands and the overlying green clay, as well as the absence of a lignite-layer above the bleached eluviation horizon, both suggest the existence of an important stratigraphical hiatus or geological time gap. This gap is well known in the literature as the "Grande Coupure" or "the Great Interruption" and coincides with an important crisis in the mammalian evolution in Europe correlated with an important cooling of the climate due to glaciation of Antarctica at the very beginning of the Oligocene[15].

Within the eluviated horizon of the podzol an extremely hard, lenticular quartzarentic sandstone bed has been formed. This apparently results from pedogenetic processes under different climate conditions, leading to the formation of hard crusts or duricrusts. Silica-rich crusts are known as silcretes. The existence of quartzarenitic sandstones (sedimentary quartzites) in Early Oligocene (Upper Tongrian) strata in the study area has already been reported by Gulinck (1968). He has observed a 30 cm thick quartzarenitic sandstone in a temporary exposure in Alden Biesen park, with a lateral extension of several tens of m^2! Although the sandstone was covering a brown colored sand, the author noted the displaced nature of the outcrop.

Two different types of silcretes can been recognized - pedogenic and groundwater silcretes[16] - according to their genetic history. Goundwater silcretes have been reported from the Oligocene

14 Janssen *et al.* 1976.

15 Hooker *et al.* 2004.

16 Ullyott & Nash 2006.

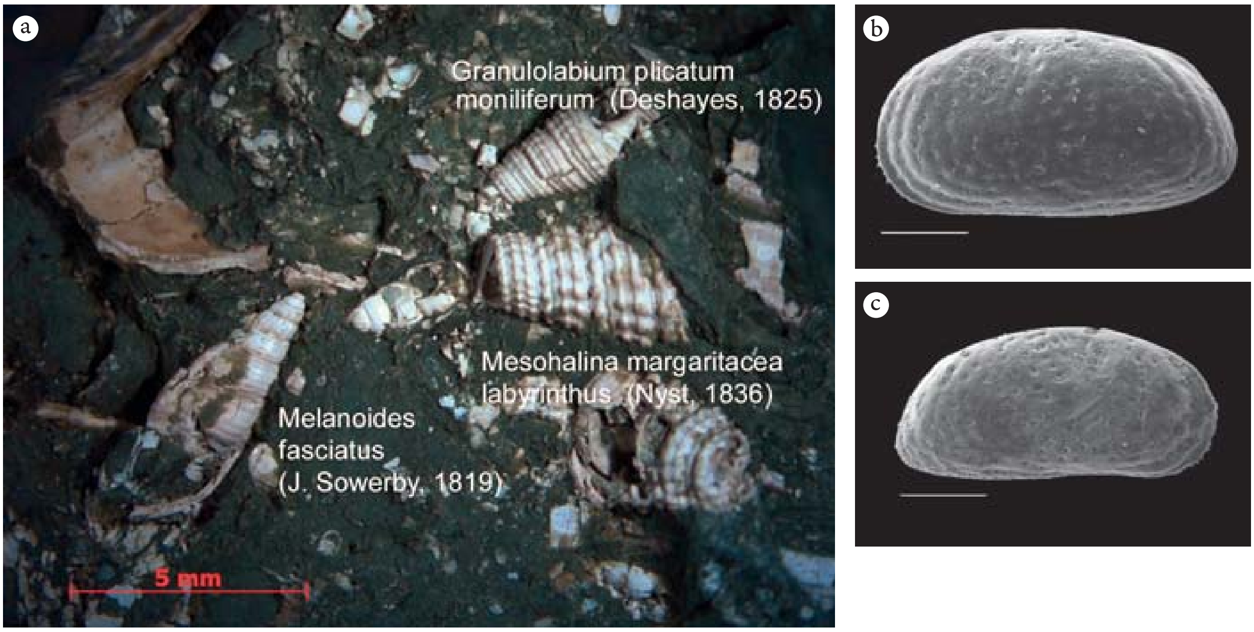

FIG. 9 a. Thin-shelled molluscs (gastropods) in the Henis Clay. In-situ macroscopic photographs. Determination by R. Marquet (© photo R. Dreesen). b-c. Ostracodes from the Henis Clay: Hemicyprideis montosa (Jones & Sherborn 1899). b. Left shell, female. c. right shell, male. Scale bar = 0,2 mm. Determination and scanning electron micrographs by K. Wouters (RBINS).

of South-Limburg by Demoulin (1989, 1990). Field observations (a. o. presence of root traces) and petrographical analysis rather suggest a pedogenetic origin for our silcrete occurrence. The quartz grains all show characteristic quartz overgrowths, the intensity of which is increasing towards the core of the sandstone. Obviously, further geochemical investigation is needed here. According to Ullyott & Nash (2006), silcrete development in sandy formations is linked to acid leaching and interactions between the water table and valley systems. Groundwater silcrete development in the southern Paris Basin has been related to leaching following the oxidation of organic matter and pyrite within the host sediment during landscape incision. Silica was transported vertically and laterally by groundwater flow, with silcrete forming at or near the water table close to outflow zones into the valleys[17]. In the case of pedogenetic silcretes, the silicification would have occurred during an arid period following an episode of humic acid leaching[18]. Pedogenetic silcretes developed in close association with overlying lignite (browncoal) beds, as can be observed for instance in the Miocene glass sand deposits of the Campine Plateau[19].

The Neerrepen Sands, topped by the Neerrepen paleosol complex (a silcrete superimposed on a thick podzol), are overlain by very heavy and plastic green clays, the Henis Clay (unit B),dominated by clay minerals of the smectite-group[20]. The conspicuous green colour points to the presence of reduced iron. This clay has been deposited under very calm water conditions in a tidal flat or lagoonal environment, as a result of a marine transgression, bringing the previous continental episode to an end. The tidal flat or lagoonal pond must have been separated from the open sea by a sand bar. Evaporation was important, leading to increased salinities, as evidenced by the occasional presence of gypsum concretions and by the occurrence of numerous species-poor euryhaline organisms, among which molluscs (bivalves and gastropods: *Polymesoda subarata convexa, Cordiopsis incrassate, Corbula gibba subpisum, Granulolabium plicatum moniliferum, Mesohalina margaritaceus labyrinthus, Melanoides fasciatus*) and ostracodes (*Hemicyprideis montosa*) (identifications by Marquet *et al.* 2008 and Wouters, written communication 2008) (fig. 9). Euryhaline organisms can live in waters of various salinities including saline, brackish and even fresh water conditions. The latter conditions have also been inferred from the study of the clay minerals[21]. Moreover, Gullentops (1956) interpreted the sedimentary structures and faunal associations of the Henis Clay as indicative for freshwater-influenced marine and brackish water conditions, characteristic for coastal lagoons or coastal lakes. In the Henis Clay several small septaria and carbonate concretions have been collected. Thin section analysis revealed the presence of thin-shelled molluscs inside of the concretions[22], indicative for quiet or stagnant water conditions. Geochemical and stable isotopic analysis of time-equivalent septaria revealed an early-diagenetic origin for the carbonate concretions, through rapid pore-filling cementation of the sediment[23] proving that the concretion growth occurred well before compaction of the sediment, at very shallow burial depths in a lagoonal environment.

The transition from the Henis Clay to the succeeding Alden Biesen Sands and Marls was not very clear from regional mapping.

17 Thiry 1999.
18 Demoulin 1990.
19 Gulinck 1961.
20 Gullentops 1996.
21 Porrenga 1968.
22 Dreesen & Dusar 2008.
23 De Craen 1998.

Thanks to the temporary exposure it is shown that the sediments at the contact between stiff clay and loose marls and sands may be strongly disturbed (unit A). Orange yellow to brown yellow sandy, cream-white marls and dark-green clayey sediments are intermingled, locally extremely rich in euryhaline and/or brackish molluscs, including: *Megaxinus striatula, Polymesoda subarata convexa, Corbula gibba subpisum, Lentidium nitidum, Lentidium donaciforme, Sandbergeria cancalleta, Granulolabium plicatum moniliferum, Mesohalina margaritaceus labyrinthus, Melanoides fsciatus, Euspora achatensis, Turboella turbinate, Hydrobia draparnaldii, Nyustia duchasteli* (determinations by Marquet *et al.* 2008).

The mass occurrence of so-called Potamides-type gastropods (*Pirenella plicata monilifera*, now: *Granulolabium plicatum moniliferus*) (fig. 4a) is characteristic for the Alden Biesen Member. These coquina layers were locally used as gravel for hardening footpaths. Their occurrence in the top subsurface (carbonate-enriched substrate) leads to interesting biodiversity contrasts in the south-eastern part of Belgian Limburg.

Depositional conditions of the Alden Biesen Member were almost identical to those of the older Henis Clay (as proved by almost identical euryhaline faunas), except for the presence of important sand influxes, probably related to temporary marine

FIG. 10 Tidal flat deposits in Northern-Germany (Jade Busen, near Wilhelmshafen): sandy upper flat with tidal gullies and storm-generated shell accumulations. Possible recent analog from a cooler climate for the Alden Biesen member (© photo R. Dreesen).

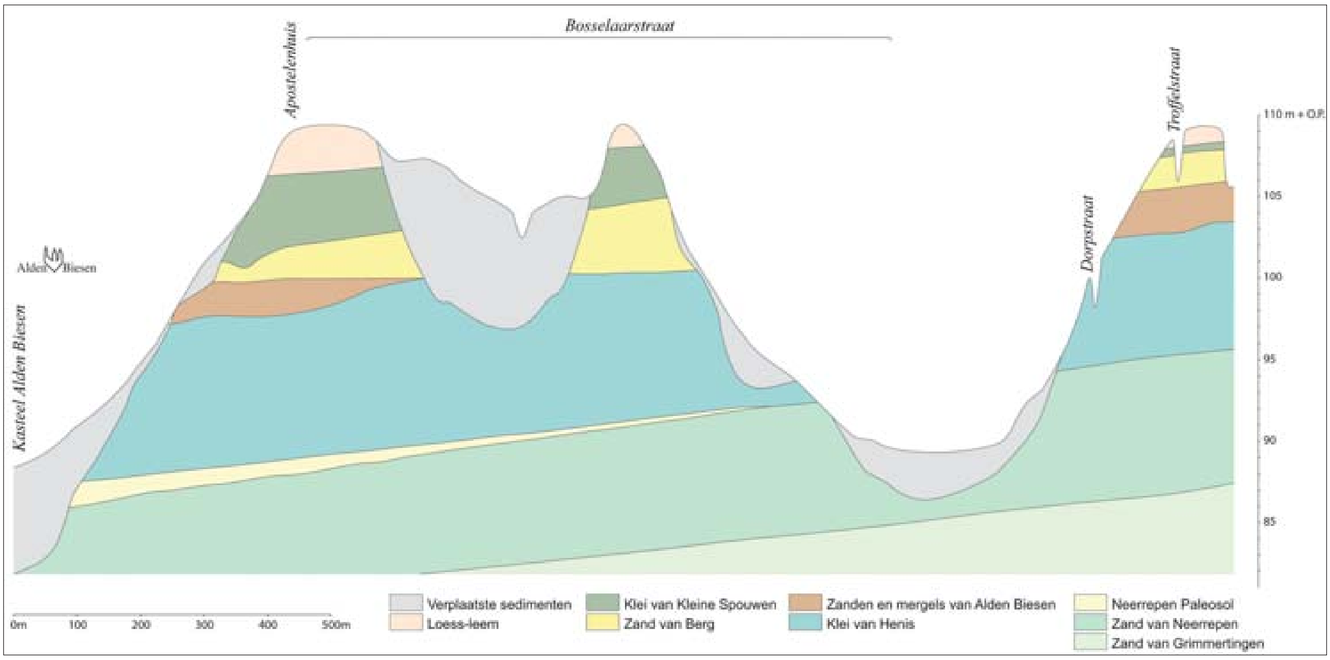

FIG. 11 Schematic geological W-E cross section between the village of Kleine Spouwen (right end) and the Castle of Alden Biesen (left end). Redrawn from Van Hinsbergh *et al.* 1973 and own observations (Dreesen & Dusar 2008).

incursions through the sand bars or to occasional fluvial influxes into the lagoon/tidal flat area (fig. 10). The latter freshwater influence is evidenced by the presence of charophytes, which could be observed where the Alden Biesen Member is less disturbed and more completely preserved.

After deposition of coastal marine and to a limited extend marine sediments of the Borgloon Formation, a true marine invasion took place in the region, resulting in the deposition of white to yellow fine sands of the fully marine Berg Member. Sediments of this Member have not been conserved as such in the Rijkhoven exposure. However, several large fossils, such as thick shells of *Glycymeris obovata,* have been reworked from this Berg Member in the landslide tongue (fig 4b).

Based on observations of drilling campaigns[24] and on the new data collected in the temporary exposure, a schematic west-east geological cross section can be made, indicating the lateral discontinuity of the Alden Biesen Member (fig. 11), seemingly cut off by the Berg Sand Member. The coquina marl beds in the top layers of the Henis Clay indicate interfingering of Alden Biesen Marl with Henis Clay. This close relationship could impose to merge the former separate Members of Alden Biesen and Henis into one single Member for mapping purposes[25].

The landscape of Southern Limburg has been strongly influenced by deep erosional events (valley incisions) during the wet episodes of the Pleistocene glaciation. These periods of erosion alternated with deposition of loess during cold, dry and windy episodes. The loess deposited during the last cold phase, (Middle Weichselian, Late Pleistocene), has been (partly) decalcified to form the loam blanket that covers the landscape now. The flint pebbles found in the disturbed lithological unit at the top of the exposed strata in the excavation pit most probably derive from the basis of this Quaternary loam-loess cover (so-called regression gravel layer). These pebbles have been reworked from the underlying younger Tertiary sand strata that have been completely eroded, except for the resistant pebbles.

5 Post-depositional phenomena

5.1 Frost cracking or pedogenetic features?

The origin of the observed "fractures" in the chocolate-brown colored illuviation horizon of the paleosoil is very intriguing. The imbricated (cross) pattern of cracks could favour the hypothesis of frost cracking (fig. 12) suggesting a possible link with permafrost conditions during the Late Pleistocene. The genesis of (subrecent) fragipan analogs is still open to debate, the definition and origin of fragipans often being the subject of argument in soil science. Their formation can be attributed to compacting of soils by glaciers during the last ice age, physical ripening, permafrost processes, or other events that occurred in the Pleistocene. However, their formation could also be related to relative "simple" mechanisms such as polygonal cracking in fragipans as a result of drying (P. Buurman, written communication), which is the more likely explanation in this case.

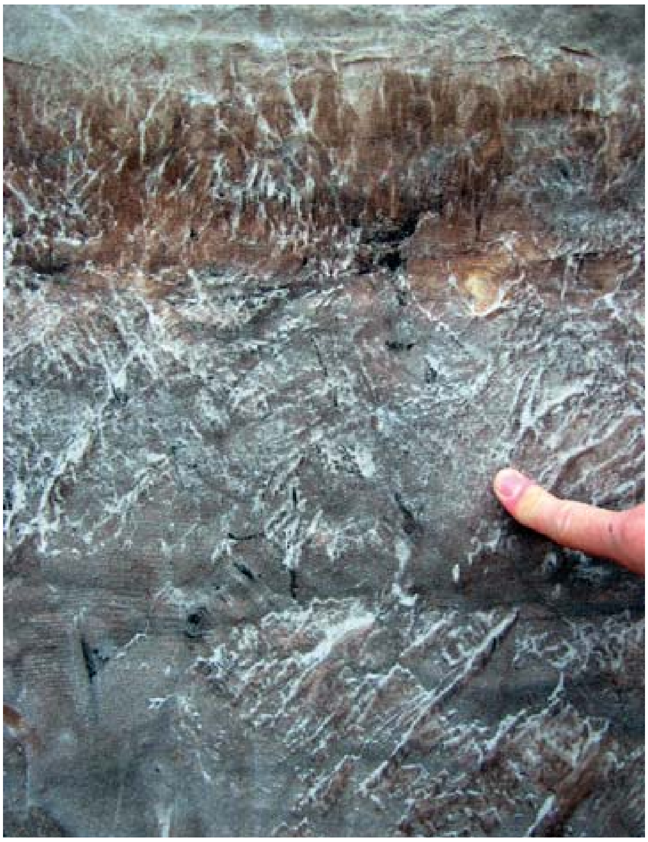

FIG. 12 Conspicuous pattern of sand-filled cracks, possibly related to frost cracking, developed in the illuviation horizon of the paleopodzol. Black spots are root traces (© photo D. Lagrou).

5.2 Landslides

The Rijkhoven excavation cut through the middle part of a landslide foot (fig. 16). The observed structures can be explained as follows.

The porous sandy deposits of the Berg and Alden Biesen Members can become strongly saturated with water, because of the underlying impervious Henis clay. If the water cannot escape laterally because of obstructions, caused by downhill movement of colluvial loam or because of former landslides, the pore water pressure in the sand layer can increase to such an extent that the shear strength between the sand grains will be lost and liquefaction occurs in case of low lithostatic pressure, as observed in near surficial deposits. Subsequently all the strata on top of the Henis clay as well as the top layers of the Henis Clay, can slide downwards in succeeding lobes tumbling over each other, whenever the slope of the land surface due to river incision has the same direction as the (weak) structural dip of the geological strata. This is the case at Alden Biesen. The initial sliding surface is formed by the top of the Henis Clay Member (fig. 13). Uphill the rotational slide leaves steep scarps at the surface of rupture, above the internally rather undisturbed downslided strata. Downhill the slide rotates outward of the hillslope and forms a bulge. Fluidized mud is formed at the outflow level of the pore water. The

24 van Hinsbergh *et al.* 1973; Janssen *et al.* 1976.

25 Dreesen & Dusar 2008.

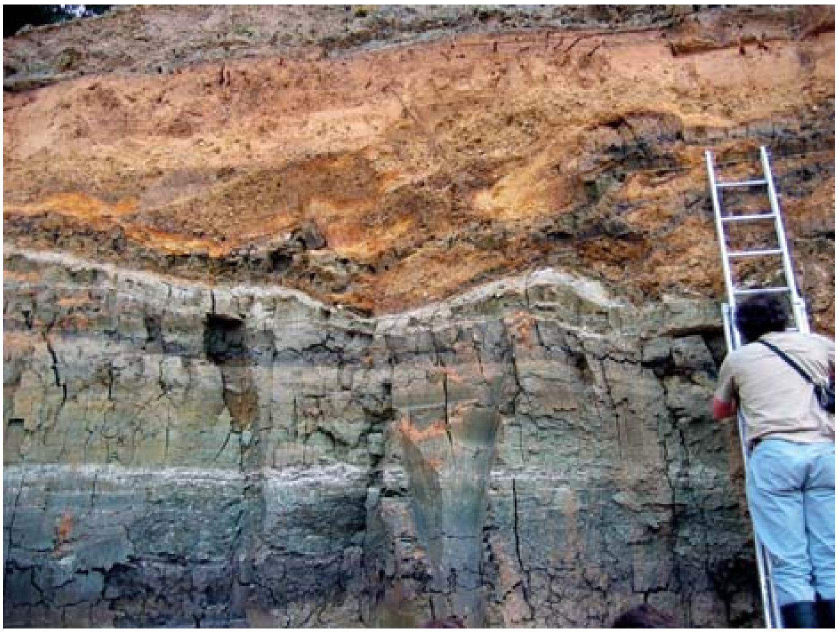

FIG. 13 Creamy white marls on top of the Henis Clay, marking the sliding surface. Eastern wall of the excavation (© photo D. Lagrou).

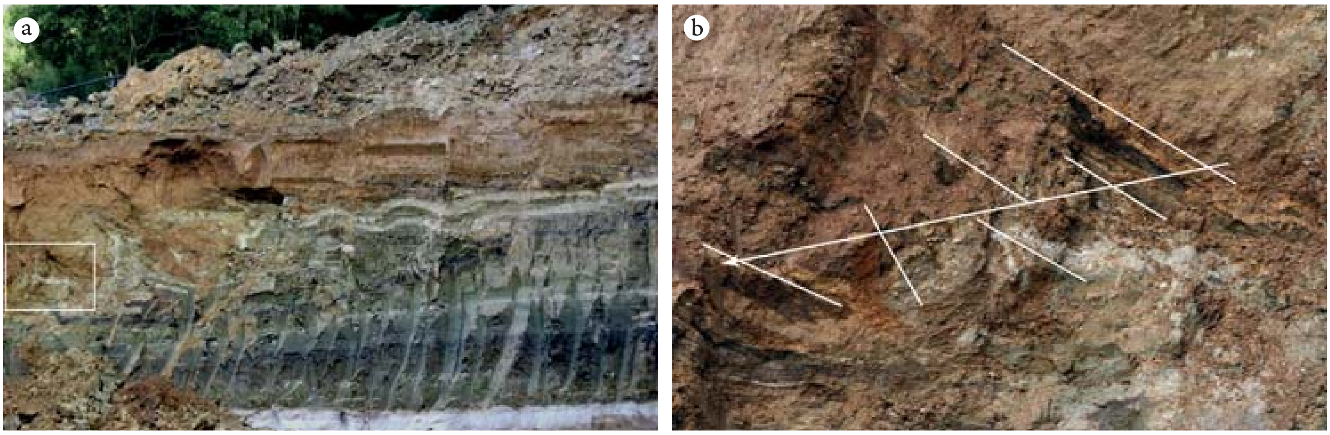

FIG. 14 a. North wall of the excavation exposing slided sediments. Note deformed white marl layers. b. Detail of fig. 14a: slided sediments; the slopes indicate the movement direction of the slide (arrow) (© photos R. Dreesen & M. Dusar).

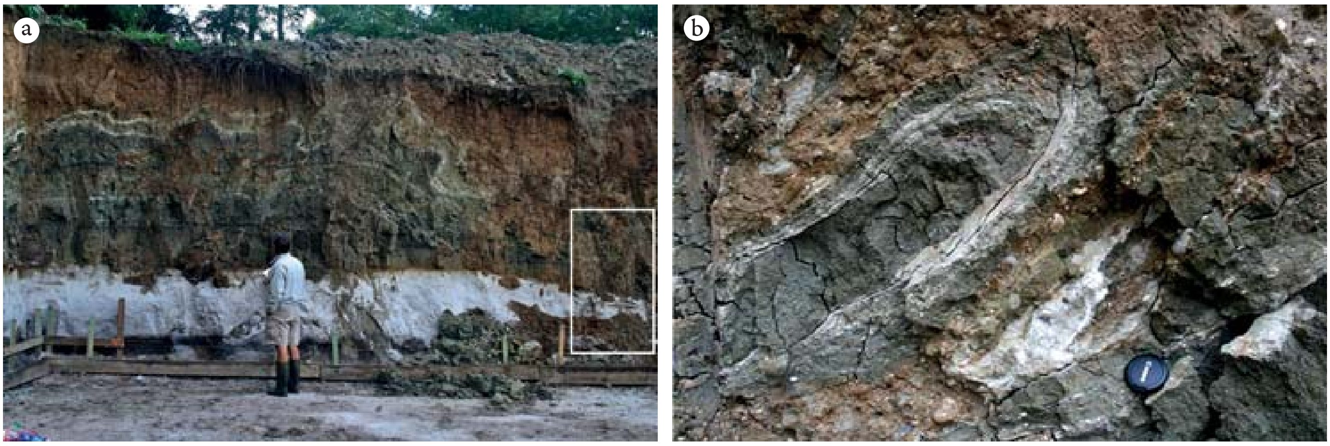

FIG. 15 a. South wall of the excavation showing the plastically folded top layers of the Henis Clay and younger sediments (previous figure). Fold frequency and inclination of fold axis increase downdip. b. Detail of Fig.15a: strongly folded isoclinal to detached slide lobes with reversed slopes (© photo R. Dreesen).

base of such a rotational slide was observed at the temporary exposure. The Rijkhoven excavation pit apparently lies within a landslide–sensitive zone and has cut deep into the tongue of a major landslide (see further). Strongly folded isoclinal slide lobes formed as a result, with reversed slopes indicating the direction of sliding, thoroughly mixing the displaced sediments of different geological age (sands, clays, marls, flint pebbles, fossil shells,...) (figs 14-15). These overturned lobes can be compared with the overturning of a wave breaking on the beach.

Gulinck (1968) mentioned the presence of 'solifluctions' and strongly disturbed sediments, affecting both the Henis Clay and Alden Biesen Sands and Marls, in a temporary exposure close to Alden Biesen Castle. The author related these phenomena, of which the typology clearly corresponds to the landslide model described here, to valley incision during the Pleistocene. Drilling campaigns reported by van Hinsbergh *et al.* (1973) and Janssen *et al.* (1976) in the same area, mentioned the existence of "displaced sediments". These were interpreted by the authors as the result of flank erosion processes and as infillings of erosion valleys.

On the other hand, well-known and large-scale landslides occur in the Flemish Ardennes, in the southern part of East-Flanders and adjacent Pays des Collines in Hainaut[26]. Here a clay-sand-clay succession of Ypresian age occurs, including fine, clayey sand that will lose its cohesion through water saturation and subsequently starts to flow and slide. In the Hesbaye area, it is the Henis Clay that is sensitive to landslides and the whole area of Alden Biesen seems to be located in this landslide-sensitive zone.

5.3 Geomorphological analysis – evidences for a major landslide?

A correct interpretation of the observations made in the previous section requires the analysis of the excavation site within a broader geomorphological context[27]. Hillshade (fig. 16) and other raster maps derived from the LIDAR based (Digital Terrain Model of Flanders[28]) (fig. 17) provide detailed images of the area surrounding the excavation. On the hillshade map one can for example distinguish morphological features that are typical for deep-seated rotational landslides similar as those observed

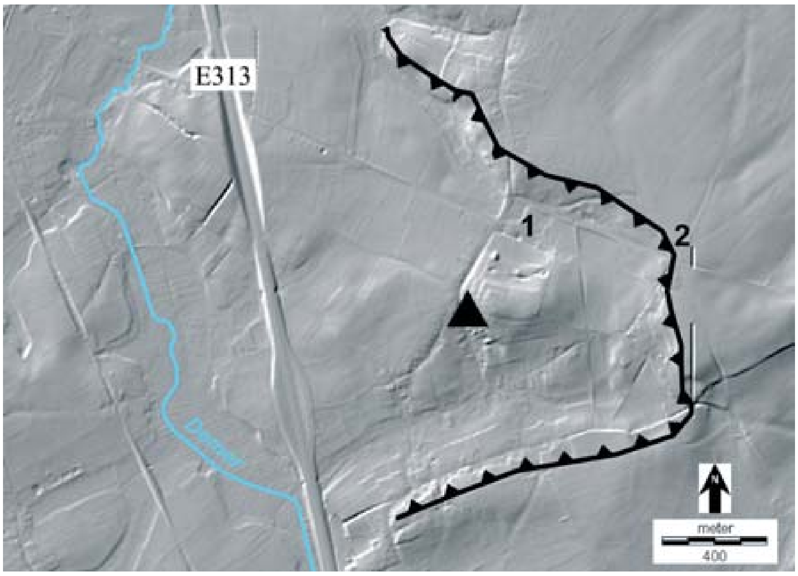

FIG. 16 Hillshade map of the Alden Biesen area with location of the excavation pit (▲), Alden Biesen Castle (1) and the Apostelenhuis (2). Note presence of a main scarp in the East and the bending of the Demer river and alluvial plain west of the highway (E313).

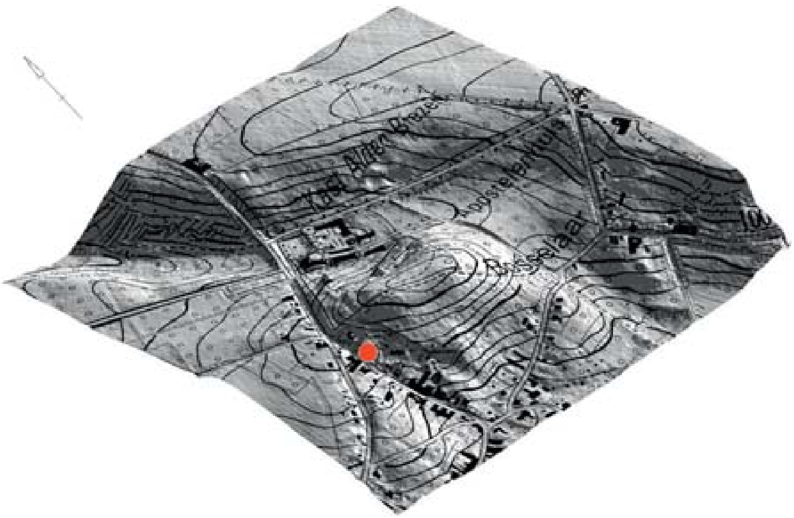

FIG. 17 Superimposed hillshade and topographic maps, looking towards the Northeast. Conspicuous scarp to the northeast of Alden Biesen Castle and then following the elevation level of Apostelenhuis further south, and foot on Winterberg (marked Bosselaar on picture) in the foreground. Red dot corresponds to the location of the excavation pit at the foot of the Winterberg.

26 Van Den Eeckhaut *et al.* 2005; 2007a.

27 Vandecaveye 2007.

28 AGIV 2005.

in the Flemish Ardennes[29]. These features are indicated on the geomorphological map of the surrounding area (fig. 18) and are listed in table 2.

In the east, between 95 and 110 m above sea level (fig. 18), the Alden Biesen site has a relatively steep slope section, which is interpreted as the main scarp of the large landslide. The Winterberg hill downslope of this scarp (figs 19-20) is possibly displaced by landsliding. The global southwestward displacement of this hill down to its forested rim, may be roughly estimated at 100-200 m.

The presence of a reverse slope suggests that the block forming the hill is slightly tilted. More downslope, west of the isolated hill the landslide debris is not displaced as a single block, but has flowed resulting in a clear convex, divergent landslide foot slope.

FIG. 18 Geomorphological map indicating the main features of the Alden Biesen landslide. To be compared with hillshade map in figs 16 and 17.

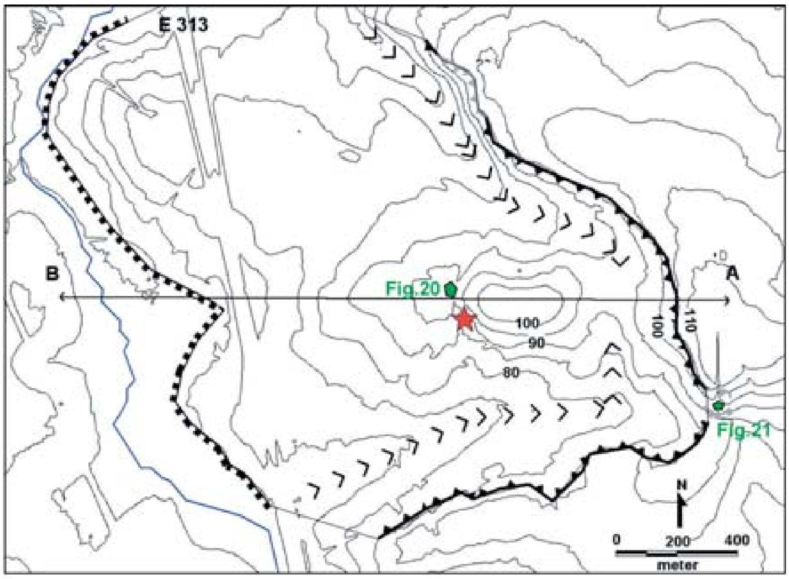

TABLE 2
Features for the presence of a large (deep-seated) landslide in Alden Biesen. Features are selected from Cruden & Varnes 1996 and Van Den Eeckhaut 2006 (After Vandecaveye 2007).

Feature	Explanation	Present
Main scarp	Steep surface at upper edge of landslide caused by downward movement of landslide debris	+
Reverse slope	Typical for rotational slides where the material moves as displaced blocks along a curved failure plane resulting in the formation of a stair-step pattern of which the upper surface is commonly rotated backward. As such, depressions can be created along which water may accumulate to create ponds or swampy areas	+
Bumpy topography	Material displaced by the landslide has a hummocky topography, typical for historical active landslides that were active within the past 50 to 100 years	+
Convex landslide foot (in profile and plan)	Portion of landslide that has moved and overlies original soil surface, generally convex in profile	+
Presence of clays	Sensitive to landsliding (especially when rich in smectite)	+
Presence of other landslides in the vicinity	Proof that the region is susceptible to landsliding.	+
Tilted trees and poles	Typical for historical active landslides that were active within the past 50 to 100 years.	+
Damage to infrastructure	Mainly cracks in walls and roads; typical for historical active landslides that were reactivated within the past 50 to 100 years	+
Displaced river channel	Relocation of river channel caused by downslope movement of landslide debris	+
Drainage pattern	Drainage pattern following the flanks of the landslides (typical for old landslide)	

29 Van Den Eeckhaut *et al.* 2007a; b, c.

The Demer river makes a conspicuous curve around this bulging landform, suggesting that the downslope movement of the landslide caused a displacement of the river channel.

The main scarp and landslide foot delineate the area affected by the presumed Alden Biesen landslide, an area of almost 2.5 km². The main scarp is ca. 1 km wide and the landslide extends over ca. 2 km. The shear plane is possibly located at a depth of 20 m or more below the topographic surface (fig. 21). Apart from the morphological landslide characteristics, table 2 lists other features indicating the existence of a major slide in the Alden Biesen area. Most of these other features were observed during field surveys. Important indications are the presence of (1) hummocky areas, (2) damage (i.e. cracks) to walls (fig. 20) and a clayey lithology that can act as a possible shear plane. Important to note are also the presence of more recent, smaller landslides (e.g. figs. 18 and 21) close to the Alden Biesen site. Although these landslides seem to be younger compared to the larger Alden Biesen landslide, no information is available on the chronology of the landslide events. Hence, we can conclude that the relatively small landslide features observed in the top part of the excavation most probably correspond to smaller piggy-back landslides developed within the larger Alden Biesen landslide unit.

An interesting phenomenon is the occurrence of an unusually thick peat layer unexpectedly occurring in part of the Demer valley south of Rijkhoven, discovered by geotechnical drillings for reconstructing a bridge over the E313 motorway between Rijkhoven and Alt-Hoeselt (GeoDoc 93W0699). The peat deposit is stratified, attaining a thickness of 4.50 m, and is buried under colluvial loamy deposits. Although this event is still under investigation, the ^{14}C age of the middle section of the peat

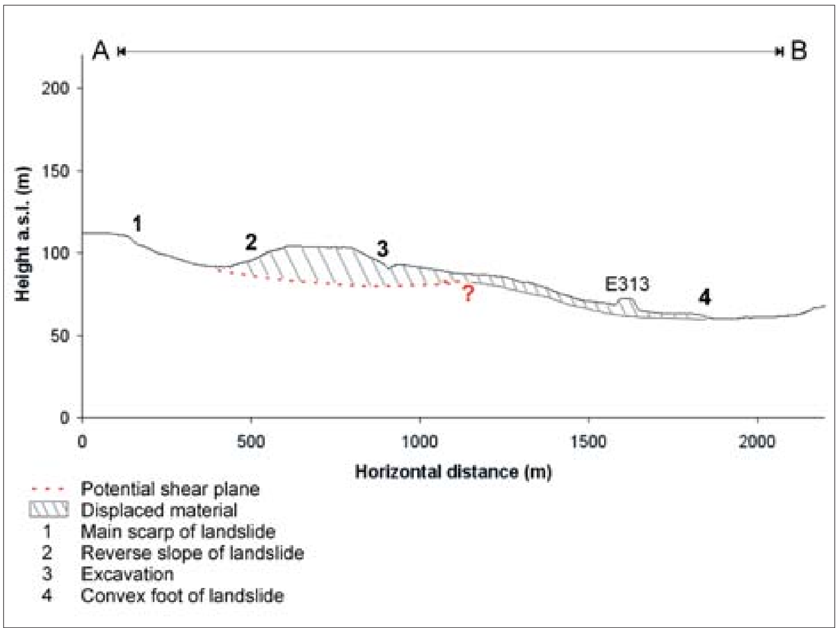

FIG. 19 Cross-sectional profile through A-B (see fig. 20).

FIG. 20 Cracks in a brick wall (Kasteelstraat) near the excavation are possibly caused by the reactivation of the Alden Biesen landslide (see fig. 18 for location; © photo J. Poesen, 2008).

deposit is already established at 3735±35 BP[30]. Its preservation required prolonged high groundwater levels which could have been caused by the presumed Alden Biesen landslide tongue located downstream of the peat. The peat connection which is still under study probably constrains the timing of this landslide to the Holocene.

5.4 Possible trigger mechanism

A possible explanation for the occurrence of larger than usual landslides is the presence of neotectonic faults, displacing the shallow subsurface[31]. Reactivation of one of these normal faults may have triggered surface rupturing and subsequent landsliding. Near the Alden Biesen site two WNW-ESE trending faults affect the Cretaceous strata. One is known as the Hoeselt fault, the other one (originally unnamed but hereby designed as the Alden Biesen fault) may be the northwestern extension of part of a fault bundle affecting the Late Paleozoic, recognized on a seismic line along the Albert canal trench near Kanne[32]. Moreover, about two and a half kilometers to the north of Alden Biesen, at least three faults, known as the Bilzen fault bundle or the 'Haut Démer' faults cut the Cenozoic layers[33] (fig. 22). Here the Oligocene sediments show a cumulative displacement up to 40 m. These faults apparently affect the present morphology (such as the boundary between the Hesbaye and Campine geographical regions), and may have been responsible for the westward deflection of the Demer river, and the presence of rapids in the Meuse river at Borgharen, near Maastricht. Normal fault displacement during the Pleistocene incision of the valleys may have strongly increased the river gradient and triggered erosion upstream

FIG. 21 Surface expression of recent smaller landslide east of the Alden Biesen landslide (see fig. 18 for location; © photo J. Poesen 2008).

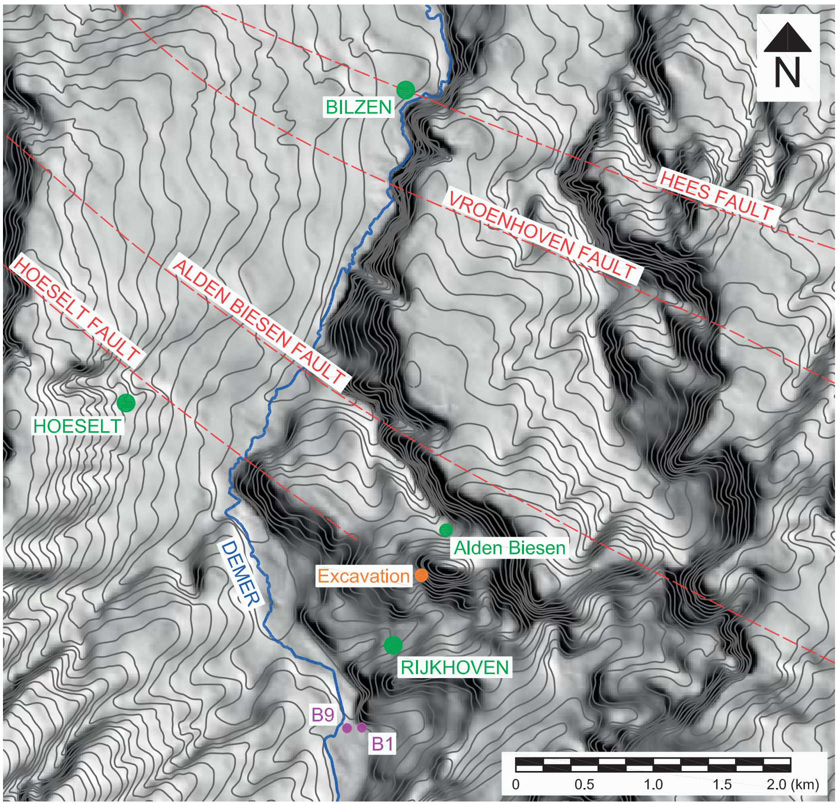

FIG. 22 Hillshade image of the Alden Biesen area with the supposed locations or paths of faults in the subsurface, and position of the geotechnical boreholes.

30 Calibrated ages by radiocarbon dating laboratory of Royal Institute for Cultural Heritage (Brussels): 68.2% probability: 4150BP (43.4%) 4070BP / 4040BP (24.8%) 3990BP 95.4% probability: 4230BP (4.3%) 4200BP / 4160BP (91.1%) 3970BP.

31 Camelbeeck 1993.

32 Dusar & Langenaeker 1992.

33 Van den Broeck & Rutot 1883; Halet 1926; Gulinck 1960; Dusar & Langenaeker 1992; Gullentops & Claes 1997.

of the faults, undercutting the slope near Alden Biesen, possibly exposing the Henis Clay and destabilizing the Winterberg and Alden Biesen historical site. The peat filling of the Demer valley upstream of Alden Biesen, between Rijkhoven and Alt-Hoeselt (filling a 7 m deep scour of the paleovalley, eroded down to the Cretaceous bedrock) may testify of the subsequent development of a barrier to dewatering of the valley, further supporting the landslide hypothesis.

6 Conclusions

The temporary exposure at Rijkhoven offered an exceptional window on the local geology, allowing to elucidate the complex geological history of the Alden Biesen area (Hesbaye, Belgian province of Limburg). The village of Rijkhoven lies within a landslide-sensitive zone. The excavation displayed well preserved superimposed paleosols in the Early Oligocene Neerrepen Sands and some textbook examples of a landslide tongue which affected different Oligocene (Henis Clay, Alden Biesen Sands and Marls, Berg Sand) and Pleistocene deposits. This sliding tongue possibly represents a shallow landslide, piggy-backed on a major rotational landslide, which is inferred from several geomorphological features and the Quaternary Demer valley fill. The total area affected by this presumed Alden Biesen landslide is almost 2.5 km^2. The shear plane is possibly located at a depth of 20 m or more below the surface. The large landslide may have been triggered by reactivation of tectonic faults influencing valley incision and was subsequently affected by a series of smaller slides. These events resulted in anomalous geological contacts and an irregular surface topography. Generally such phenomena are interpreted as signs of human activity but thus may be of natural origin, depending on the suitability of the geological substrate for surficial deformation.

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Predicting landslide susceptibility for areas with archaeological sites in residential regions: a case study from the Flemish Ardennes

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Abstract

Landslides represent one of the most dangerous gravity-induced surface processes, causing damage to buildings, roads and infrastructure, but also to archaeological sites. Due to the limited spatial occurrence of landslides in Flanders (mainly reported and studied in the Flemish Ardennes) archaeologists, aware of soil erosion and sediment deposition caused by water, wind or tillage, tend to forget this hillslope process. During the last decade, landslides were studied in the Flemish Ardennes. So far most attention was paid to the spatial occurrence of past and future landslides. A landslide inventory map showing the location of 210 old and recent landslides has been produced. The application of statistical (logistic regression) modelling furthermore resulted in a landslide susceptibility map showing the propensity of an area to generate future landslides, classified in zones with very high, high, moderate and low susceptibility. The main objective of the current paper is to assess the impact of landslides on archaeological sites in the mapped region, the Flemish Ardennes. When this impact is assessed as being significant, this slope process has to be taken into account when studying site taphonomy or assessing site preservation potential.

An overlay of the landslide inventory and landslide susceptibility maps with the Central Archaeological Inventory, showed however that currently no known archaeological sites are directly threatened by landsliding. This absence of archaeological sites on landslide susceptible hillslopes might indicate that in prehistorical and historical times humans were more familiar with local environmental characteristics and avoided unstable hillslopes. The confrontation of the landslide inventory with topographic maps (i.e. 1777-2001) on the contrary indicate that during the past 250 years buildings and infrastructural works have been constructed within old landslides. This human activity on these unstable hillslopes increases the risk for future landslides.

Keywords

Landslide susceptibility, Central Archaeological Inventory, Ferraris map, Popp map, topographical map, Flemish Ardennes, geovalues

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1 Introduction

Landslides, or the perceptible downslope movement of a mass of rock, debris or earth down a slope[6], constitutes one of the major natural processes threatening human life and property[7]. Mapping areas prone to landsliding and assessing the risk to buildings and infrastructure are therefore essential for land use planning and -management in hilly or mountainous regions[8]. A 'landslide hazard map' shows the propensity to generate a landslide of given intensity, in a defined area, during a given period of time[9]. Because the intensity and timing of slope failures are difficult to predict, 'landslide susceptibility maps' showing only the spatial distribution of the actual and potential slope failures are more commonly produced[10]. 'Elements at risk' in a given area include population, properties, economic activities and public services[11], while 'vulnerability' represents the degree of loss of these elements as a consequence of slope failure[12]. Although archaeological heritage values are generally not mentioned as elements at risk, many case-studies report damage and threats to archaeological sites through landsliding[13]. Other studies report recent anthropogenic interventions contributing to landslide reactivation near and within archaeological sites[14].

For the Flemish Ardennes, Flanders' region most prone to landsliding, it is not known whether archaeological sites are damaged or threatened by slope instability. Most of the time archaeologists predominantly consider other slope processes such as soil erosion and sediment deposition by water, wind or tillage when assessing the preservation potential of and threats to archaeological sites[15]. Given the widespread occurrence and density of archaeological finds in Flanders[16] it is likely that within the Flemish Ardennes archaeological sites are threatened or already damaged by landslides. However, it can be hypothesised that people in prehistoric and historic times had a better understanding of their environment, including knowledge on the presence of old landslides and inherently unstable hillslopes, and avoided these sites for settlement. According to this hypothesis the occurrence of archaeological sites in landslide areas should be relatively limited. Recent landslide events (e.g. fig. 1)[17] on the other hand show that currently landowners and land use planners pay less attention to local slope stability when planning and carrying out construction works, because they are not aware of the presence of landslides, or because they believe that current building practices allow construction of buildings and infrastructure on inherently unstable sites. If these indications are true, human occupancy in landslide susceptible areas is increasing in the Flemish Ardennes, a phenomenon which was also reported for e.g. Cairns (Australia)[18] and the Urseren Valley (Switzerland)[19].

This study deals with two research questions distilled from the abovementioned hypotheses: (1) is the archaeological heritage in the Flemish Ardennes threatened or damaged by landslides, and how important is this threat? And (2): are humans currently indeed less familiar with the local environment, and are they increasing landslide risk by constructing buildings and infrastructure within old landslides? The first research question is more important for archaeology and heritage management as its answer will contribute both to the taphonomic study of archaeological sites and to the assessment of their preservation potential.

2 Study area and landslide inventory

The study area is the so called Flemish Ardennes, a 710 km^2 hilly region in the south-eastern part of Flanders, Belgium (fig. 2). In this area Tertiary lithology consists of alternations of sands and less permeable smectite-rich clays. Slope gradients are generally (i.e. in 95.7% of the area) below 0.10 $m.m^{-1}$. The regional landslide inventory map (fig. 2) shows the location of 210 landslides, and was obtained through detailed field mapping aided by the visual analysis of LIDAR-derived (Light Detection and Ranging) hillshade and contour line maps (fig. 3; Van Den Eeckhaut *et al.* 2007b). 77.6% (n=163) of the observed landslides are deep-seated (estimated shear surface deeper than 3m below the current surface), are larger than 1 ha (averaging ca. 4 ha), are old (before 1900[20]), and are classified in the inventory map as rotational earth slides (e.g. fig. 1: A-C, 3)[21]. Shallow landslides (estimated shear surface less than 3m below the current surface) represent 22.3% (n=47) of the total, with areas less than 1 ha (averaging 0.5 ha). They are classified chiefly as rotational slides with a flow component at the toe. Many of the shallow failures occurred inside pre-existing deep-seated landslides.

3 Landslide susceptibility map and triggering factors

Understanding the role of individual factors controlling landslide locations and geographical patterning is important to predict 'where' landslides can occur in the future, thus to assess 'landslide susceptibility'[22]. For establishing landslide susceptibility in large areas logistic regression is nowadays a widely used statistical modelling technique[23]. We adopted a specific type of logistic regression, i.e. Rare Events Logistic Regression[24] that accounts for the low spatial occurrence of landslides in the study area[25]. The technique was applied to find the best-fitting model for describing the relationship between the dependent variable (i.e. the presence or absence of

6 Cruden 1991.
7 Varnes & IAEG 1984; Guzzetti *et al.* 1999.
8 Dai & Lee 2003.
9 Guzzetti *et al.* 1999.
10 Brabb 1984.
11 van Westen *et al.* 1993.
12 van Westen *et al.* 1993.
13 e.g. Bromhead *et al.* 1994; Canuti *et al.* 2000; Rohn *et al.* 2005; Cherkez *et al.* 2006; Coppola *et al.* 2006.
14 e.g. Lazzari *et al.* 2006.
15 For example Vanmontfort *et al.* 2006.
16 e.g. De Loë 1931; 1937; 1939; Meganck *et al.* 2002; Meylemans 2004.
17 Van Den Eeckhaut *et al.* 2007a.
18 Leiba *et al.* 1999.
19 Meusburger & Alewell 2008.
20 Van Den Eeckhaut *et al.* 2007c.
21 Van Den Eeckhaut *et al.* 2010.
22 Varnes & IAEG 1984; Soeters & van Westen 1996; Guzzetti *et al.* 1999; 2005.
23 e.g. Carrara *et al.* 1995; Atkinson & Massari 1998; Begueria & Lorente 1999; Vanacker *et al.* 2003; Lee 2007.
24 King & Zeng 2001.
25 Van Den Eeckhaut *et al.* 2006; 2010.

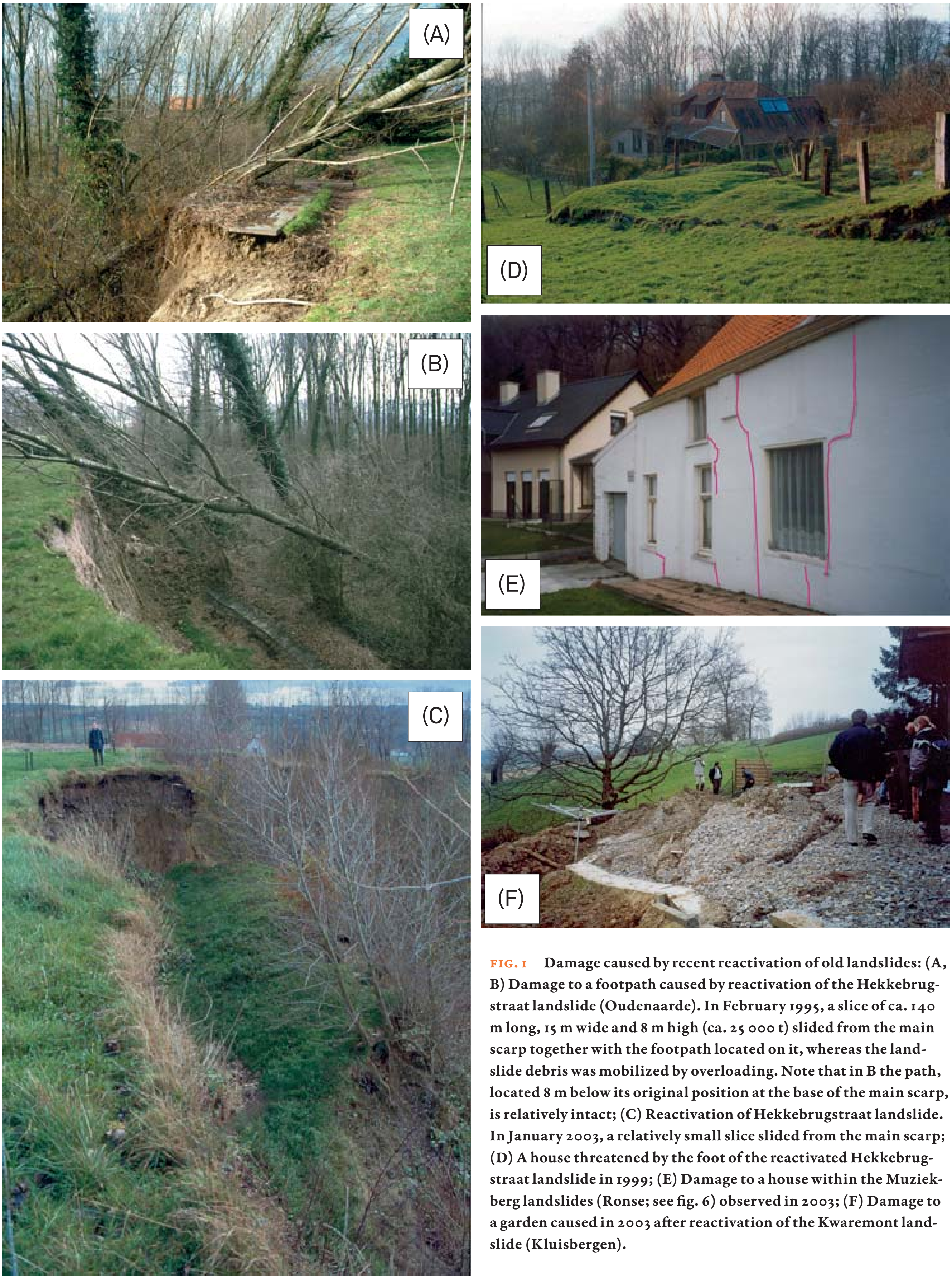


FIG. 1 Damage caused by recent reactivation of old landslides: (A, B) Damage to a footpath caused by reactivation of the Hekkebrugstraat landslide (Oudenaarde). In February 1995, a slice of ca. 140 m long, 15 m wide and 8 m high (ca. 25 000 t) slided from the main scarp together with the footpath located on it, whereas the landslide debris was mobilized by overloading. Note that in B the path, located 8 m below its original position at the base of the main scarp, is relatively intact; (C) Reactivation of Hekkebrugstraat landslide. In January 2003, a relatively small slice slided from the main scarp; (D) A house threatened by the foot of the reactivated Hekkebrugstraat landslide in 1999; (E) Damage to a house within the Muziekberg landslides (Ronse; see fig. 6) observed in 2003; (F) Damage to a garden caused in 2003 after reactivation of the Kwaremont landslide (Kluisbergen).

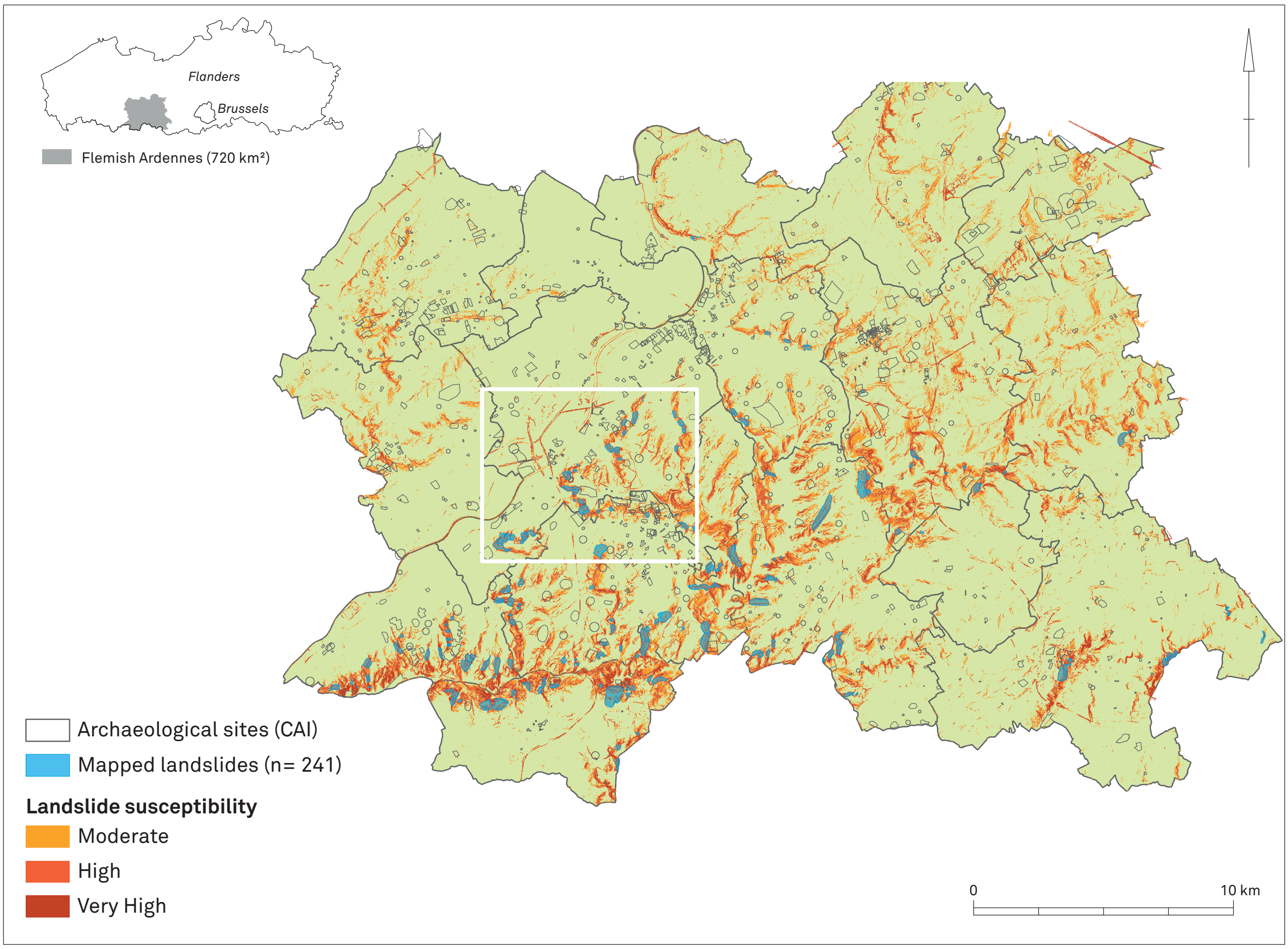
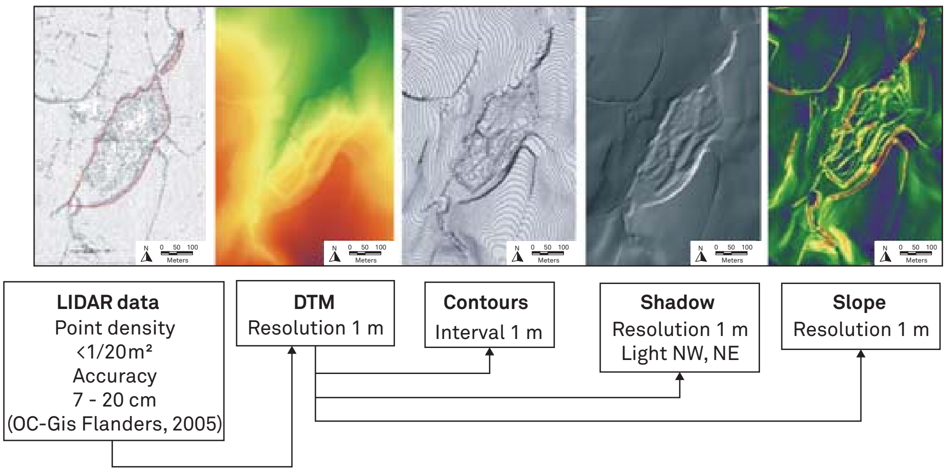


FIG. 2 The Flemish Ardennes: location in Belgium, and classified landslide susceptibility map. The landslide inventory showing a higher concentration of landslides south of the Scheldt and the archaeological sites (CAI 2008) are overlaying the susceptibility map. White rectangle shows excerpt shown in fig. 4A.

FIG. 3 Production of derivative maps from topographical data obtained with Light Detection and Ranging (LIDAR). Excerpt shows digital terrain model (DTM), contour line map, hillslope map and slope map of an old rotational slide with fresh morphological characteristics (i.e. main scarp, reverse slopes, hummocky topography) currently located under forest.



landslide depletion areas) and a set of independent variables (i.e. terrain height, slope gradient, aspect, plan and profile curvature, Tertiary geology, soil drainage, distance to rivers and distance to faults).

Several models including different combinations of independent variables were evaluated with the same evaluation parameters as explained in Van Den Eeckhaut *et al.* (2006, e.g. Area under Receiver Operating Characteristic Curve and other parameters calculated from confusion matrices). The best landslide susceptibility model is the one correctly classifying the largest number of mapped landslide grid cells as susceptible without incorrectly classifying a large number of landslide-free grid cells as susceptible. This model can be written as[26]:

$$log\left(\frac{\hat{p}}{1-\hat{p}}\right) = -13.418$$

$$+ (0.386 \times \text{slope gradient})$$

$$+ (2.520 \times NW) + (2.948 \times W) + (2.043 \times SW) + (2.399 \times S) + (1.653 \times SE)$$

$$+ (2.337 \times GeVl) + (2.407 \times GeMe) + (1.488 \times Tt) + (1.381 \times KoAa) \quad (1)$$

where $\hat{p}$ is a value between 0 and 1 reflecting the probability of occurrence of a landslide depletion (initiation) area, and is assigned by the model to every grid cell in the study area. Hillslopes with

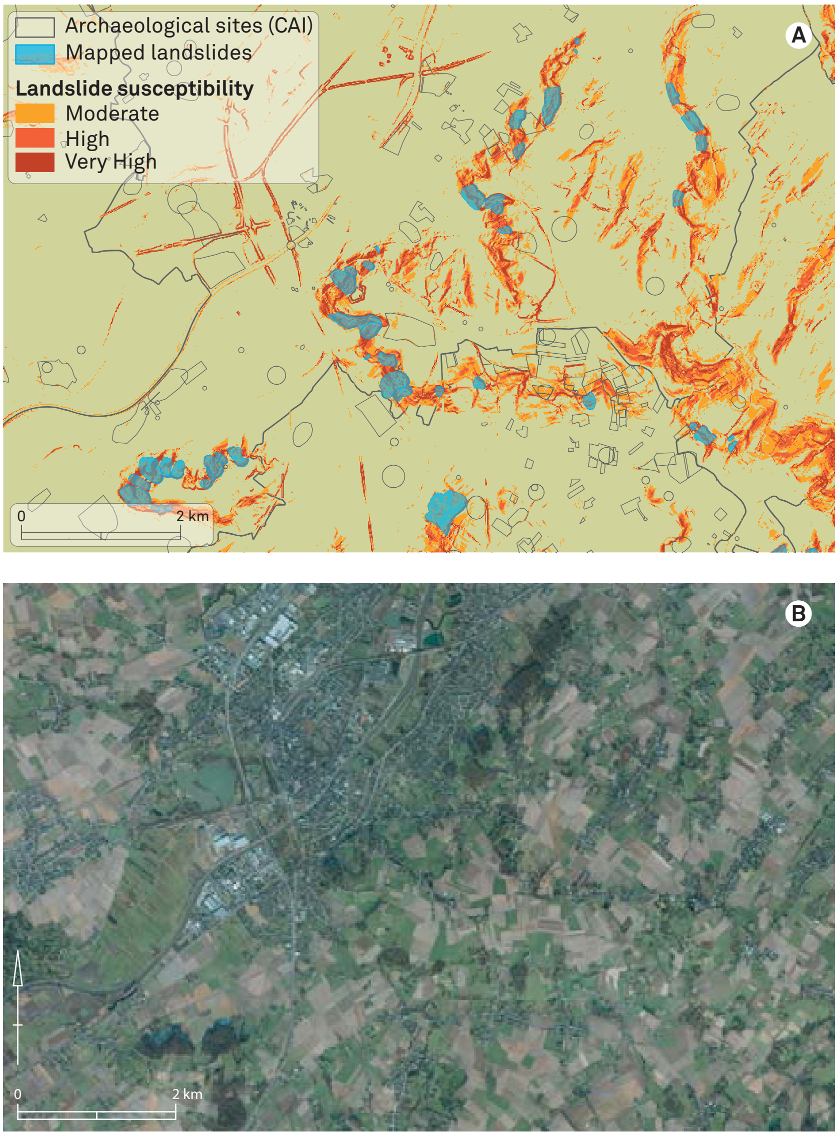


FIG. 4 Excerpt (south of Oudenaarde) taken within the Flemish Ardennes (see fig. 2 for location in study area). Overlay of landslide inventory and archaeological sites (CAI 2008) on: (A) the classified landslide susceptibility map. Whereas landslides are located within areas with very high to moderate landslide susceptibility, archaeological sites are mainly recorded outside mapped landslides, in areas with low susceptibility. White rectangle in fig. 2 shows excerpt shown in B; (B) the orthophoto of 2002 (AGIV 2002). The landslide inventory contains almost no archaeological sites on the forested or grassed landslide-affected hillslopes. Instead archaeological findings are mainly reported on cropland and pasture with relatively low slope gradients.

26 Van Den Eeckhaut *et al.* 2010.

a slope gradient above 0.10 $m.m^{-1}$, a southeast to northwest orientation, and where a lithology rich in swelling clay (i.e. GeVl, GeMe, Tt, KoAa) is located at relatively shallow depths are classified with very high, high or moderate susceptibility (fig. 2, 4: A). Sediment accumulation zones originating from landslides are more difficult to delineate by this model, as the landslide debris is sometimes deposited on slope sections with a low (< 0.05 $m.m^{-1}$) slope gradient. The high correspondence between the mapped landslides and the zones with very high, high and moderate landslide susceptibility proofs that a classified landslide susceptibility map produced from Equation 1 is capable of delineating inherent unstable hillslope sections, where landslides can be expected to occur in the future.

Hillslope gradient, aspect and lithology are thus the important factors 'controlling' the spatial patterns of landslides. To initiate or reactivate landslides a 'triggering' factor bringing the slope from a marginally stable to an unstable state is needed[27]. It is often not possible to define the most important landslide triggering factor[28]. In the Flemish Ardennes, anthropogenic interventions generally cause a temporal or permanent reduction of slope stability. These interventions are mainly overloading of the depletion area, for e.g. construction of buildings and other infrastructure, removal of hillslope material (i.e. lateral support) for construction works, poor drainage due to insufficient sewerage systems, obstruction of springs, and increased surface runoff from the upslope drainage area towards the main scarp[29]. In some cases such interventions alone triggered the failure. More often however, a hydrological threshold needs to be exceeded to bring the hillslope from a marginally stable state to an unstable state, and to initiate failure. In the Flemish Ardennes landslide events were generally reported to occur after a month with more than 100 mm rainfall and after twelve months with more than 1000 mm cumulative rainfall[30].

4 Materials and methods

4.1 Influence of landslides on settlements: Palaeolithic-1800

In a first study we focus on the influence of slope instability on the location of archaeological sites. For this, the landslide inventory and landslide susceptibility map (fig. 2) were confronted with the location of reported archaeological sites in the study area (fig. 2). This approach is similar to the one used by Lollino & Audisio (2006) to assess the risk of cultural heritage included in the UNESCO World Heritage List to landsliding in Italy. For our study the archaeological data is obtained from the Central Archaeological Inventory[31], a relational database with a vector map indicating the location of archaeological finds. The database includes information on the location (with indications of accuracy; i.e. up to 15 m, up to 150 m and up to 250 m), reported archaeological structures, age, interpretation, events (for example fieldwalking, excavation…), and bibliographic and other references. The Central Archaeological Inventory is mainly designed for heritage management purposes and includes more than 22 000 archaeological findspots (from the Palaeolithic to 1800 AD) for the whole of Flanders. Archaeological information from a wide variety of sources is included, differing in nature, quality and precision[32]. However, the database is currently the best available archaeological inventory for the study area.

4.2 Influence of landslides on settlements: 1771-2002

The second study addresses the more recent (i.e. 1771-2002) human activity on landslide-affected hillslopes[33]. More specifically, for two municipalities in the Flemish Ardennes (i.e. Ronse and Maarkedal), the landslide inventory was confronted with historical maps. Buildings located inside mapped landslides (n=59) were digitized from georeferenced scans of:
(1) the Ferraris map (i.e. *Carte-de-Cabinet de Pays-Bas Autrichien* 1771-1778; 1:18 500);
(2) the so called 'Popp map', a cadastral atlas of the Belgian municipalities (i.e. *Atlas cadastral parcellaire de la Belgique publié avec l'autorisation du Gouvernement sous les auspices de Monsieur le Ministre des Finances*, ca. 1860: 1:1 250, 1:2 500 or 1:5 000);
(3) the topographical maps of 1951-1959 (sheet 30/1-2 of 1951 (NGI 1957; 1:15 000), sheet 30/5-6 of 1951 (NGI 1956; 1:15 000), sheet 29/3-4 of 1959 (NGI 1964; 1:15 000) and sheet 29/7-8 of 1958 (NGI 1964; 1:15 000); and
(4) the digital topographical map of 2002 (NGI 2002; 1:10 000).

Without going into detail it is important to take into account the possible errors and their influence on the results obtained, such as map errors either related to the planimetric accuracy of the original historical maps (e.g. degree of rotation, shrinkage and stretching), or resulting from scanning and georeferencing of the maps. These errors are mainly present in the data extracted from the Ferraris map. The second type of error deals with the digitizing of the buildings, more specifically with the fact that some nearly contiguous buildings (e.g. farms and stables) are mapped as one building on one of the historical maps and as several separate buildings on another historical map. These two types of errors are not expected to influence the overall results obtained. Overall, the influence of the map errors is limited. This was evaluated by comparing the relative position of buildings with regard to roads and field boundaries, during the digitizing of these buildings inside mapped landslides. This means that even if the overlay of the mapped landslides and the georeferenced historical map showed that a building on the historical map was located inside (outside) a mapped landslide, the person analysing the data can have decided to exclude (include) the building because the building is only located inside (outside) the landslide due to low planimetric accuracy of the historical map. Errors related to differences in representation of nearly contiguous buildings are limited by accounting these buildings as consistently as possible on the four historical maps.

27 Glade & Crozier 2005.
28 Popescu 2002.
29 Van Den Eeckhaut *et al.* 2007a.
30 Van Den Eeckhaut 2006.
31 Meylemans 2004; Van Daele *et al.* 2004, CAI 2008.
32 Van Daele *et al.* 2004.
33 Van Den Eeckhaut *et al.* 2010.

5 Results

5.1 Influence of landslides on settlements: Palaeolithic-1800

The confrontation of the landslide inventory and landslide susceptibility map with all archaeological observations in the Flemish Ardennes (e.g. fig. 2; 4: A) confirms that there is indeed a very limited presence of prehistoric settlements or stray finds on landslide-affected or landslide susceptible hillslopes. Slope sections already affected by or susceptible to old landslides are often located under forest or pasture. As already mentioned these sites are found on slope sections with an average slope gradient above 0.10 $m.m^{-1}$. Archaeological findings, on the other hand, are predominantly reported on sites currently located under cropland or pasture and with a relatively low slope gradient (i.e. plateaus and valley floors). This limited presence of archaeological findings within landslide susceptible sites makes a study of possible diachronic variation useless.

However, care should be taken when interpreting the absence of (pre)historical settlements on unstable hillslopes. This absence might also reflect (i) that archaeological findings have been removed or covered with debris after landsliding or through erosion and sediment deposition, or (ii) that so far archaeological surveys have focussed on the cropped loess plateaus and not on the landslide susceptible hillslopes that are often located under forest. Overall however, our results reinforce our hypothesis, i.e. that people in prehistoric and historic times were acquainted with local natural hazards such as landslide susceptible areas.

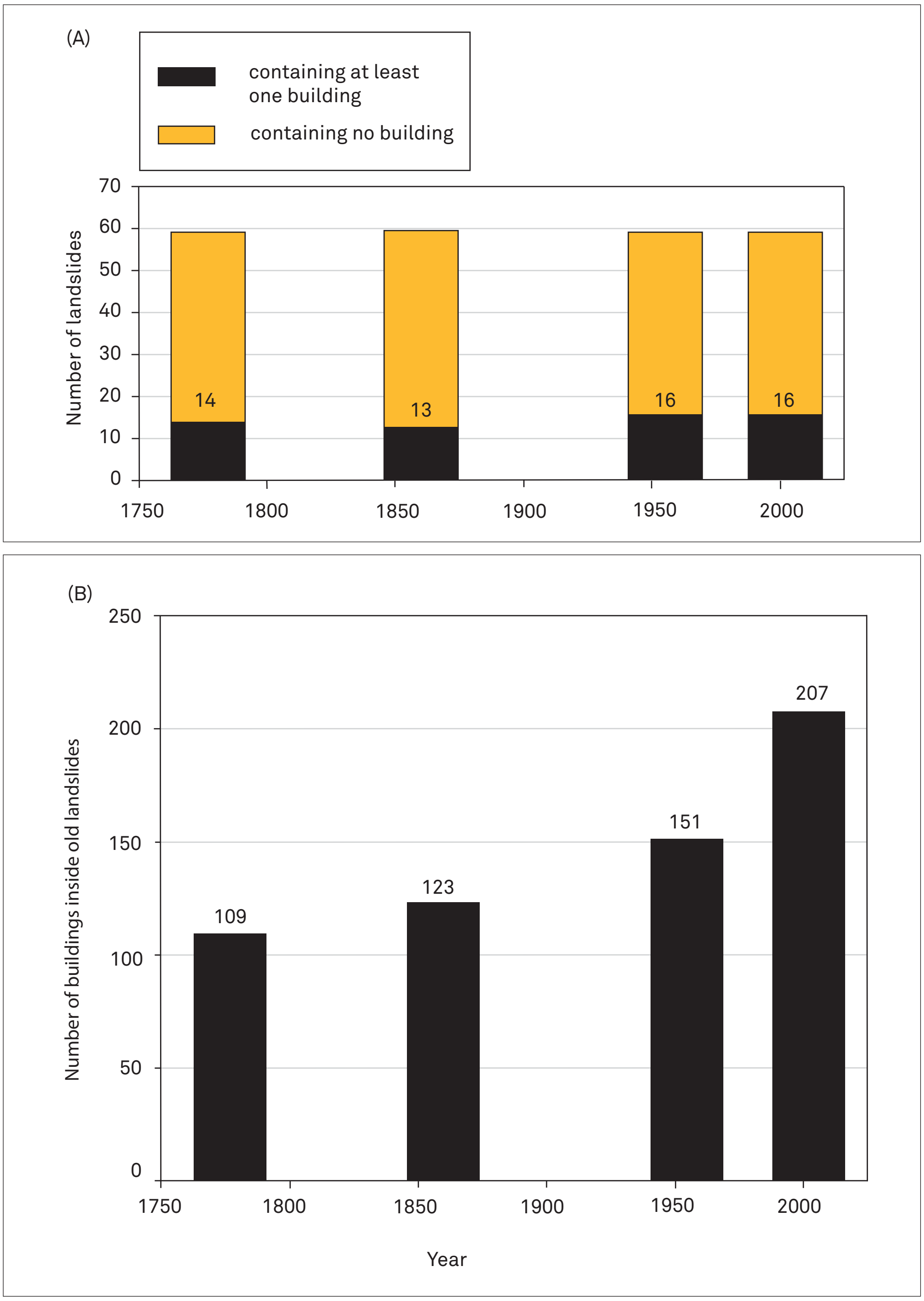


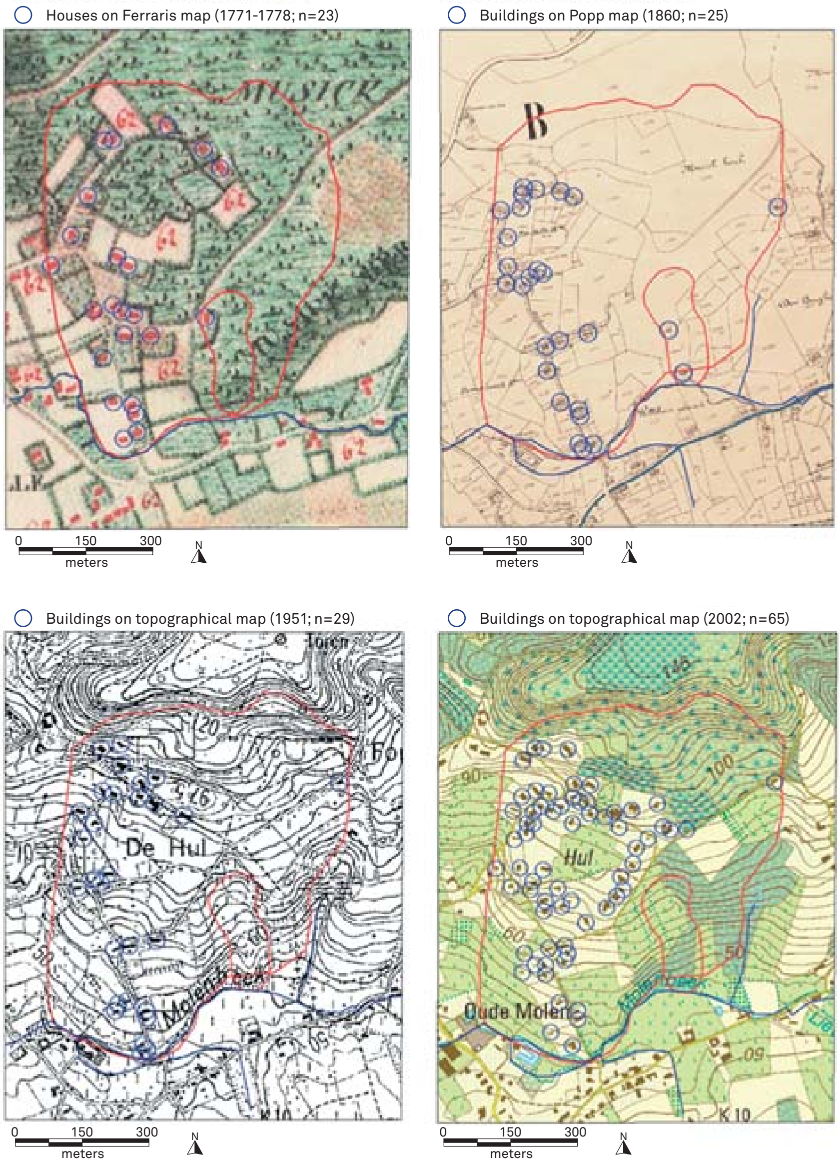
FIG. 5 **(A) Evolution of the number of old landslides containing at least one building in Ronse and Maarkedal. The total number of old landslides is 59; and (B) Evolution of the number of buildings within old landslides in Ronse and Maarkedal. Buildings are mapped from the Ferraris map (1771-1778), the Popp map (ca. 1860) and the topographical maps of ca. 1950 (1951-1959) and 2002.**

However, more archaeological surveys on hillslopes are required to draw final conclusions. When compiling the Central Archaeological Inventory Meylemans (2004) already concluded that the database reveals a large amount of archaeological survey bias. Our overlay of the archaeological inventory on a land use map (e.g. excerpt of orthophoto in fig. 4) suggests that, due to low visibility, archaeological surveys within forests are limited and often even absent.

5.2 Influence of landslides on settlements: 1771-2002

The number of old landslides in which buildings were constructed increased from 14 of 59 mapped landslides around 1777, to 16 of 59 mapped landslides around 2002 (fig. 5A). However, the increase in the number of houses within these landslides, from 109 buildings around 1777 to 207 around 2002 (fig. 5B), was much more important. New buildings on landslide-affected sites were mainly constructed during the last five decades investigated in the analysis. This increase in buildings in the second half of the 20th century differs from landslide to landslide. With an affected area of 42 ha this is the largest old landslide of the Flemish Ardennes. Whereas the Ferraris map, the Popp map and the topographical map of 1958 show the location of respectively 23, 25 and 29 buildings, the recent topographical map of 2002 shows the location of 65 buildings within this landslide (fig. 6). It is quite surprising that many landowners were not aware of the presence of this landslide when constructing their house on this site, because the landslide-affected hilslope shows (i) morphological characteristics typical of landslides (i.e. main scarp, reverse slope, landslide foot), (ii) the displacement of the river channel downslope of the landslide foot by landslide debris, (iii) a more recent (1926) landslide reactivation and (iv) several buildings with cracks and other damage caused by landsliding (e.g. fig. 1: E). The evolution of buildings was less spectacular within the *Waardebroeken* landslide (fig. 7), possibly caused by the more remote location of this site. On the *Muziekberg* landslide the development of a residential area was instigated by the vicinity of the city of Ronse and by the scenic view on the Rone valley. The large size of the landslide and the unawareness of the land use planners and landowners might have hampered the identification of the landslide.

FIG. 6 Evolution of the number of buildings within the Muziekberg landslide (Ronse) during the period 1777-2002.



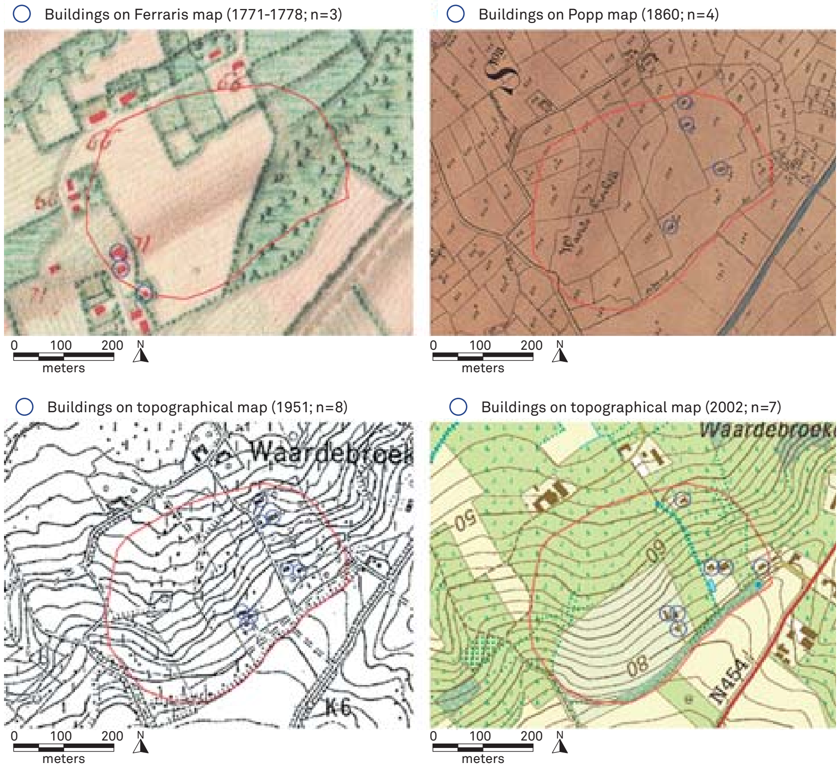


FIG. 7 Evolution of the number of buildings within the Waardebroeken landslide (Maarkedal) during the period 1777-2002. In contrast to the evolution within the Muziekberg landslide (fig. 6) no increase in the number of buildings was observed between 1958 and 2002.

6 Conclusions

This study shows that in the Flemish Ardennes landsliding is an important degradation process, with 210 landslides inventoried and mapped. We first focussed on the natural controlling factors of landsliding. By applying a logistic regression model we found that hillslope sections with a slope above 0.10 $m.m^{-1}$ and with clay lithology at relatively shallow depth are most susceptible to landsliding. These hillslope sections are classified as very high, high and moderate susceptible on the landslide susceptibility map. Confrontation of this susceptibility map with an inventory of archaeological sites (Palaeolithic-1800) and with buildings mapped from historical maps (1777-2002) shows that only a limited number of archaeological sites coincide with landslides but that since 1777, and especially since the 1950s, an important increase in the number of buildings was observed. These results confirm our hypothesis that human occupancy on landslide susceptible sites is indeed increasing. As the increase of new buildings within landslides is neither due to a lack of construction sites in areas without landslide risk, nor to significant price differences between building grounds on landslide free and landslide-affected sites, this case study indicates that despite scientific progress in geomorphic hazards made over the last decades, humans have a decreasing understanding of the physical hazards in their environments.

The availability of the landslide susceptibility map allows qualified authorities to link specific land use regulations to the susceptibility zones and to delineate zones where human interventions reducing slope stability should be limited. The strategy of avoidance should be followed where possible, and for the prevention of landslides and landslide-related damage a 'landslide test', checking whether a planned intervention can initiate or reactivate landslides causing damage to the planned or to existing infrastructure, could be developed. Persons living on landslides should take remedial measures, such as the installation of well-maintained drainage systems, to increase slope stability.

For archaeologists the landslide inventory and landslide susceptibility map might seem less important as an evaluation and a management tool. The number of known archaeological sites on landslide susceptible sites is low. Hence, no special conservation measures are urgently required. Important, however, is that this study has brought to light that there might be a lack of detailed archaeological surveys on forested hillslopes which often coincide with old landslides in the study area. Hence, our conclusions on the familiarity of prehistoric and historic people with their environment are only preliminary, and need to be strengthened with further archaeological research.

Acknowledgements

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Preservation and prospection of alluvial archaeological remains: a case study from the Trent Valley, UK

Keith Challis[1] & Andy J. Howard[2]

Abstract

Since the early 1970s, the archaeological record of the Trent Valley has been the focus of intensive research and is now arguably one of the most comprehensively studied river valleys in Europe. In contrast to other temperate lowland river systems, which have remained relatively stable throughout the Holocene and deposited thick sequences of fine-grained alluvium, the Trent has been highly dynamic and mobile, migrating back and forth across its valley floor. This has led to the burial of a range of cultural archaeological remains within coarse-grained sands and gravels as well as within and beneath finer-grained alluvium. The abandonment of numerous palaeochannels has also led to the preservation of organic sediments capable of providing proxy records of climate, vegetation and land-use. Determining the location (prospection), preservation potential and effectively managing the archaeological resource of the Trent Valley has required the development of a detailed understanding of its geomorphological history. Since 2001, funding from UK central government (via the Aggregates Levy Sustainability Fund) has allowed the development of a co-ordinated series of research projects that seek to unravel the geoarchaeological record of the Trent Valley further. This paper describes the findings of some this work and outlines the newer approaches we have used to provide an expanded toolkit for geoprospection.

Keywords

Geoarchaeology, Remote sensing, LIDAR, Landscape modelling

1 Introduction

For nearly a century archaeological prospection has demonstrated both the significant quality and quantity of post-glacial (Holocene) archaeological remains preserved upon and buried within British river valleys[3]. However, until the very last decade of the 20th Century, these alluvial archaeological records were characterized by zones of dense activity often associated with gravel islands, and archaeologically blank areas, often where fine grained alluvium covered these valley floors. By taking a geomorphological approach it has become apparent that an understanding of landform assemblages and valley floor evolution is essential to elucidate archaeological visibility, spatial patterning and preservation potential of the record[4]. However, understanding the 4-Dimensional Holocene stratigraphy (i.e. 3-D sedimentary architecture within a time framework[5]) required a step change in methodological approaches to geoprospection, which until the end of the 20th century had been based largely on aerial photographic analysis and fieldwalking followed by trial trenching and the limited use of geophysics (primarily resistivity and magnetometry[6]). In England, this need for methodological development coincided in 2001 with the start of a major national government funding initiative, the Aggregates Levy Sustainability Fund (ALSF), which amongst its many aims, sought to improve research and knowledge transfer surrounding archaeological geoprospection in aggregate bearing landscapes (see http://www.english-heritage.org.uk/server/show/nav.1315). With funding from the Aggregates Levy and working under the auspices of Trent Valley GeoArchaeology (www.tvg.org.uk), a range of developing non-invasive aerial and ground based remote sensing technologies have been tested and linked with new approaches to subsurface investigation as well as more traditional methodologies to provide a toolkit approach for geoprospection[7]. This paper describes the newer elements of this toolkit by reference to examples of work in the Trent Valley, UK.

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3 Needham & Macklin 1992; Howard *et al.* (eds) 2003.

4 Howard & Macklin 1999; Passmore *et al.* 2006.

5 See Brown 2008.

6 Gaffney & Gater 2003.

7 Carey *et al.* 2006; Howard *et al.* 2008.

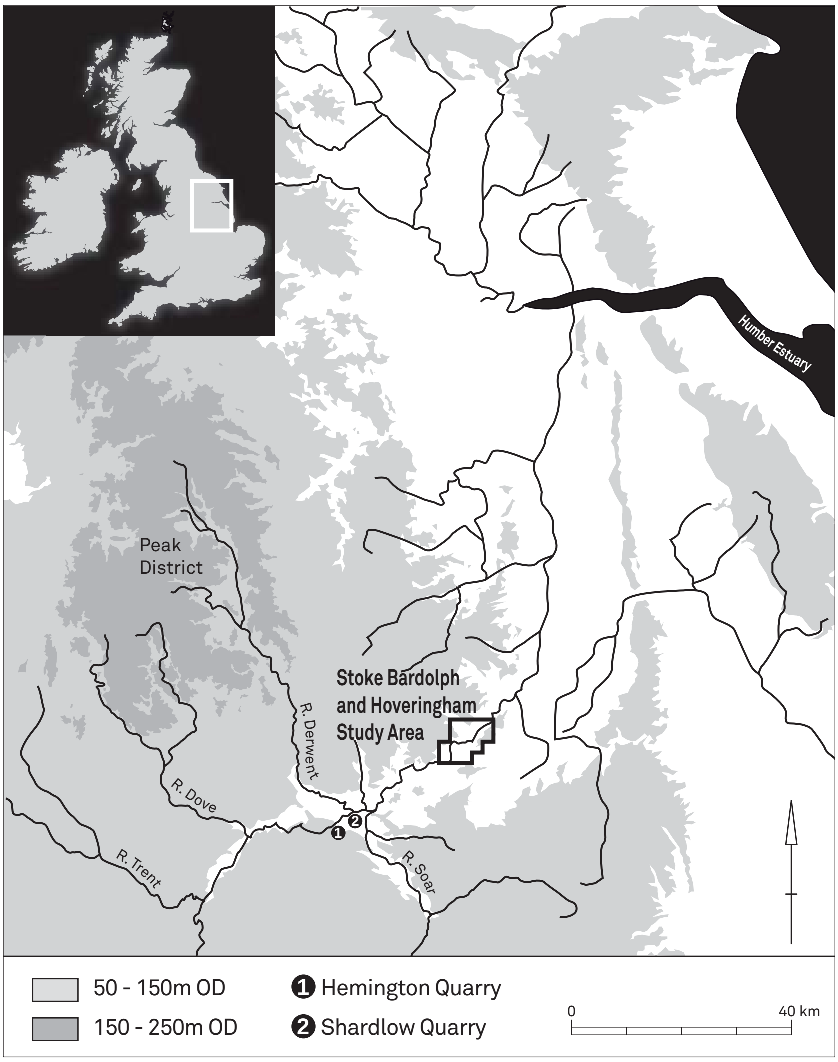
2 The Trent Valley

The Trent is one of the main arterial rivers of Britain rising on the Staffordshire Moorlands of the Peak District (fig. 1) and flowing a distance of approximately 210 km to the Humber Estuary[8]. It is also one of Britain's major aggregate producing landscapes and includes the potential for Palaeolithic archaeological evidence extending back to the end of the Anglian glaciation (MIS 12)[9]. In contrast to other lowland river systems in midland and southern Britain, which have developed largely through vertical accretion in a stable river corridor during the Holocene[10], the Trent has been highly mobile, reworking large tracts of sand and gravel that were initially deposited during the Late Pleistocene across the valley floor[11]. This high mobility reflects the response of the river, particularly in its middle reaches, to higher magnitude floods associated with waters entering the main trunk channel from tributaries (the Dove and Derwent) draining the nearby uplands of the Peak District[12]. The reworked sands and gravels of Holocene age are defined by the British Geological Survey as a mappable terrace unit called the Hemington Sand and Gravel[13].

Evidence for occupation on the gravel terraces and islands that rise about the contemporary valley floor is diverse and ranges from major cropmark complexes indicative of farming and settlement[14] to those of ring ditches, henges and cursus monuments indicative of later prehistoric ritual and funerary activity[15]. Artefactual evidence collected from the terrace surfaces through fieldwalking also provides a significant corpus of information[16].

However, in contrast to other lowland valley floors, as a result of the significant lateral migration of the river, the Trent Valley is notable for both the quality and quantity of archaeological evidence recovered from Holocene alluvial contexts. This point is well illustrated by data from the quarries of the middle Trent around Long

FIG. 1 The River Trent, its main tributaries and places mentioned in the text.



8 Ward 1981.
9 Howard *et al.* 2007; White *et al.* 2008.
10 Brown *et al.* 1994.
11 Large & Petts 1996; Howard 2005.
12 Brown 1998.
13 Brandon 1996.
14 Whimster 1989; Frere & St Joseph 1983; Pickering & Hartley 1985.
15 Pickering & Hartley 1985; Loveday 2004.
16 Garton 2002.

Eaton. For example, individual remains recovered from the now exhausted Hemington Quarry (fig. 1) include Neolithic to Medieval fish-weirs, eel baskets and associated fishing related artefacts; larger structures include a Medieval mill-dam and probable mill race, three Medieval bridges, and a large fixed engine fishing platform, also of Medieval date[17]. At nearby Shardlow Quarry, two Bronze Age log boats have also been recorded[18], as well as several clusters of Bronze Age metalwork in this same approximate area[19].

In addition to the cultural evidence, the numerous palaeochannels mapped across the valley floor[20] contain significant organic sediments capable of providing high-resolution records of climate, vegetation and land-use[21].

3 Approaches to prospection and interpretation

The significant thicknesses of fine grained alluvium in addition to the burial of archaeology within these valley floor sands and gravels provide significant problems for archaeological prospection using the traditional approaches such as aerial photography and fieldwalking. To overcome these problems, a number of new techniques have been tested and evaluated. In terms of non-invasive airborne remote sensing, the use of vertical and oblique aerial photography for the identification of features and landform assemblages[22] has been augmented by the use of LIDAR[23] and multi-spectral imagery[24]. On the ground, geophysical prospection has concentrated on the use of Ground Penetrating Radar (GPR) and Electrical Resistivity (ER; also known as Electrical Resistivity Ground Imaging [ERGI]), whilst systematic auger survey has been used to record the subsurface stratigraphy, which is subsequently modelled with the pseudo 3-D environment of ArcGIS[25].

3.1 LIDAR

Airborne LIDAR provides access to high resolution, high accuracy terrain information and as a secondary output a laser "image" of the land surface derived from measurements of the intensity of reflection of each backscattered laser pulse. A detailed description of LIDAR is provided in Wehr & Lohr (1999). Archaeological applications of LIDAR have focused largely on its ability to provide a high resolution record of terrain variation, allowing the detection and mapping of subtle archaeological features[26], mapping of fluvial geomorphology[27] and its unique ability to penetrate vegetation cover to map underlying archaeological earthworks[28].

In the Trent Valley LIDAR data collected by the UK Government's Environment Agency (usually at 2m spatial resolution) has been used alongside other data collected at higher resolution (usually 1m with accompanying intensity information). Work has demonstrated that LIDAR is particularly effective for mapping geomorphological features of the mature, middle reach floodplains of the Trent and its tributaries, which are dominated by lateral channel movement and desiccating peat dominated wetlands/floodplains, where in both cases variations in the microtopography of the valley floor in the order of 0.1-0.5m reveal geomorphological features[29] (fig. 2). However, LIDAR is less effective in upper river reaches, which are dominated by rapid erosion with poor survival of palaeolandscape features and in lower river reaches, where accretion is the dominant process. LIDAR also has a significant role to play in mapping and documenting the cultural landscape of the Trent Valley and its tributaries. For example, in the Middle Dove Valley study of LIDAR data for a 25 km stretch of the valley floor identified 915 archaeological features covering 1471 ha, the majority of which had no previous documentation[30]. Such results suggest that even in extensively studied landscapes, systematic examination of airborne LIDAR data offers considerable potential for the enhancement of historic environment records in landscapes dominated by upstanding earthwork remains.

Examination of LIDAR intensity imagery from a variety of geomorphological settings indicates that these data contain information not present in the corresponding elevation record[31]. Empirical interpretation, based on a common understanding of the character of soils, sediments and vegetation in the area under examination, allows the use of intensity images to add qualitative information to the interpretation of a landscape area. In effect the intensity image is subject to the same knowledge-based interpretation as might be used to extract information from a conventional aerial photograph.

Since intensity data is (or can be) routinely collected during a LIDAR flight aimed primarily at gathering topographic data, in the Trent Valley it has been suggested that the examination of these data is routinely incorporated in the archaeological interpretation of existing LIDAR data, and that their collection always form part of the parameters of an airborne LIDAR survey commissioned for archaeological purposes.

3.2 Multi-spectral remote sensing

Mapping and characterising the spatial distribution of cultural remains from the air has been a central pillar of archaeological research since the 1920s[32]. In the Trent Valley the potential of multispectral airborne remote sensing has been investigated using a Daedalus 1268 Airborne Thematic Mapper (ATM) and a Compact Airborne Spectrographic Imager (CASI)[33]. Whilst multispectral and hyperspectral remote sensing technologies have been available for more than two decades, they have received surprisingly little consideration by the archaeological community[34], although the potential of such instruments for geological and geoarchaeological prospection were clearly highlighted by several authors in the past[35].

17 Salisbury 1992; Cooper 2003.
18 Garton *et al.* 2001; R. Cuttler, pers. comm.
19 Scurfield 1997.
20 Baker 2007.
21 Knight & Howard 2004; Howard 2005.
22 See Passmore *et al.* 2006
23 Bewley *et al.* 2005; Challis 2006; Challis *et al.* 2008.
24 Challis *et al.* 2009.
25 Carey *et al.* 2006; Howard *et al.* 2008.
26 Bewley *et al.* 2005.
27 Brunning & Far-Cox 2005; Challis 2005; Challis 2006; Carey *et al.* 2006; Challis *et al.* 2006; Jones *et al.* 2007.
28 Crow *et al.* 2007; Deveraux *et al.* 2005.
29 Challis 2006.
30 Challis *et al.* 2008.
31 Challis *et al.* 2011.
32 Crawford 1923.
33 Challis *et al.* 2009.
34 Challis & Howard 2006.
35 Donoghue & Shennan 1988; Allsop 1992.

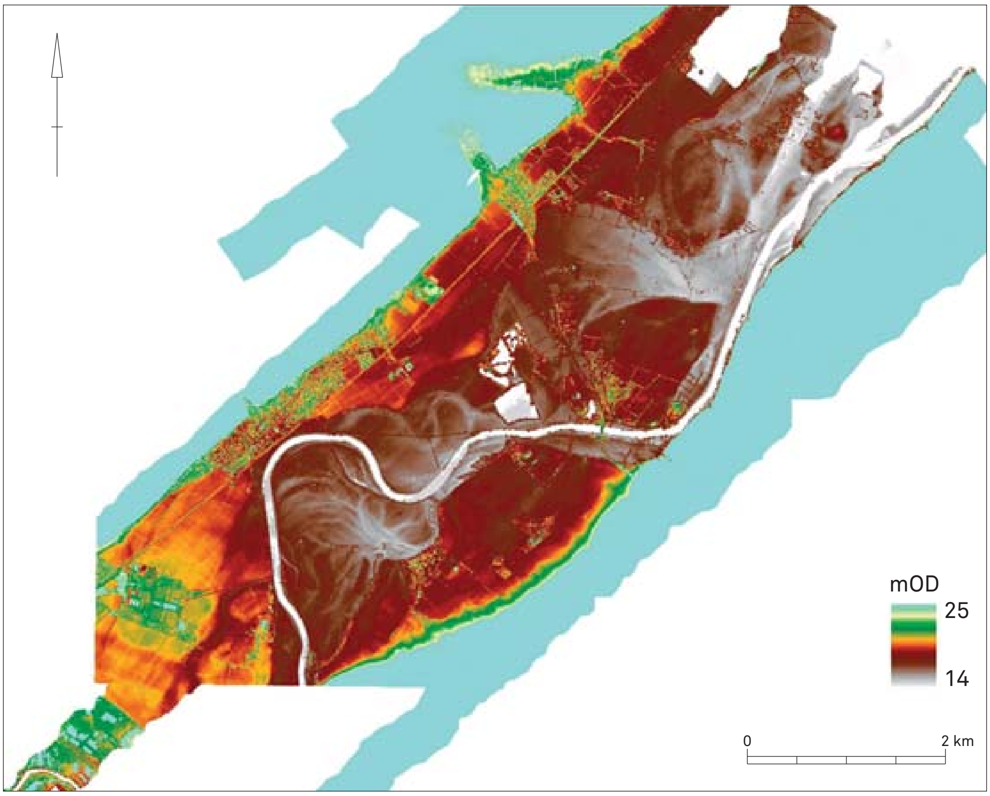


FIG. 2 LIDAR digital surface model of the River Trent between Stoke Bardolph and Hoveringham, Nottinghamshire. The elevation data has been carefully colour shaded to highlight variations in terrace and floodplain microtopography that reveal the Holocene development of Trent.

The instruments used in the Trent Valley are typical of those available to archaeologists across Europe. The Daedalus 1268 ATM is a multispectral sensor recording spectral reflectance and infrared radiation in 11 discrete bands ranging in wavelength from visible blue to thermal infrared (420nm – 13000nm). Reflectance is recorded on an 8-bit digital scale (image pixel values from 0-255) at a typical spatial resolution of 2 m. The CASI is a highly configurable hyperspectral scanner capable of recording spectral reflectance in up to 288 spectral channels at varying spatial resolution, although typically set to record vegetation variation using 14 bands (c.400nm-890nm) with reflectance recorded on a 12-bit digital scale (image pixel values 0-4096) at a spatial resolution of 2m.

The research undertaken in the Trent has demonstrated the physical characteristics of crops and soils that reflect underlying archaeology, principally cropmarks generated as a result of soil moisture deficit affecting crop growth. Where these physical characteristics are expressed and given appropriate image processing operations, multispectral imagery will usually be able to detect them, even if they are not apparent in the visible spectrum and so invisible to conventional photography (fig. 3). The strength of multispectral techniques lies in their combination of rapid, broad area coverage combined with data collection beyond the visible spectrum, but flights are expensive and there is no sense in which a single multispectral flight could substitute for a season of opportunistic flying using conventional photography. Rather it is suggested that multispectral data collection forms part of a balanced approach to airborne prospection. In seasons when cropmark formation is good then a well-timed multispectral flying campaign, undertaken when general cropmark formation is at its height, might be expected to reveal as much, and probably significantly more, than a single conventional flight.

3.3 Subsurface investigation

To reconstruct high-resolution 3-D sedimentary architecture and identify associated archaeology, GPR and ER geophysical survey has been combined within a GIS framework with the analysis and modelling of borehole records.

The analysis of commercial geotechnical records has long been used by geoarchaeologists to gain an insight into subsurface stratigraphy. Within the GIS framework irregularly spaced borehole data can be used to reconstruct accurate 3-dimensional stratigraphic models by interpolation to create regularly spaced gridded surfaces[36]. Bates and Bates (2000) have demonstrated the value of using selected geophysical techniques to augment borehole data and more recently, Bates *et al.* (2007) have shown the potential of collecting additional selected geotechnical engineering data to assess stratigraphic character (e.g. cone penetration to determine resistance of sediments and hence physical character).

In the Trent Valley, GPR survey using a GSSI SIR3000 system with a 200MHz antenna has been used to study the internal geometry of both the Pleistocene and Holocene terrace sands

36 See Challis & Howard 2003.

and gravels[37]. Whilst GPR has provided valuable information on the structure of the sands and gravels, attenuation of the signal within the fine-grained sediments of palaeochannel fills, where water tables are generally high, prevents the recovery of interpretable data[38]. In these environments, ER[39] has been the preferred method of data capture and has allowed the recognition of stratigraphy, including organic-rich horizons in these fine-grained environments[40]. Ground-truthing ER data using hand auger survey has demonstrated that ER is capable of defining the depth and cross-sectional geometry of individual channels; indirectly, resistivity values can also provide an indication of sediment wetness, which may provide a first assessment of organic preservation potential.

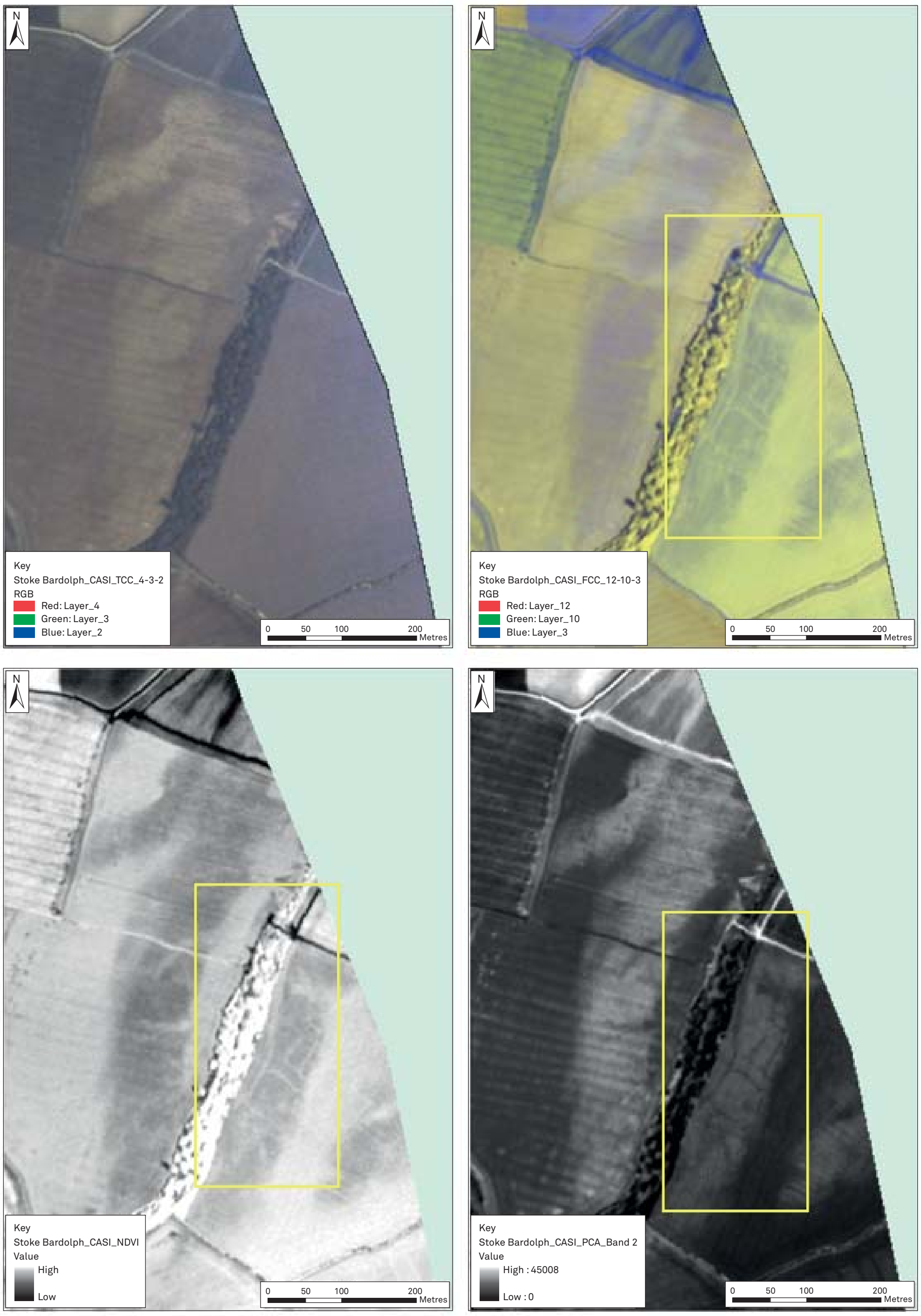


FIG. 3 CASI multispectral imagery showing archaeological cropmarks at Stoke Bardolph, Nottinghamshire. The four images show the same area and reveal how image processing techniques serve to reveal otherwise invisible cropmark features. Top: True colour and False colour composite images; bottom: Normalised Difference Vegetation Index and first principal component.

37 Carey *et al.* 2006.
38 Vandenberghe & Overmeeren 1999.
39 Baines *et al.* 2002.
40 Carey *et al.* 2006.

4 Building Models of Landscape Evolution

Geoprospection using this toolkit approach has generated large amounts of spatial data which has been integrated and managed within a GIS framework. Within the Trent, the GIS have been managed using ESRI's ArcView (currently version 9.3), although ranges of other software are available. A primary consideration when choosing the software to be used must be compatibility with software preferences of the end-user community, which usually includes local government departments as well as private companies. Interrogation of the archaeological, geological and landform assemblage datasets within a GIS has allowed the construction of terrace sequence models, which also serve as maps of archaeological potential as well as risk.

Whilst the relative age of valley floor sequences and hence some crude assessment of landscape evolution can be developed from morphostratigraphy and the distribution of archaeological remains, high-resolution chronological control can only be achieved through radiometric-dating of selected deposits. For the Late Pleistocene and Holocene, dating control is usually achieved using radiocarbon techniques, which are becoming increasingly sophisticated in terms of chronological precision through the analysis of multiple radiocarbon datasets within a Bayesian modelling framework[41]. Increasingly, with technical innovations, other methods of dating, which can also deal with longer timescales are being considered and in this respect, optically stimulated luminescence of quartz grains is particularly important[42].

5 Conclusions

This paper provides an overview to the approaches taken to archaeological geoprospection in the alluvial landscape of the Trent Valley, UK. It demonstrates that by adopting a multi-methodological toolkit approach combining non-invasive remote sensing technologies with more traditional geoarchaeological field survey, it is possible to unravel complex spatial patterns within the cultural record. Such approaches to geoprospection are gaining widespread use and acceptance within the archaeological community. To date, the majority of this work has been undertaken at a 1-2 km (reach) scale of investigation and the next major challenge must be to understand archaeological preservation on larger scales[43], as well as ground truthing the spatial distribution of archaeological sites predicted through statistical modelling approaches such as Bayesian analysis[44]. A final consideration in any methodological advancement is the need to place the record of natural landscape development and human activity within a secure chronostratigraphic model, which must ultimately be provided by radiometric dating[45].

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41 Gearey *et al.* 2009.
42 Duller 2004.
43 Ward *et al.* 2009.
44 Finke *et al.* 2008.
45 Walker 2005.

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High tides and low sites: the effects of tidal restoration on the archaeological heritage in the Kalkense Meersen area (Lower Scheldt Basin, Belgium)

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Abstract

From 2008 onwards a large number of areas along the rivers of the Lower Scheldt Basin in Flanders (Belgium) are being subjected to tidal restoration. These developments will have a significant impact on the rich archaeological and cultural historical heritage record of these alluvial areas. Because of this a pro-active approach was developed in cooperation between Waterways and Seacanal nv and the Flanders Heritage Agency, involving interdisciplinary surveys, archaeological excavations, and if possible taking mitigating measures to ensure preservation *in situ* of archaeological sites.

The surveys and excavations demonstrate the vast archaeological potential of these alluvial areas, both in the number and the quality (conservation capacity) of sites. The cooperation clearly demonstrates the merits of this pro-active approach for both the developer as for archaeological heritage management. However, the long term evolution of the tidal restoration areas remains an issue of much speculation. Because of this a monitoring program for these areas will have to be developed.

Keywords

Alluvial archaeology, geoarchaeology, in situ preservation, wetland management

1 Introduction

Following the European Water Framework Directive (2000/60/EC), and instigated by the expected rise of water levels due to 'global warming', a large number of alluvial areas in the lower Scheldt basin are being subjected to tidal restoration or wetland creation (the so-called 'Sigmaplan': www.sigmaplan.be). This is expected to cause erosion or the masking through sedimentation of historic landscape relics. Archaeological sites are also likely to be affected, by the infrastructural works themselves, and by erosion through the incision and migration of tidal channels.

There is very little knowledge about the presence of archaeological sites in the areas envisaged by the Sigmaplan. This is because in these alluvial areas, archaeological sites are covered by thick layers of floodplain sediments, but also because of a lack of attention by archaeologists for riverine wetlands in Flanders, up to the beginning of the 21st century[8]. However, contrasting with this lack of knowledge, it was expected that these areas have an enormous archaeological potential, both in quantity as in quality of sites.

Following these considerations a cooperation was set up between *Waterwegen en Zeekanaal nv* (Waterways and Seacanal; WenZ) and the *Vlaams Instituut voor het Onroerend Erfgoed* (now Flanders Heritage; Agentschap Onroerend Erfgoed), for the survey of the areas affected by the Sigmaplan. Based on the results of these surveys, project plans are adjusted to ensure *in situ* preservation if possible, or archaeological excavation if not.

This paper first describes the international and national policy framework concerning cultural heritage and wetland

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7 Agentschap Onroerend Erfgoed, Koning Albert II laan 19 bus 5, 1210 Brussel, inge.verdurmen@rwo.vlaanderen.be.
8 Crombé 2006; Demerre *et al.* 2009.

management, and the current policy on cultural heritage management within the Sigmaplan. Further we present two case studies through which the effects of wetland creation on the archaeological heritage are evaluated.

2 Wetland management and cultural heritage values

2.1 The international policy framework

The importance of wetlands was valued in 1971 by the 'Convention on wetlands of international importance', known as the 'Ramsar' convention (Iran)[9]. Although recognizing the importance of cultural aspects of wetlands, little attention was paid to this topic in the applications of the convention. This changed with 'Resolution VIII.19: Guiding principles for taking into account the cultural values of wetlands for the effective management of sites' (Valencia, 2002), and Resolution 'IX.21: Taking into account the cultural values of wetlands'. Following these resolutions the 'Ramsar Culture Working Group' (CWG) was installed in 2006. This working group produced a guidance document for the management of cultural aspects within wetlands (Convention on Wetlands (Ramsar, 1971 - Culture Working Group, 2008). Aspects of this guidance are '*To safeguard wetland-related cultural landscapes*'; '*To take carefully into account and protect ancient sites and structures (archaeological heritage)*'; and '*To encourage research on palaeoenvironmental, paleontological, anthropological and archaeological aspects of wetlands*'. This last issue is of key importance, stressing the general lack of archaeological knowledge in most wetland areas, due to practical problems concerning survey methodology.

Also important for the management of wetlands are the 'European Water Framework Directive' (2000/60/EC), and the European Floods Directive (2007/60/EC). Cultural and archaeological aspects of wetlands are missing however in these directives. On a European level the best basis for the integration of cultural resources in wetland management thus remains the 'European convention on the protection of the archaeological heritage (Valetta, 1992), and the 'European Landscape Convention' (Firenze, 1999).

Despite, or maybe just because of this lack of formal attention for the cultural and archaeological heritage in European wetland management strategies, a number of European projects pay specific attention to wetland heritage management, like the EAC[10], and the PlanarchII-[11] and SPARC[12]-projects.

2.2 The national policy framework

2.2.1 Protection and management of cultural landscapes

In Flanders, protection and management of cultural landscapes, built monuments, and archaeological heritage, are the subject of different legislation. For cultural landscapes, scheduling is made possible by the '*Decreet houdende de bescherming van landschappen*' (decree on the protection of landscapes; 16-04-1996). Preluding the implementation of this decree, the mapping of cultural heritage landscapes started in 1995, resulting in the '*landschapsatlas*' (landscape atlas)[13]. Besides this, in 2004 the '*erfgoedlandschappendecreet*' (13-02-2004; decree on heritage landscapes) was signed. This legislation offers the possibility of assigning sets of protective measures and provisions for a selection of the most valuable landscapes (the so-called '*relictzones*' (relic areas) and '*ankerplaatsen*'; 'anchor places'), outside the scope of legal scheduling.

2.2.2 Archaeological heritage management

The management of archaeological sites is covered by the '*decreet houdende de bescherming van het archeologisch erfgoed*' (decree on the protection of the archaeological heritage; 30-06-1993). Implementing a number of the Valetta objectives, this document provides the possibility of scheduling archaeological sites[14]. However, in the 20 years of the decree only a limited number of sites have received this status.

Concerning the implementation of article 5 of the Valetta Convention (integration of archaeology in the planning of large infrastructural works) some work still needs to be done. The Flemish archaeology decree only stipulates integration of preventive archaeology in governmental building applications, thus after the planning phase of projects. For example, integration of archaeology in Environmental Impacts Assessment procedures has long been of a piecemeal and sketchy nature to say the least, being obligatory only from 2002 onwards[15].

2.2.3 The 'Sigmaplan' and the management of cultural heritage values

Cultural heritage was from the start not a primary issue of concern within the 'revised Sigmaplan'. Nonetheless, the Environmental Impact Assessment main report from 2004 does mention the cultural heritage richness of the envisaged areas, as well as a general lack of archaeological knowledge in the alluvial areas due to the masking clay cover[16]. The report also stresses the probable significant erosion of the cultural heritage landscape, because the majority of the areas of the Sigmaplan are either scheduled heritage landscapes, either mapped as anchor places or relic areas[17] (fig. 1). For areas that will be subjected to full tidal influence the document also mentions the significant threat of erosion of the archaeological heritage[18]. The EIA sub-report on the effects of the Sigmaplan on cultural heritage values provides a further elaboration on these topics, discussing the expected effects for each of the Sigma areas[19]. This report again stresses the lack of knowledge, and proposes a mitigating approach entailing surveys on threatened areas, including geological and archaeological surveys, and preventive excavation of threatened sites[20].

9 Convention on Wetlands (Ramsar, 1971) Culture Working Group 2008: *Culture and wetland, a Ramsar guidance document*, Gland.
10 Coles & Olivier (eds) 2001.
11 www.planarch.org; Dyson *et al.* (eds) 2006.
12 www.sparc.org; Van den Bergh 2008.
13 Hofkens & Roosens (eds) 2001.
14 Overviews of Archaeological heritage management structures in Flanders are provided by Bauters *et al.* 2001, Meylemans *et al.* 2005 en Van Impe 2007.
15 Meylemans *et al.* 2005.
16 AWZ-Afdeling Zeeschelde 2004a, 122-123.
17 *Idem*, 144, 149.
18 *Ibid.*
19 AWZ-Afdeling Zeeschelde 2004b.
20 *Idem*, 129-130.

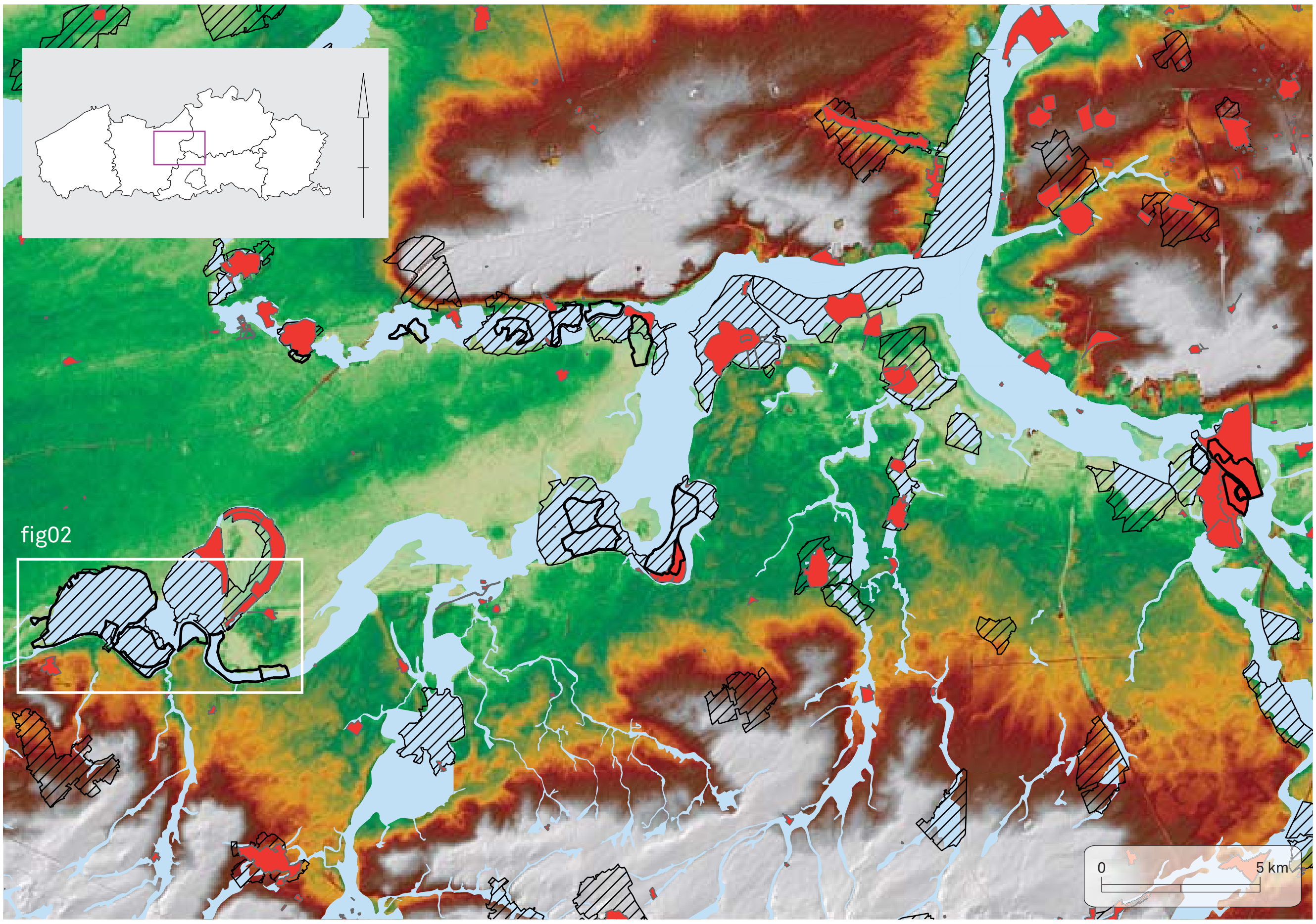

FIG. 1 Overview of alluvial areas (light blue) in the lower Scheldt basin, with indication of scheduled landscapes (red), 'anchor' places (crosshatched), and the 2010 project areas of the Sigmaplan (black outline).

Following this suggestion in the EIA report a cooperation was set up between WenZ and VIOE, conducting multidisciplinary survey projects from 2008 onwards, and focusing on the areas that will be affected the most. Based on the results of these surveys a set of recommendations was presented, aimed at preservation *in situ* if possible, preservation by record (preventive archaeology) if necessary, or the conduction of complementary archaeological surveys[21]. Based on these recommendations mitigating measures were formulated before the start of the building application procedure. This approach allows in the first place a 'last chance effort' of making adaptations in the constructions plans. Secondly, preventive archaeology is integrated in the general set up and execution of the different projects.

3 The effects of tidal restoration

Besides direct soil disturbances such as the construction of new dikes and sluices, the main physical impact of the Sigmaplan is to be expected in the areas that will be subjected to reduced or full tidal restoration. Within these areas daily tidal influence will cause significant erosion and sedimentation processes. The effects on the short and long term are however hard to predict. The incision and development of tidal channels for example depends on a large number of interplaying local factors, such as the location and width of in- and outlets, local tidal amplitudes, the existing drainage network, vegetation development, local geological and soil characteristics, etc.[22]. A number of monitoring projects on already developed areas along the lower Scheldt show that when subjected to full tidal influence initial erosion through gully incision and development evolves rapidly in a first stage[23]. In areas with reduced tidal influence, such as the *Lippensbroek* polder, this effect is both less radical and more controllable. However, also in this area erosion in the present tidal gullies, both vertical and lateral, does occur[24].

Another possible effect of tidal restoration is the impact on the 'conservational capacity' of these wetlands. Continuously high water tables offer excellent preservation conditions for both organic and inorganic artifacts such as wooden, bone and metal objects. In some areas tidal restoration might in this respect have a positive effect. For other areas a negative effect is possible due

21 Bogemans *et al.* 2008; 2009a-b-c; 2010 a-b.

22 Van Oevelen *et al.* 2000.

23 Eertman *et al.* 2002; Van den Bergh *et al.* 2005.

24 Maris *et al.* (eds) 2007.

to fluctuating water tables caused by the tidal regime[25]. The conservational capacity of wetland environments also depends on the delicate balance of a large number of chemical properties of the soil[26]. The influx of water of the river Scheldt also can have a negative impact on this balance. One of these is the high level of heavy metal pollution in the water of the Scheldt basin today[27].

4 Two case studies: the Bergenmeersen and Wijmeers 2 areas of the Sigma cluster Kalkense Meersen

4.1 Study area

The Sigma cluster *Kalkense Meersen* is situated in the lower Scheldt basin between *Wetteren* and *Schoonaarde* (fig. 2). The top of the alluvial plain is situated at ca. +4m TAW. A number of river dunes form outcrops reaching heights of +10m TAW and more where they are preserved. The mean tidal amplitude of the River Scheldt in the area is ca. 2,5m, ranging from ca. 2m TAW to ca. 4,5m TAW[28].

The *Kalkense Meersen* cluster is subdivided in six areas (fig. 2), with different future functions. Four of the areas (*Kalkense Meersen*, *Wijmeers 1*, *Paardeweide, Paardenbroek*) will become Controlled Flood Areas (*Gecontroleerde overstromingsgebieden*; GOG). These will serve as buffers during extreme storm surges and high tides, and will not have daily tidal regimes. The other two areas will be converted to floodplains with full (*Wijmeers 2*) and reduced (*Bergenmeersen*) tidal influence. Our research mainly focused on these last two areas.

4.2 Methodology

The surveys involved geology, palaeo-ecology, archaeology, and cultural historical research. Geological data were collected through an extensive manual augering campaign[29]. A selection of sediments was sampled for palaeo-ecological analyses (palynology) and dating (radiocarbon and OSL)[30].

The palaeo-environmental reconstructions and the location of the fossil Late Glacial channels (fig. 3) provided the framework for the archaeological surveys. These consisted mainly of borehole surveys, a methodology developed for buried environments such as alluvial areas[31], and already applied successfully in the Scheldt valley in a number of cases[32]. In the *Wijmeers 2* area this was followed by two test pit evaluations[33]. Geophysical surveys were carried out in two areas. This consisted of electromagnetic and resistivity survey, where the conditions (outcropping or undeeply buried sand substrates) allowed this approach. In 2012 three zones (two in the *Bergenmeersen*, one in the *Wijmeers 2* area) were the subject of preventive excavations.

Cultural historical research was carried out using historical maps and archives. Also a field survey was made for surviving historical relics and structures.

A number of remote sensing data was available, among which two LIDAR based DEM's. The first one is a DEM covering the whole of Flanders ('DHM Vlaanderen; DHMV)[34], with a raster resolution of 5 by 5m. The second DEM with a higher resolution (several measure points/m²), covers only a stretch of 250m on both sides of the River Scheldt[35].

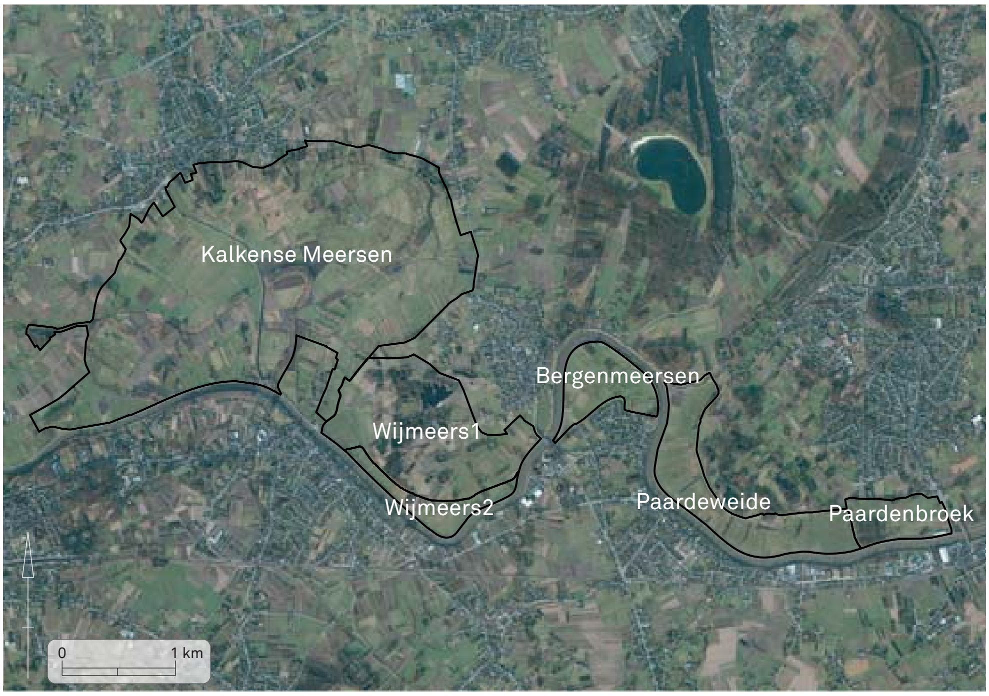

FIG. 2 **Overview of the Sigma cluster *Kalkense Meersen*.**

25 Van den Bergh 2008.
26 Corfield 2007.
27 Maris *et al.* (eds) 2007.
28 Coen 2008, 112.
29 Bogemans *et al.* 2012.
30 Bogemans *et al.* 2008; 2009a & b; 2012; Bogemans & Vandenberghe 2011.
31 Groenewoudt 1994.
32 Bats 2007; Bats *et al.* 2006; Crombé 2006.
33 Meylemans *et al.* 2009; Perdaen *et al.* 2011a.
34 De Man & Brondeel 2004.
35 Bertels *et al.* 2011.

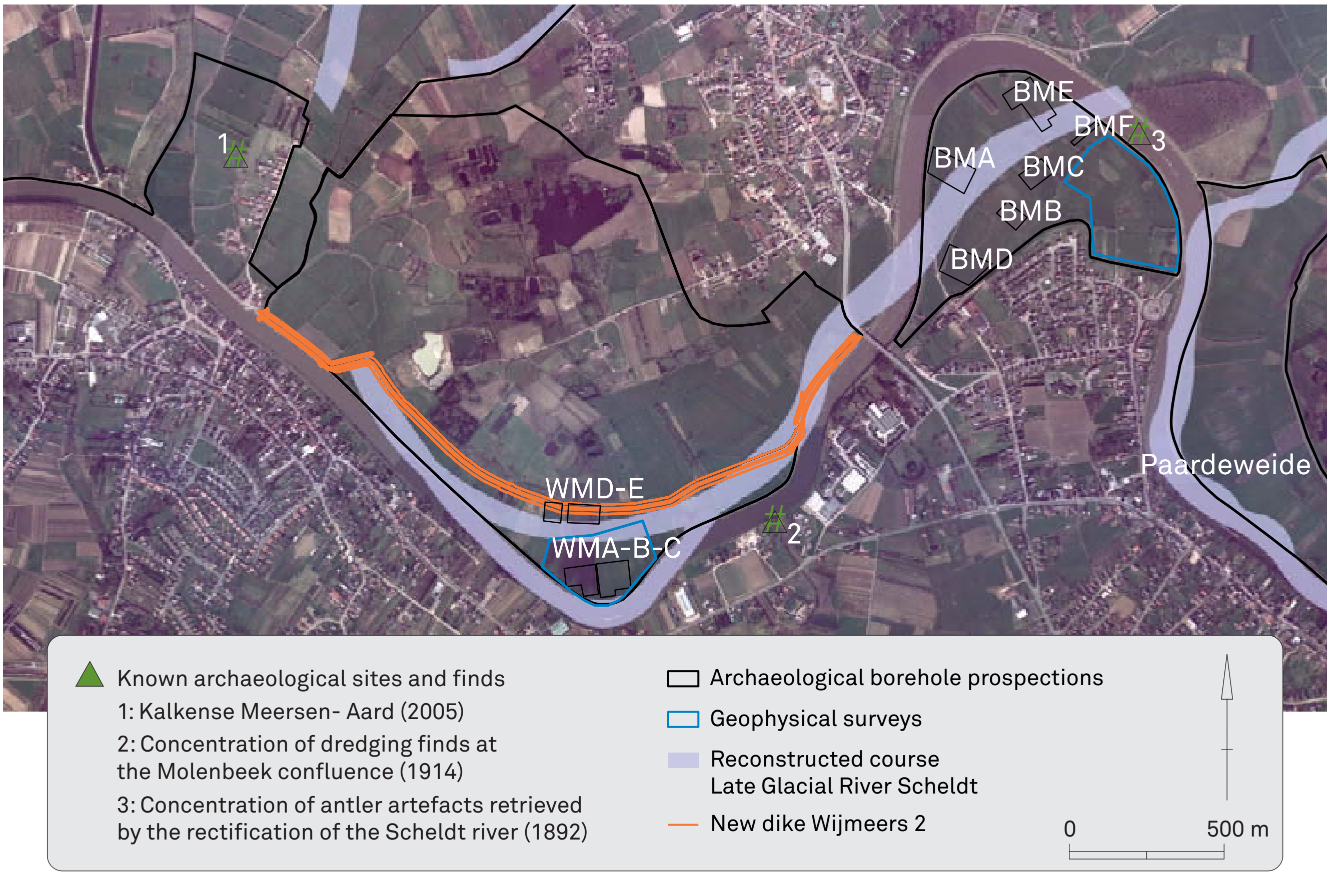

FIG. 3 Aerial photograph of the *Kalkense Meersen* cluster, with indication of fossil Late Glacial gullies, archaeological finds, and archaeological survey and excavation areas.

4.3 Results

In the following overview we present a brief summary of the survey and excavation results. First however, we briefly present an overview of the data available prior to these surveys.

4.3.1 Available data

Previous geological research in the vicinity of the study area was carried out on the meanders loops of *Overmere*[36] and the *Kalkense Meersen*[37]. Next to this, a number of palynological studies are available from the *Wijmeers 1* area and the surrounding region[38].

A limited number of archaeological observations was available prior to our surveys (fig. 3). Most finds were retrieved during dredging operations at the beginning of the 20th century[39]. These dredging operations were followed by a number of local collectors, resulting in finds ranging from the Early Prehistory to the Post-Medieval period. The finds include Final Palaeolithic/Early Mesolithic barbed bone points[40], Mesolithic/Neolithic antler artifacts[41], and a large amount of Bronze and a smaller amount of Iron Age metalwork[42]. A large number of finds was found at the mouth of the '*Molenbeek*', including prehistoric, Bronze and Iron Age finds, Late Roman *Wijster* type pins[43] and also Early Medieval metalwork[44]. Another concentration of finds was collected during the rectification of the Scheldt river at the site of the *Paardeweide* in the *Bergenmeersen*[45] and consists of more than 180 antler artifacts (fig. 4). ^{14}C-dates on five of the artifacts range between 6180 and 5150BP[46]. More recent data on archaeological sites in the *Kalkense Meersen* area come from borehole and test pit surveying at two locations: *Kalkense Meersen Aard* and *Molenmeersen*. These surveys showed the presence of Mesolithic and Neolithic find concentrations on top of the Late Glacial point bar deposits, which are covered by alluvial clay[47].

36 De Coster 1977; 1982.
37 Mijs 1986.
38 Verbruggen 1971; for an overview see Deforce 2007.
39 For overviews *cf.* Verlaeckt 1996 a-b; Warmenbol 1992.
40 Doize 1983.
41 Crombé *et al.* 1999; Hasse 1934, 1935, 1953; Hurt 1982a-b, 1992; Maertens 1922; Dierckx 2009.
42 Maertens 1920; Verlaeckt 1993,1996a-b; Warmenbol 1992.
43 Verlaeckt 1995; Verlaeckt & Proos 1996.
44 De Mulder & Verlaeckt 1999.
45 Moens 1904-1905; Hasse 1934, 1935.
46 Crombé *et al.* 1999.
47 Bats 2005; Bats *et al.* 2006; Bats & De Reu 2006.

FIG. 4 **A selection of antler artifacts retrieved by the rectification works at the *Paardeweide* in 1892.**

4.3.2 Survey results

Geology and palaeo-ecology:

The general morphology of the area was defined in the Late Glacial period. At the onset of this period, or at the end of the Pleni-Weichselian, river dynamics changed from a braided river to a single channeled meandering pattern[48]. This highly dynamic river formed large meander loops, which shaped the outline of a large part of the alluvial plain as it is visible today. Testimony to these migrating channels are the point bar deposits, present in the whole of the *Kalkense Meersen* cluster. The distinct ridge and swale topography of these deposits is clearly visible on the DEM in the meander loop of *Overmere* (fig. 2). Based on the results of the geological survey we can reconstruct the course of the last phase of this Late Glacial channel and one of its chute channels in the *Wijmeers 2* and *Bergenmeersen* (fig. 3). ^{14}C-dating and the palynological data show that the formation of gyttja deposits in these channels started in the Late Glacial period. During the Early Holocene the gradual accumulation (mostly clay and organic sediments) in the fossil channels continued, with small underfit gullies within these channels constituting the river network. According to the ^{14}C-dates and the pollen records the fossil channels were completely filled up at the end of the Atlantic or the beginning of the Subboreal period[49]. From then onwards sedimentation of fluvial deposits also occurred outside the banks of these channels, laterally extending the alluvial plain. The higher ridges of the point bar topography remained uncovered in this stage. The fluvial regime in this period shifted from a single to an anabranching channel network. Hydrological conditions changed, probably at the onset of the Subatlantic period, to a single channelled meandering river once again. The

48 Bogemans *et al.* 2012.

49 *Ibidem;* Meylemans *et al.* 2013.

FIG. 5 Profile photo of Roman waste layer, sloping down in a fossil crevasse gully (*Wijmeers 2*).

incision and (limited) lateral migration of this channel locally formed new point bar deposits, as is visible in the north of the *Bergenmeersen* area[50]. The exact date of this evolution to the current course of the River Scheldt is unclear but it must have been completed before the Roman period[51]. Associated with this new Scheldt a number of crevasse gullies and -splays are present (*cf.* fig. 5). From the Roman period onwards vertical aggradation of fluvial deposits (clay) dominated the fluvial environment, extending the alluvial plain to cover its current width. According to the presence of archaeological sites and features in these deposits the chronology and sedimentation rate strongly depends on local conditions, and probably also on human interference with this process (*infra*). The next defining stage of development of the alluvial plain is constituted by the Late Medieval land reclamation, with the construction of an extensive network of dikes and the creation of flood meadows and drainage canals.

The observed vegetation evolution through the pollen analyses generally accords with the regional pattern described by Verbruggen *et al.* 1996. Human activity like cereal cultivation is clearly visible in various pollen records from the Subboreal period onwards (the Bronze Age period). This increases in the Iron Age, as is shown in a pollen sample from one of the archaeological test pits in *Wijmeers 2*, of which the ^{14}C-calibration curves range between 760-410 calBC[52]. Finally pollen analysis of deposits from the Roman period show an intense anthropogenic influence in the alluvial plain of the *Wijmeers 2* area, with an almost completely deforested environment, and the presence of *cereals*, indicating agriculture in the immediate vicinity.

Archaeological survey and excavation results:

Wijmeers 2:

In the *Wijmeers 2* area the chosen survey locations were based on the geological data and the expected impact of the future infrastructural works (position of the tidal inlet and course of the new dike). Two zones were prospected, first by a borehole survey, which was followed by test pitting (fig. 3).

The first zone (WM A-B-C) is situated in an area with Late Glacial point bar deposits, which are covered by sandy crevasse deposits. The borehole survey resulted in a large number of archaeological indicators (ceramics, iron nail fragments, charcoal etc.)[53]. A test pit on the location with the highest density of finds showed the presence of a Roman waste layer (2nd century AD)[54], suggesting the presence of a settlement in the immediate vicinity (fig. 5). The waterlogged conditions of the lower part of the waste layer, deposited in a fossil crevasse gully, provides excellent conservation of organic arte- and ecofacts, such as wood, plant-macrofossils, pollen, mollusks, diatoms, and unburned bone. Also inorganic artifacts, such as metal objects, were very well preserved. In the clay covering the site Roman artifacts and traces were present at the bottom of this clay layer. In a higher position within this clay accumulation a shallow pit and a number of ard/plough marks with a charcoal rich fill dated at 410-580 cal AD (Bèta276412). Because this area is located near the future tidal inlet, and it is believed that the sandy crevasse splay deposits will offer little resistance to channel erosion, part of the area was excavated in 2012. This excavation demonstrates the presence of a rural Roman settlement from the 2nd century AD, consisting of at least two farmsteads, and a central 'ritual' zone (fig. 6).

In the second zone (WMD-E) a borehole and test pitting survey indicated the presence of Mesolithic and Neolithic find concentrations (flint and handmade pottery) on top of two parallel point bar ridges (fig. 7), flanking a Late Glacial chute channel[55]. In one of the test pits Roman sherds were present in the bottom part of the covering clay (fig. 8).

Bergenmeersen:

In the *Bergenmeersen* 6 zones were subjected to a borehole survey (fig. 9). The most striking result of this survey is the presence of a large prehistoric site complex, situated on top of a distinct point bar ridge flanking the Late Glacial main channel (fig. 10). The retrieved artifacts (flint) point to a Mesolithic date of this find complex[56]. Radiocarbon dating of the top of the organic sediments in the fossil channel shows that this ridge remained a

50 Bogemans *et al.* 2009a.
51 Bogemans *et al.* 2008; Bogemans *et al.* 2012; Kiden 1991.
52 KIK39609.
53 Bogemans *et al.* 2008.
54 Bogemans *et al.* 2008; Meylemans *et al.* 2009.
55 Perdaen *et al.* 2011a.
56 Perdaen *et al.* 2009.

FIG. 6 Generalized ground-plan of the excavation in the *Wijmeers 2* area. Features and traces of the Roman settlement are indicated in grey, main buildings with red dotted line. The edge with the crevasse channel (*cf.* fig. 5) in the south is indicated by the black dotted line.

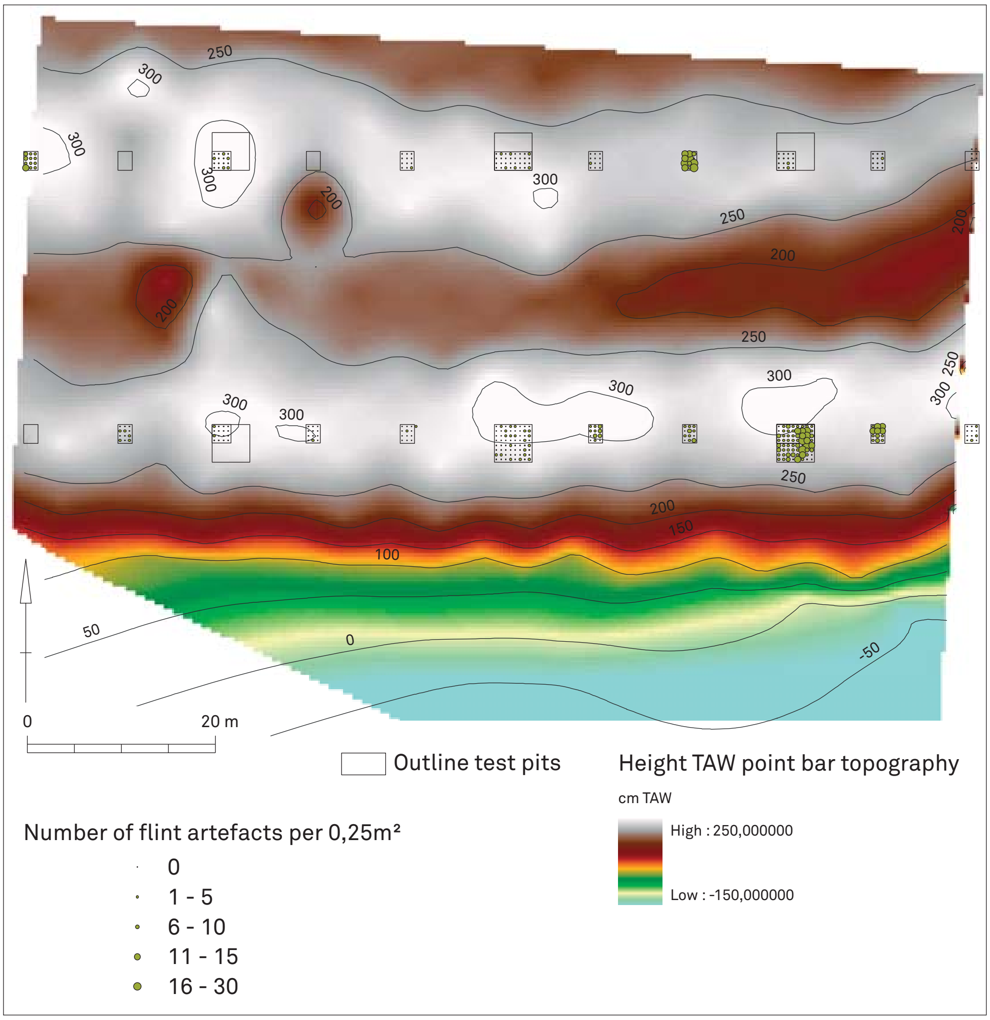

FIG. 7 DEM of point bar deposits in survey area WME with indication of the quantity of flint artifacts in the test pits.

FIG. 8 Profile photo with indication of Roman sherds at the base of the clay accumulation in WME survey zone.

visible element in the landscape at least until 3000 cal BC. After this period, towards the end of the Neolithic period, the lower lying part of this ridge gradually became covered with floodplain sediments. From this lower part of the ridge, located at 2,8m to 4,3m under the current surface, a small number of unburned bone fragments were retrieved. On the higher parts of the ridge no unburned ecofacts with a possible link to the prehistoric occupation were present. The north eastern part of the ridge is situated near the concentration of finds in the *Paardeweide* (*supra*). The other two borehole surveys, both located in the northern part of the *Bergenmeersen*, delivered finds from younger periods. In the BME zone these consisted of a number of Roman sherds and a concentration of charcoal. In the BMA zone a number of small iron slag fragments was present, in association with strongly burned oak fragments. A ^{14}C-date of one of these suggests a Medieval age for these finds (680-890 cal AD; Beta 263625).

In the southern part of the *Bergenmeersen*, a geophysical and borehole survey was conducted, steered by the presence of a Post-Medieval site (known as the '*Hof ter Zeypen*'), and the possible presence of a Medieval moated site as indicated by historical sources[57]. The area is characterized by the presence of an oxidized sand substrate, either exposed or only covered by a thin layer of clay. This survey, corroborated by a number of augerings, indeed showed the presence of a circular ditch, about 12 m wide and up to 2 m deep[58]. Next to this, the outlines of the Post-Medieval site with its rectangular ditches are clearly visible in the landscape and on the available DEM's (fig. 10).

In 2012 both these areas were excavated. This confirmed the presence of the moated site (fig. 11), of which the circular ditch delivers a large number of artifacts dating this site to the 13th-14th

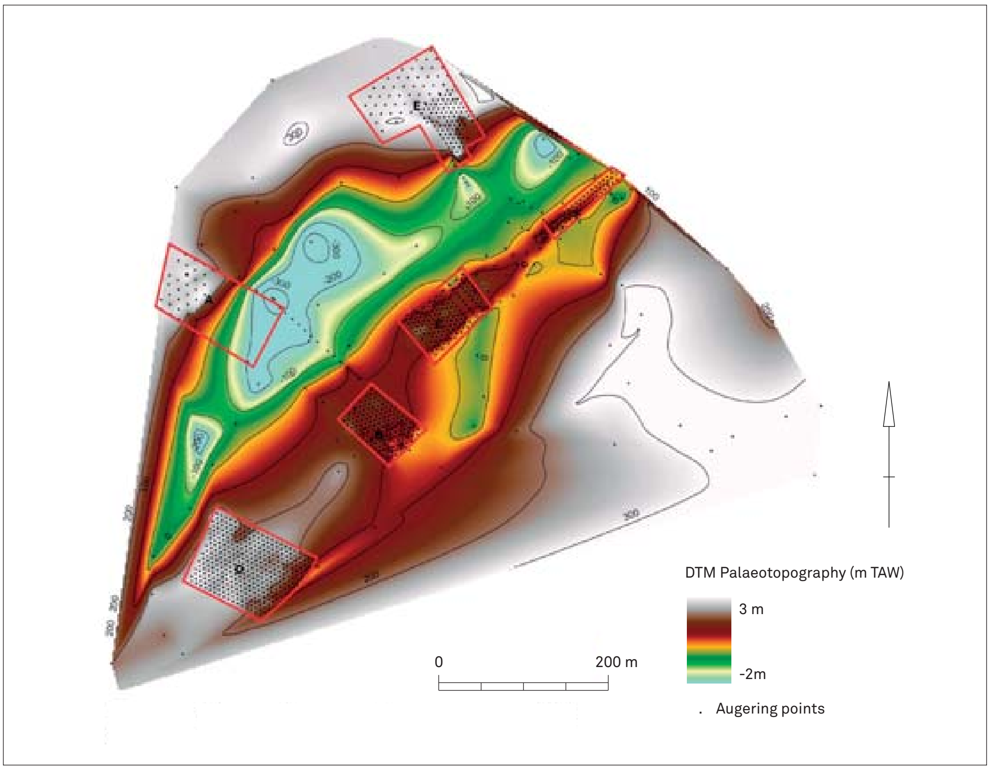

FIG. 9 DEM of the palaeotopography in the *Bergenmeersen* area, with indication of the archaeological borehole survey areas and augering points.

57 Bogemans *et al.* 2008.

58 Orbons 2009.

centuries. The ditch fillings also provided excellent conditions for the preservation of bone and other organic materials.

In the area of the '*Hof ter Zeypen*' (fig. 12) most of the traces and finds are from the 16th and 17th century. However, this area also delivered a number of traces from other periods, including Iron Age and Roman ditches and pits, and a fairly large number of early prehistoric finds and concentrations[59].

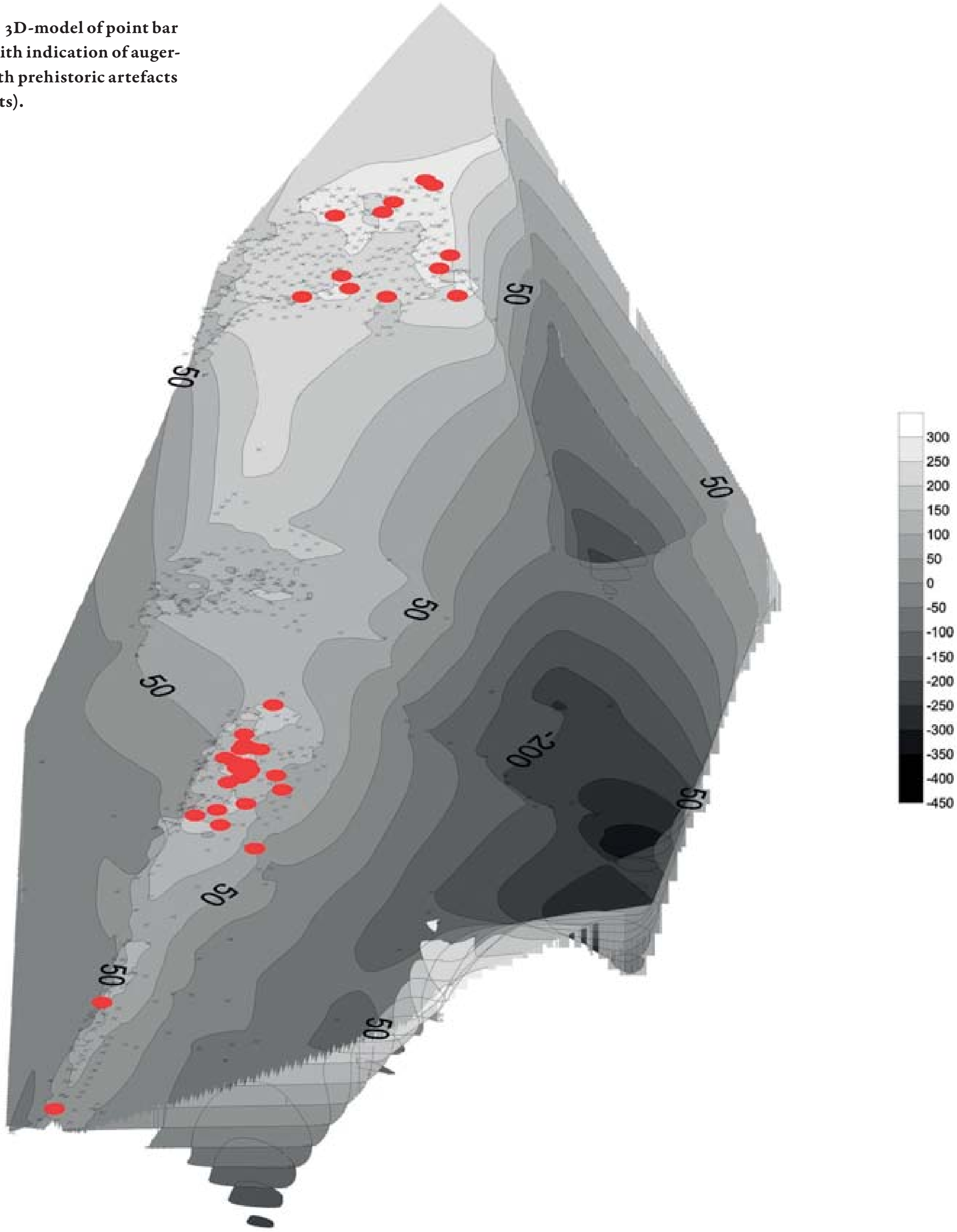

FIG. 10 **3D-model of point bar ridge with indication of augerings with prehistoric artefacts (red dots).**

59 Perdaen *et al.* 2013.

4.4 Conclusions of the archaeological surveys and excavations

4.4.1 Archaeological potential

The archaeological fieldwork shows the presence of sites and finds in all of the survey areas. Prehistoric sites (Mesolithic-Neolithic) are present in both the *Wijmeers 2* and the *Bergenmeersen*. The distribution of these finds show a preference for the higher parts of the Late Glacial point bars, adjacent to the fossil Late Glacial river channels. This pattern is corroborated by similar sites present in the *Kalkense Meersen* (*supra*) and other Sigma-areas[60], showing an almost continuous spread of find concentrations along the edges of the Late Glacial River Scheldt.

The survey further shows the presence of archaeological sites from younger periods (Iron Age, Roman, Medieval and Post-Medieval periods). The presence and nature of these sites is clearly linked to the later stages of development of the alluvial plains[61]. The Roman occupation in the *Wijmeers 2* for example probably ended

FIG. 11 **Excavated cross section through the Late Medieval circular ditch structure in the *Bergenmeersen* area.**

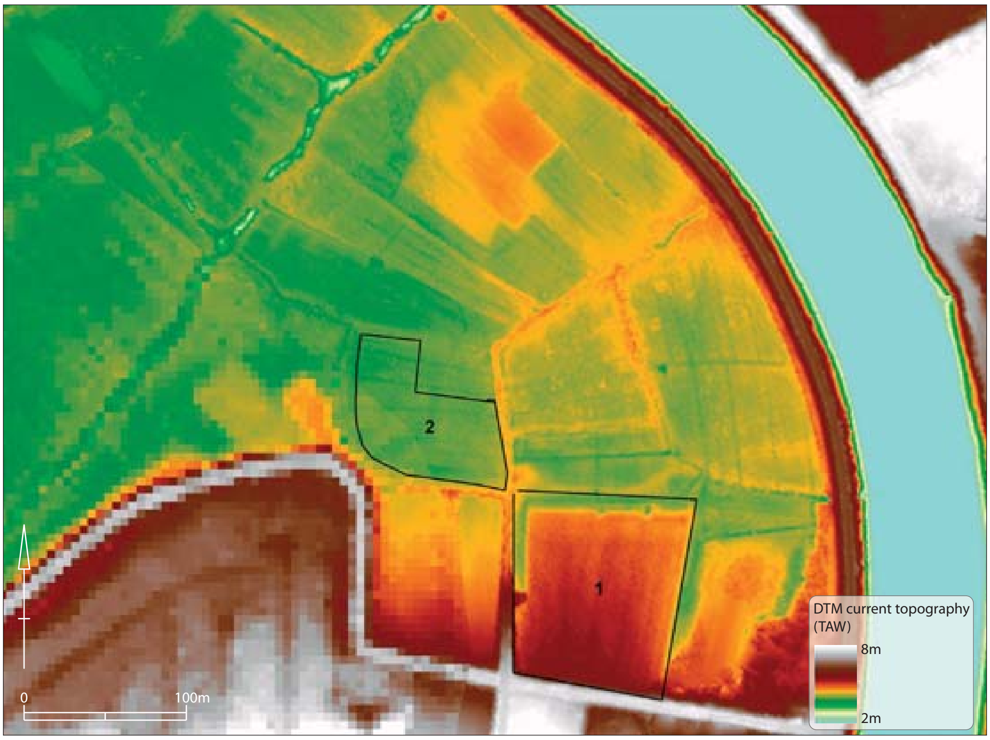

FIG. 12 **High resolution DEM of the excavated area in the *Bergenmeersen*. 1: location of the Post-Medieval site '*Hof ter Zeypen*'; 2: location with 13th-14th-century moated site.**

60 Bogemans *et al.* 2009c, 2010a, b; Perdaen *et al.* 2008, 2009, 2011a; Jacops *et al.* 2010; Meylemans *et al.* 2011; Meylemans *et al.* 2013.

61 Bogemans *et al.* 2012.

because of increased flooding, while traces of Early Medieval agricultural practices are visible in this clay cover. In the *Bergenmeersen* it seems that occupation remained possible on more elevated positions in the south of the floodplain, until the Post-Medieval period.

The archaeological potential of both areas thus shows to be enormous. Moreover, we must be aware of the limitations of the applied survey methodology. Because of these a range of site types present in alluvial sediments can remain undetected. This might explain the dichotomy between the large number of dredging finds from the Bronze Age period, and the lack of Bronze Age finds during our surveys. It is likely that the Bronze Age occupation, considering the swampy environment of the area at that time, was limited to *off site* activities, thus leaving only 'low density' sites and ritual depositions, such as the retrieved dredging finds.

4.4.2 Conservation potential

The conservation potential of organic material is strongly interlaced with the geological development of the area. This is illustrated by preservation and date range of the observed palynological record.

For the prehistoric periods, roughly up to the Middle Neolithic period, organic rich deposits accumulated within the fossil Late Glacial channels. Its conservation potential is demonstrated by the bone and antler artifacts retrieved by dredging and rectification works. It is likely that these represent the remains of refuse layers deposited on the inner banks of these gullies, such as observed through a recent excavation of a Final Mesolithic to Middle Neolithic site at *Bazel Sluis*, downstream of the *Kalkense Meersen* cluster[62]. The large amount of antler artifacts retrieved by the rectification works at the *Paardeweide* (*Bergenmeersen* area) can probably be interpreted in this sense, as the geological survey demonstrates the presence of the Late Glacial fossil channel at just this point (fig. 3).

By the end of the Neolithic, alluvial accumulation also started outside the confines of these gullies. In the *Wijmeers 2* for example organic clay accumulated at the base of one of the swales from ca. 2500 cal BC onwards. In the Subboreal period the marshy environment resulted in an accumulation of organic rich clays, with waterlogged conditions offering a good conservation capacity.

This conservation capacity, as illustrated by the range of the pollen records, generally diminishes from the Subatlantic period/Iron Age onwards. The alluvial deposits such as crevasse sands and clay are nearly always of a mottled or oxidized nature, thus leaving little chance for the preservation of uncharred organic remains. As shown by the excavation of the Roman site however, there are exceptions. The present crevasse gullies, with their lower parts below the permanent water table, demonstrate excellent preservation conditions for organic remains. Organic materials from later (Medieval – Post-Medieval) periods are probably only preserved in deep anthropogenic features, like the Medieval and Post-Medieval ditches in the *Bergenmeersen* area.

5 Tidal restoration and archaeological heritage management

In this section we describe the expected effects of tidal restoration on the observed archaeological record, for both the *Wijmeers 2* as the *Bergenmeersen* areas. We also present an overview of further management strategies for both areas.

5.1 *Wijmeers 2*

Tidal restoration in *Wijmeers 2* started in 2010 (fig. 11). One of the problems was the presence of the prehistoric site on the planned course of the new dike. For the construction of the dike ca. 1 m of clay was to be removed, thus topping of the prehistoric

FIG. 13 Construction of the dike in the *Wijmeers 2*.

62 Perdaen *et al.* 2011b.

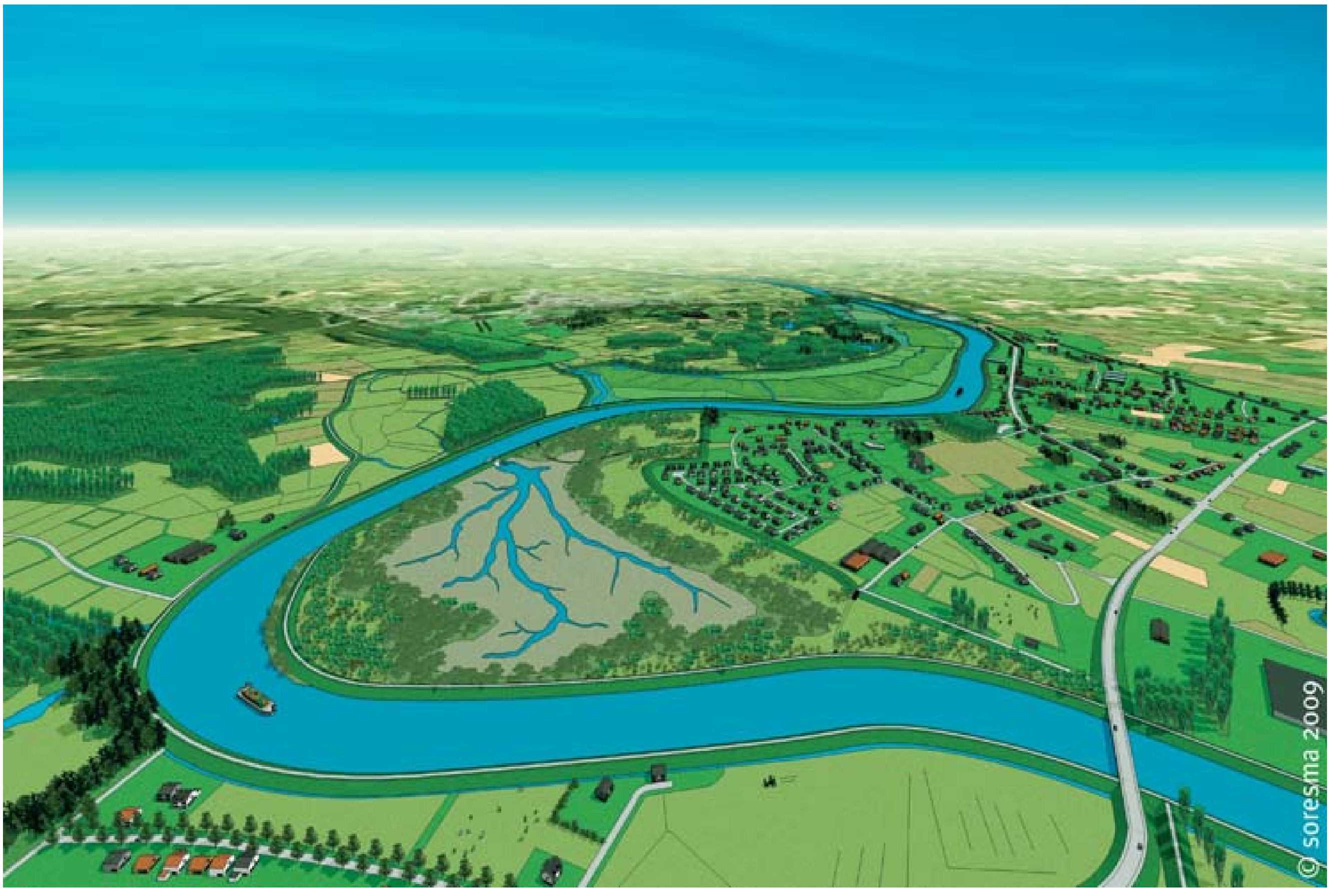

FIG. 14 **Artist impression of the future development of the *Bergenmeersen*.**

site (fig. 13). Because of the high cost of an archaeological excavation of this site, under supervision of archaeologists only ca. 40 cm was excavated, thus leaving a buffer of 40-80 cm of clay. Because of the absence of preserved organic materials on the top of the ridge this does not present a threat to the site complex.

Preservation of the Roman site was more problematic. The tidal inlet, about 40m wide, will be situated directly to the south of the site. As an onset for further creek development a channel will be dug to a depth of low tide, i.e. ca. 2m TAW. The initial erosion and creek development in this area is expected to be severe. This erosion will probably be aggravated by the presence of sandy crevasse splay deposits, on which the site is situated. Therefore this site was (partly) excavated. The further development of the area will be monitored, which possibly will result in more excavations.

5.2 *Bergenmeersen*

The tidal inlet in the *Bergenmeersen* will be situated in the east of the area (fig. 12). This inlet will be controlled by a sluice, with its foot at ca. +2,7m TAW. To stimulate creek development, two gullies will be dug, with their base at ca. +2m TAW (fig. 14). Originally, the northern gully would run straight from the sluice to the west. This would disturb a large part of the prehistoric site complex. As in the *Wijmeers 2* area an alternative scenario was developed which involves relocating the northern channel. To achieve this, the future gully crosses over the prehistoric site complex, where its top is situated at ca. +1m TAW or less. Moreover, the western bank of this bend will be reinforced to prevent future erosion towards the higher parts of the ridge.

Since the foot of the tidal inlet sluice is about +0,7m above low tide, no significant future lateral or vertical erosion is to be expected from this gully, so that the prehistoric site complex as well as the Roman and Medieval finds in the north of the area are safe.

The southern gully runs towards the Medieval ditch and Post-Medieval site. The geological survey shows a sandy substrate at +3m TAW or higher in the whole of this area. It is expected that this will offer little resistance to erosion. Like the Roman site in the *Wijmeers 2,* this site was thus chosen to excavate.

5.3 Preservation and monitoring

As outlined above, several sites can be preserved *in situ* in the tidal restoration areas. However, a number of questions rise concerning future development of the areas, such as long term effects because of climate change, and alterations in the conservation capacity through changes in hydrology and chemical processes. These effects can only be assessed on the longer term, and require surveys and monitoring of a number of elements like water level fluctuations, and evolution of ph values and redox potential[63].

63 E.g. Lillie 2007.

6 Conclusions

Our surveys and excavations demonstrate a very rich archaeological record in the alluvial areas, ranging from the Early Prehistoric to the Post-Medieval periods. A multidisciplinary approach (geology, palaeo-ecology, archaeology, historical research) is of key importance in these wetland environments. We must keep in mind however that the applied survey methods such as borehole sampling undoubtedly leave a number of site types undetected. This is indicated by the test-pit evaluations, were a number of *off site* traces and artifacts were registered in alluvial deposits.

Despite the fact that our surveys were conducted after the planning stage of both projects, it was possible through minor changes of the planned construction works, to ensure preservation *in situ* for a number of sites. Other sites were excavated. These excavations were integrated in the infrastructural works, minimizing delays and costs.

Compared to national and international policies concerning archaeological heritage and wetland management, the cooperation between Waterways and Seacanal, and the Flanders Heritage Institute shows a number of positive points. On an international level the concerns of the recent Ramsar guidance documents are largely met, as well as the key elements of the Valetta convention (preservation *in situ* when possible, integration of preventive archaeology in large construction works, and finally the 'polluter pays' principle). This means that on a national level this approach is an enormous enhancement compared to the current legislation. Moreover the continuous dialogue between engineers and archaeologists, and the joint efforts of presenting the results of the archaeological surveys to the general public, for the first time creates an awareness that cultural heritage is an important aspect of wetland management.

However, a number of aspects of the future development of the tidal restorations remain uncertain. An important aspect of future heritage management in these areas is the application of a long term monitoring strategy.

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Relic Holocene colluvial and alluvial depositions in the basins of the Scheldt, the Meuse, the Somme, the Seine and the Rhine (Belgium, Luxemburg and Northern France). A prospective state of research in rescue excavations

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Abstract

This article presents a review of recent studies from rescue excavations and soil analyses of colluvia and alluvia, for the Holocene period. The close collaboration on a large number of archaeological excavations allows to attribute all the quoted examples of colluvial and alluvial deposits with a relative dating. These were sorted according to pedo- and geo-regions. The proposed preliminar palaeo-environmental synthesis of this data is to be confronted with other approaches, such as off-site studies. Through this approach differing chronologies for the initiation of anthropogenic erosion can be established for the studied regions. These differences might partly coincide with the variety in soil types.

Keywords

Geoarchaeology, archaeopedology, erosion, sedimentation

1 Introduction

1.1 Context

It has long been a common belief among Belgian geomorphologists that most of the colluvial deposits resulted from modern agriculture[5]. From the late 1980s onwards however systematic field interventions of soil scientists enabled to surpass this idea and to observe and date a number of older erosion and sedimentation events. In the study area this involved mostly rescue excavations resulting from large-scale construction works, such as the high speed train lines (Paris-Lille, Lille-Brussels, Brussels-Köln, Paris-Strasbourg), highways (Lille-Brussels, Nivelles-Leuven, Luxembourg-Saarbrücken), pipelines (9 throughout Belgium), airports (Metz, Chalons-en-Champagne), industrial zones and large-scale housing areas.

These and other studies have progressively shown that much older phases of erosion and sedimentation could be attested. Some colluvial or alluvial deposits were clearly cut by and thus at least contemporary with Medieval, Roman or, in isolated cases, even older archaeological structures. These deposits are also younger than any periglacial phenomenon, and are thus clearly related to the Holocene period[6]. Langohr[7] indicated that, in our study area, these events could nearly always be related to and explained by a lacking vegetation cover due to anthropic activities. He further insisted on the distinction between different types of man-made erosion and the way to recognise their palaeo-forms in the field. Based on those premises, this article presents an overview of recent, mostly archaeo-pedological studies about past erosion-sedimentation on rescue excavations in the mentioned study area. It aims at completing other types of approaches, and serves as a complement for studies in other geographical areas.

1.2 Limitations

In the scope of this study it was impossible to present a complete regional overview, due to the large amount of sources available. Thus a selection of sources was made, in order to allow some

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5 E.g. for the loess area of Middle Belgium: Bollinne 1976; 1977.

6 E.g. De Decker 1989; Fechner 1994b.

7 Langohr 1990.

comparison with our own data. Other references are added for further reading, with the main aim of facilitating a more complete regional synthesis in the future. For detailed data and a critical survey of the primary data on the sites presented in this paper, we refer to the specific publications and reports[8].

Our focus is mainly on large-scale phenomena, of which the impact is visible in the field sections, and which have modified slope topography. However, besides this focus each chapter will present a number of more regional (repetitive) and more local (so far isolated) traces. Micro-scale events are excluded from the analysis. Examples of such events are erosion-sedimentation in archaeological structures (especially in ditches[9], local accumulations of sediment in ploughed fields, as in hedge rows and ridges[10], or in plough horizons with tillage erosion[11]. In contrast, large-scale effects of tillage practices (colluvium, notable erosion), are mentioned in the article.

For the Holocene, erosion-sedimentation phenomena on regional scales have been active mainly from the Neolithic period onwards, related to the progressive reduction of the vegetation cover. As mentioned in our study area, in a rather stable climate and with usually weak slopes, these are considered to be of human origin unless proved otherwise[12].

For colluvial as well as alluvial deposits, we limit ourselves to cases that are potentially related to direct or indirect anthropic influence.

Concerning alluvia, we will give a particular attention to fine grained (clay to fine sands), low velocity floodplain deposits. These can in some cases be related to an increasing human impact on the landscape, inducing erosion in upstream areas, and resulting in an increased sediment load in the river system, as well as more floodplain inundations in the downstream areas[13]. However, several authors have stressed the fact that even small climate fluctuations in the course of the Holocene can create sedimentation phases, especially in fluvial systems[14]. Besides this, the combined effects of land-use and climatic effects must be considered.

1.3 Objectives

The following main topics are treated in this paper:

- The main focus is to present a prospective state of the art concerning soil studies in the context of rescue archaeology. To this purpose our case studies are listed according to region and archaeological period. This allows screening for general trends, regional differences, and possible causes of erosion/sedimentation per region. This way we intend to facilitate the future confrontation with other study areas and periods[15], as we noted the relative scarcity of syntheses on the topic for the study area[16]. We thus contribute to fill a gap between the study areas of Britain[17], the Netherlands[18], the Middle and Lower Seine Basin and the Loire Basin[19], and Germany[20].
- The second aim of this article is to establish a chronology for erosion/sedimentation events. This is born out of the opportunities our data provides, i.e. deposits that often have *ante* and/or *post quem termini*. In the study area, it is until now rather seldom that the relation of these events with archaeologically dated structures or other chronological elements is well established. Cases with a more precise dating potentially permit to distinguish between events that are a consequence of anthropic impact and those that result from climatic events[21]. On the other hand, rescue archaeology seldom concerns areas that are off-site, which are thus largely lacking in this article and should be considered as the necessary complement[22].
- Thirdly, the field data we present can to some extent improve the interpretation of the published soil maps, for example the soil map of Belgium. This very detailed map is based on a mean density of one auger per hectare, all reaching a depth of 125 cm. In some areas, our observations have a higher density, were deeper, and provide a relative dating thanks to archaeological indicators. Latter details allowed us in certain cases to correlate the type of soil development mentioned on the soil map with well-dated relic colluvia and alluvia[23]. This correlation broadens the interpretation of the concerned soil map units, and provides additional information to the users of these maps.
- As a fourth point, this paper aims at providing information for archaeologists in the field, on recognising erosion and sedimentation events. These events are indeed an integral part of the everyday record of any archaeological excavation. False lithostratigraphical interpretations of these events result in errors and gaps in the archaeological record. Especially relic colluvia often look similar to the parent material. Here, the use of some easily recognisable characteristics can intervene as a routine instrument with a special interest for archaeology[24]. Once recognised, buried alluvial and colluvial layers are useful markers for a finer chronostratigraphy of the site and can help deciding on the depth(s) of excavation, as well as the choice of sampling strategies.

8 For limited accessible reports, see a.o. the first author and the thematic documentation centre of INRAP in Villeneuve d'Ascq (France).
9 E.g. Langohr 1990; 2000.
10 E.g. Bollinne 1976; Langohr 1990; Gebhardt *et al.* in press.
11 I.e. the thickening of such a horizon by addition of colluvium during its formation, e.g. Govers *et al.* 1994; Fechner *et al.* in press; Laurelut & Louwagie 2002.
12 Langohr 1990; Leopold & Völkel 2006.
13 E.g. Butzer 1982; Lüning 2000; De Ceunynck *et al.* 1985.
14 E.g. Starkel (ed.) 1996; Dotterweich 2008; Bork *et al.* 1998.
15 Especially for the first half of the Holocene: Bravard & Magny 2002, 12.
16 K. Wilkinson, personal comment.
17 E.g. Evans 1972; Burrin 1985; Brown & Barber 1985; Taylor & Lewin 1996 and 1997; Brown 1997, 192-230; Macklin 1999.
18 E.g. Bolt *et al.* 1980; Mücher 1974 and 1986; Kwaad & Mücher 1979; Berendsen & Stouthamer 2000.
19 E.g. Helluin *et al.* 1991; Kuzucuoglu *et al.* 1991 and 1992; Pastre *et al.* 1997; Ballut 2001; Ballut *et al.* 2003; Bravard & Magny 2002.
20 E.g. Bork 1983; Saile 1993; Semmel 1995; Lang & Hönscheidt 1999; Herget 2000; Lüning 2000; Lang 2003; Zolitschka *et al.* 2003; Dotterweich 2008 and 2012; Dotterweich *et al.* 2003. For Central Europe as a whole, see also Starkel 1991; Starkel (ed.) 1996; Bork *et al.* 1998; Dotterweich 2008; 2012.
21 E.g. Bravard & Magny 2002, 39, 41, 120.
22 E.g. in the study area: Bogemans *et al.* 2012; Brou *et al.* 2009; Cordier *et al.* in press; Houbrechts & Petit 2003 and 2004; Houbrechts & Weber 2007; Meylemans *et al.* 2013; Naton *et al.* 2009; Notebaert & Verstraeten 2010; Notebaert *et al.* 2009, 2010, 2011a, 2011b; Pastre *et al.* 2002; Riezebos & Slotboom 1978; Rommens *et al.* 2005, 2006, 2007; Verstraeten *et al.* 2009a-bb.
23 Louwagie 1996.
24 Fechner *et al.* 2004.

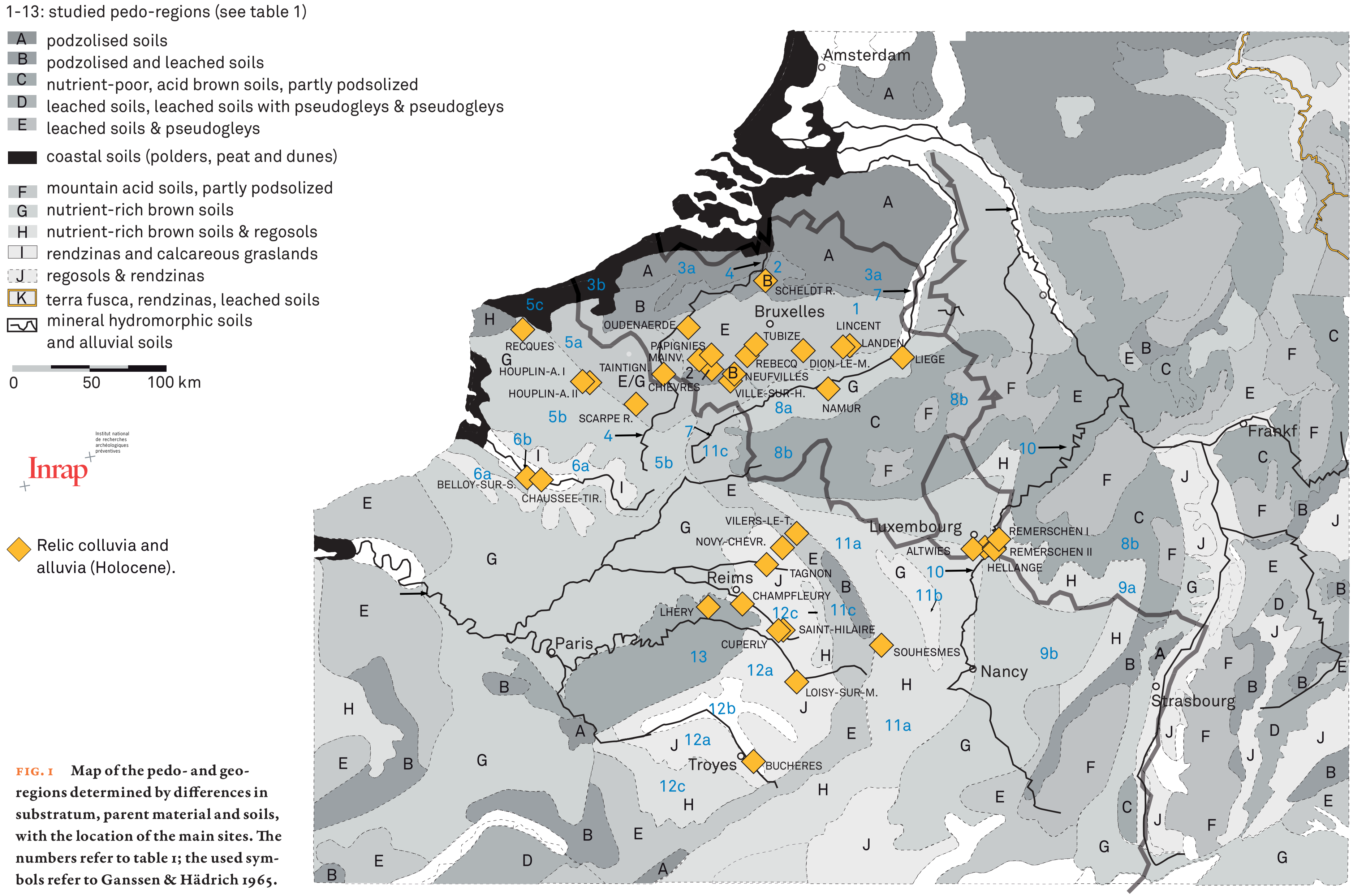


FIG. 1 Map of the pedo- and geo-regions determined by differences in substratum, parent material and soils, with the location of the main sites. The numbers refer to table 1; the used symbols refer to Ganssen & Hädrich 1965.

TABLE 1

Legend of regions shown in fig. 1, simplified.

Region	Substratum	Parent material	Soils (Ganssen & Hädrich 1965)	Particularities
1. Middle Belgium loess (Scheldt and Meuse Basins)	Mostly Tertiary (Eocene, rarely Oligocene, sands and clays)	Largely continuous Late Quaternary loess cover	Leached soils and pseudo-gleys (*G*, largely on decalcified loess)	Includes some valley bottoms with Quaternary (largely Holocene) alluvium, among others part of regions 4 and 7
2. Middle Belgium sandy outcrops and sandy loess (Scheldt and Meuse Basins)	Mostly Tertiary (Eocene, rarely Oligocene sands and clays)	Sometimes with Quaternary sand and/or sandy loess cover	Leached and podsolised soils (*G/E*)	Partly surrounded by region 1, lateral contacts with regions 3 and 5
3. Low Belgium (Scheldt Basin)	Mostly Tertiary (Eocene sands and clays), locally outcropping	Late Quaternary and Holocene sand cover	Podsolised soils (on sand) (*E*)	Includes some valley bottoms with Quaternary (largely Holocene) alluvium (among others part of region 4)
4. Valley bottom of the Scheldt/Escaut River (France, Belgium) (Scheldt Basin)	-	Mostly Quaternary (largely Holocene) alluvium	-	Lateral contacts with regions 1, 2, 3 and 5
5. Nord-Pas de Calais (France, some small parts in Belgium) (Scheldt Basin, small independent basins of the Canche, the Authie and the Aa)	Mostly Secondary (Cretaceous, mostly Upper Cretaceous limestones) and Tertiary (Eocene, rarely Oligocene or Miocene, sands & clays)	Very important Quaternary loess cover.	Mostly leached soils and pseudo-gleys (*G*, on decalcified loess)	Includes a lot of subareas with patchy Late Quaternary loess cover and Quaternary (largely Holocene) alluvium, among others part of region 4
6. Somme (France) (Somme and Seine Basins)	Mostly Secondary (Upper Cretaceous limestones)	Very important Quaternary loess cover	6a: mostly brown soils, rich in nutrients (*G/K1*); 6b: along the the Somme Valley: some rendzinas (*v1*) and some leached soils and pseudo-gleys (*G*, mostly on decalcified loess)	Includes some valley bottoms, especially the one of the Somme River, mostly made of Quaternary (largely Holocene) alluvium
7. Valley bottom of the Meuse River (France, Belgium) (Meuse Basin)	-	Mostly Quaternary (largely Holocene) alluvium	-	Lateral contacts with regions 1, 8 and 11
8. Ardennes (Belgium, Luxemburg and France) (Meuse Basin)	Mostly Primary (often Devonian sandstones, quartzites, schists and psammites) in higher landscape positions, elsewhere possibly Secondary	Occasional Late Quaternary periglacial deposits and local loess cover	8b: mostly acid brown soils, poor in nutrients (*K2*); 8a: at its northwest border: brown soils, rich in nutrients (*G/K1*).	Includes some valley bottoms with Quaternary (largely Holocene) alluvium, among others part of region 7 Lateral contacts with regions 1, 8 and 11
9. Eastern Lorraine (France and Luxemburg) (Rhine Basin)	Mostly Secondary (Trias, often sandstone)	See substratum	9b: mostly brown soils, rich in nutrients (*G/K1*). 9a: acid brown soils, poor in nutrients (*K2*)	Includes some saline rocks and soils, some valley bottoms with Quaternary (largely Holocene) alluvium, among others part of region 7
10. Valley bottom of the Mosel/Moselle River (France, Luxemburg) (Rhine Basin)	-	Mostly Quaternary (largely Holocene) alluvium	-	Lateral contacts with regions 9 and 11
11. Western Lorraine (France and Luxemburg) (eastern part: Rhine Basin; western part: Seine Basin)	Mostly Secondary (Jurassic, often marl and limestone)	Marl, chalk, sand stone; rare Late Quaternary loess cover	11a: mostly brown soils, rich in nutrients and regosols (*K1/Y1*); 11b: only brown soils, rich in nutrients (*G/K1*); 11c: along the eastern border: leached soils and pseudo-gleys (*G*), often on clays)	Includes some valley bottoms with Quaternary (largely Holocene) alluvium, among others part of region 7

Region	Substratum	Parent material	Soils (Ganssen & Hädrich 1965)	Particularities
12. Champaign (France) (Seine Basin)	Mostly Secondary (cretaceous, mostly limestone)	Predominant calcareous, locally slightly decalcified substratum, seldom dissolution phenomena; very localized late Quaternary loess cover especially along large river valleys (Seine and Marne)	Mostly regosols and rendzinas (*Y1/v*)	Includes some valley bottoms with Quaternary (largely Holocene) alluvium
13. Tardenois and Aisne (France) (Seine Basin)	Mostly Tertiary (Eocene and Oligocene sands and clays)	Local Late Quaternary loess cover, mostly calcareous substratum with dissolution phenomena	Leached soils and pseudo-gleys (*G*) and brown soils, rich in nutrients (*G/K1*)	Includes some valley bottoms with Quaternary (largely Holocene) alluvium

- Finally, this research intends to stress the importance of off-site archaeology, even if the focus on rescue excavations limits our data mostly to the near surroundings of settlements. These off site data make it possible to assemble soil-based information on activities next to the settlements and anthropogenic impact on the landscape, and their evolution through time. Erosion-sedimentation sequences observed in archaeological contexts furthermore complete those based on pedogenetic evolutions throughout the Holocene[25].

1.4 Study area and geographical context

The catchments concerned by the present study are those of the Scheldt (Escaut), the Somme, the Meuse, the middle part of the Rhine Basin, and the upper part of the Seine Basin. They are situated in Northern France, Luxemburg and Belgium, an area surrounded by the Netherlands and Germany, and limited in the south by a horizontal line between Strasbourg, Nancy, Paris and Rouen. Thirteen pedo- and geo-regions can be distinguished on the basis of differences in soils (fig. 1, table 1). Many rivers have a catchment situated in more than one region. As such, alluvial processes are often a result of conditions of more than one region, which justifies a distinct treatment for some major valley bottoms (table 1: regions 4, 7 and 10).

The study area is characterised by a considerable climatic diversity, as is illustrated by conditions at different extremes of the area, as Brussels "Uccle" (regions Middle Belgium loess/sandy outcrops of fig. 1 and table 1)[26], the Belgian Ardennes[27], Metz "Fretzat" (regions Mosel valley/Western Lorraine)[28] and Chalons-en-Champagne (region Champaign)[29]. The mean annual precipitation is 840 mm in Brussels and 1150-1500 mm in the Ardennes, against 674 mm in Metz and 618 mm in Chalons-en-Champagne, whereas the mean annual evapotranspiration is 640 mm in Brussels and 540-650 mm in the Ardennes, against 654 mm in Metz and 634 mm in Chalons-en-Champagne. The latter station is the only area where there can be, on average, a little excess of evapotranspiration over the amount of water that penetrates the soil, partly explaining a very different soil development, with limited soil leaching, and, related to this, differences in potential erosion.

2 Material and methods

The data presented here include:
- 74 sites with one to seven generations of relic Holocene essentially man-induced colluvium.
- 26 sites with relic Holocene alluvial depositions that are potentially anthropogenic.
- Some cases mentioned by literature that contribute to the subject are incorporated in the analysis.

2.1 Terminology and definitions

A debate concerning terminology and definitions has been ongoing between researchers in our study area during the last years. The following paragraphs propose a synthesis that might be a compromise on this topic.

⊙ At a first level (fig. 2) we distinguish between:
- *Relic* colluvium and alluvium, which is buried under other sediments, and:
- *Active* colluvium and alluvium, which appears at or just below the present-day surface, and is only affected by the present-day humiferous surface horizon.
  This term relic colluvium is preferred to "ancient" or "old" colluvium[30]. In the same way, we propose the term "active", more frequently used in literature[31], rather than "recent" colluvium/alluvium.
  Both these terms have the advantage that they are neither chronological nor determined by well-defined processes.
  The proposed taxonomy enables a preliminary classification that can be used before such more detailed appreciations (see below: second and third level). The latter are often only obtained in a second phase of the research or sometimes even remain hypothetical.

25 E.g. Langohr & Sanders 1984; Van Vliet-Lanoë *et al.* 1992; Langohr 2001; Schalich 1983.
26 Baes 1985.
27 Ministère de la Région wallonne 2005.
28 De Decker 1989.
29 Météo France 2005; Léviel 1996 referring to Ballif 1994.
30 E.g. Scheys 1955; Liekens 1962; Louis 1969; Bolt *et al.* 1980.
31 Scheys 1955; Liekens 1962; Louis 1969; Bolt *et al.* 1980; Fechner 1995.

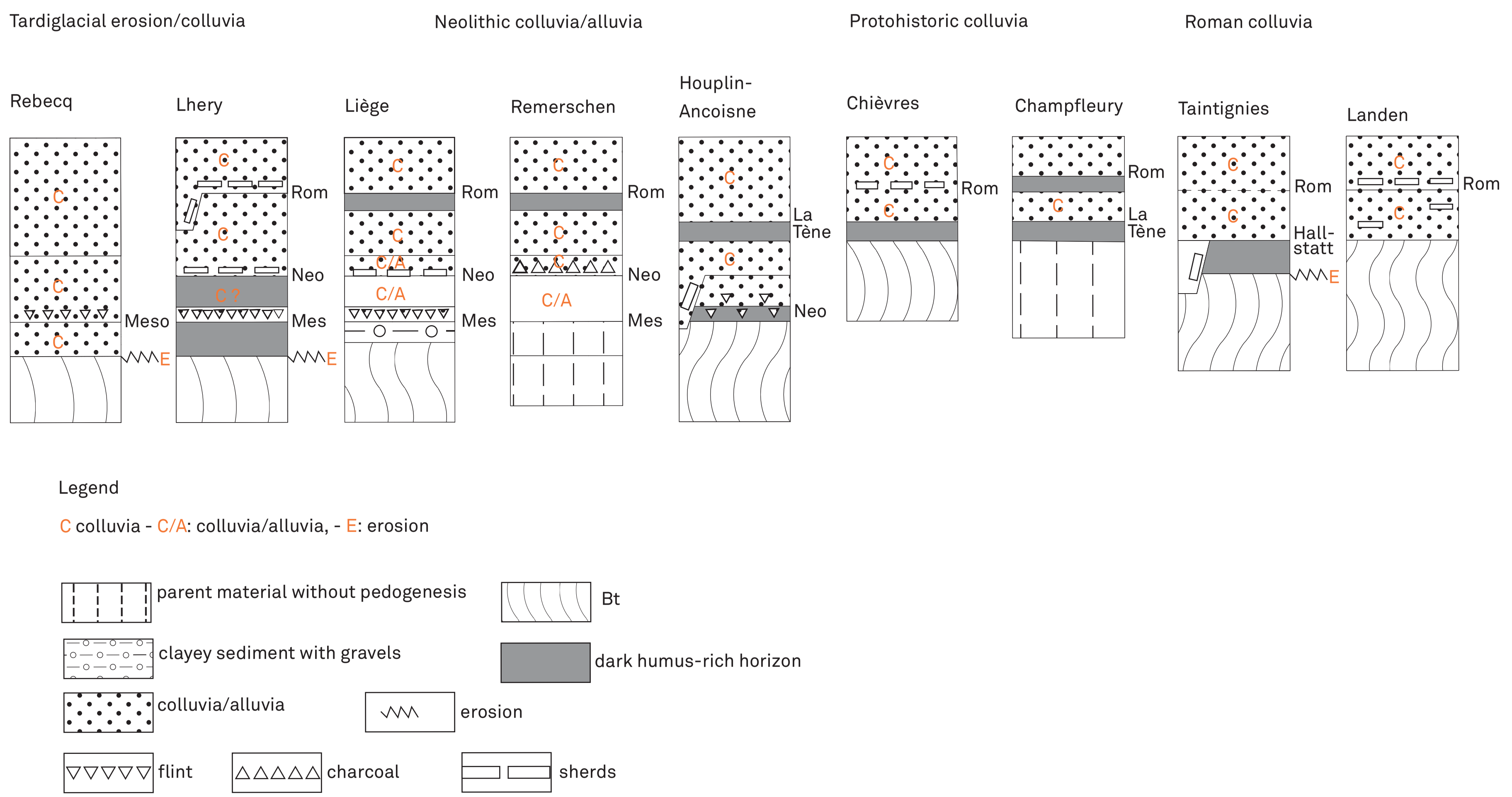


FIG. 2 **Comparison of some of the sequences of colluvium in Middle Belgium and adjacent areas. For more recent periodes, it has long been believed that large-scale erosion in Middle Belgium did not occur before the Late Middle Ages (e.g. Bolline 1977, 196). On the other hand, palynological results had shown that large parts of Middle Belgium were globally as deforested as today from the Iron Age onwards (Munaut 1988). The results of archaeopedological studies on rescue excavations have indeed revealed extended Roman colluvia in some areas that were rarely in direct association with a settlement (Fechner 1998a).**

⊙ At a second level, we can also follow the terminology proposed by Bolt *et al.*[32], also used in the thesis of Louwagie[33] and by Baes *et al.*[34]. It distinguishes between:
- *Anthropogenic* colluvium and alluvium, and,
- *Natural* (or geogenetic) colluvium and alluvium.

Here, too, the present article only treats the first category.

⊙ At a third level, the relative chronology can be used for a further distinction between:
- *Pre-Roman and Roman* colluvium and alluvium (before the Middle Ages), and,
- *Post-Roman* colluvium and alluvium (from the Middle Ages up to nowadays).

As mentioned, a precise relative dating can only be indicated in case of sufficient data, which makes it difficult to use this criterion for a systematic classification of the observed cases.

The terms used in this article combine one or more of the upper distinctions, according to the available information for each individual case. This leads to a number of possible categories, of which only the ones with a grey background in table 2 are further discussed in this article.

As far as colluvium in the study area is concerned, some general trends can be noted.
- *Active colluvium* always occurs at or just below the present-day surface. The colour and granulometry of this colluvium are often characterised by a pronounced mixture of materials, which indicate that different horizons, including deeper-lying ones, were affected by erosion, and that the colluvium might in some cases be the result of a succession of erosion-sedimentation cycles (cf. also cascade model of Lang[35]). The underlying soil or parent material is almost always strongly eroded. In the colluvial material, pedogenesis is absent or very restricted compared to lower-lying colluvia.
- Relic colluvium almost always includes indicators of continued soil formation, as for instance clay coatings, often only visible in thin sections. The colour and granulometry of this colluvium often recall *in situ* horizons (dark, humiferous, "A_1"-horizon; orange, well-developed, "B_{2t}"-horizon etc.) and indicate the absence or scarcity of mixture of different soil horizons affected by the erosion. Moreover, in most cases, the underlying soil or material is not eroded or only to a very limited extent.
- In exceptional cases, we can encounter a colluvium that is at the present-day surface and has all the other characteristics of relic colluvium, confirmed by analyses or micromorphology. This reflects a palaeo-event that has never been followed by a recent sedimentation or where later deposits have been eliminated since then. Here we propose to use the term "*present-day surface relic colluvium*". However, until now this case remains hypothetical as the probable examples are only based on indications as morphology or pollen spectra and lack any certain dating evidences[36].

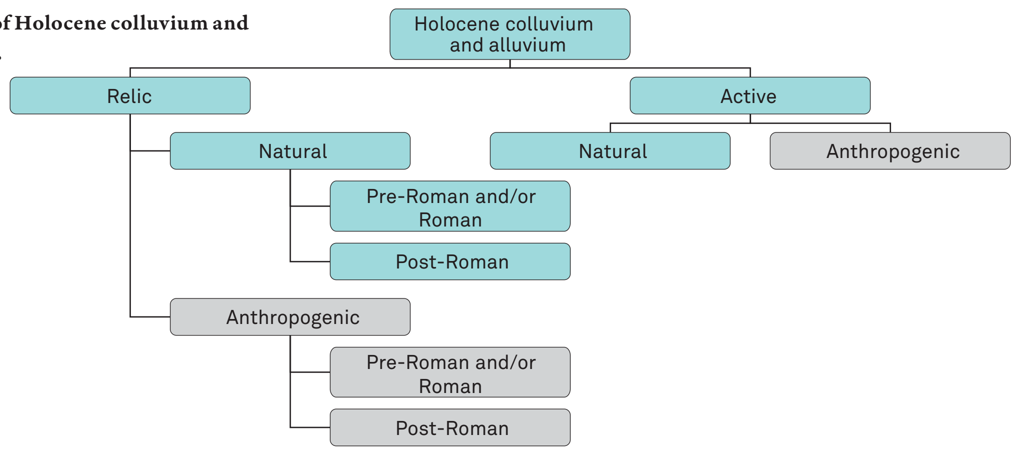
Note also that pre-Holocene colluvium (usually related to natural erosion-sedimentation processes in glacial environments) is in literature often referred to as "*colluviated parent material*", for instance "*colluviated loess*"[37]. In the study area, its relative age is shown by the fact that it is always affected by the impact of permafrost that intervened at the very end of the Tardiglacial (Dryas III).

2.2 Pedostratigraphical approach and dating

Soil horizon description was done according to FAO-guidelines[38]. The terminology of soil types follows the FAO-legend[39], except for the legend of the map (fig. 1, table 1) which follows Ganssen & Hädrich[40].

The results from the individual sites are based on a mixed approach of soil science and lithostratigraphy, integrating data obtained from archaeology. Field soil descriptions, collected over

TABLE 2.
Proposed categories of Holocene colluvium and alluvium in the study.



32 Bolt *et al.* 1980.
33 Louwagie 1996, 96.
34 Baes *et al.* 2000.
35 Lang & Hönscheidt 1999; Zolitschka *et al.* 2003, 82.
36 E.g. discussion concerning the top part of the colluvia in Rebecq "Spinoi" below and in Fechner *et al.* 2010.
37 Fagnart 1988; Peulvast 1983; P. Haesaerts, pers. comm.
38 FAO 1968.
39 FAO 1988.
40 Ganssen & Hädrich 1965.

several years and often in continuous valley cuts, constitute the base of this study, and are completed with physico-chemical and micromorphological characterisations. For the detailed methods used for these observations and analyses, we refer to other publications[41]. The case studies are part of an extensive database of field soil descriptions, micromorphology and laboratory data that can be consulted in the mentioned reports or with the authors.

All of the studied horizons are dated by relative chronology through the relation with archaeological finds or based on lithopedostratigraphical grounds. Some horizons can be dated more precisely, by both a *terminus post quem* and *ante quem*. The limited amount of information on absolute chronology can partly be overcome in some regions through the large number of case studies available. This is obtained by the juxtaposition of all the cases that possess a relative dating (e. g. "colluvium deposited prior to installation of a Late Medieval ditch") with the few cases that have absolute dating (e. g. "initial colluvial layer that buried an *in situ* peat layer, itself dated by ^{14}C to the 1st century AD"). ^{14}C-dates are presented with a 2 σ precision.

3 Results per pedo- and geo-region

In this chapter we first present per region the data on relic colluvium which reflect regional or subregional tendencies based on occurrences in similar time spans and in neighbouring sites, valleys or slopes. Second, we mention the most important sites that don't coincide with such recurrent phenomena in our present state of research, and which might thus also reflect only site-specific or local events. Thirdly, relic alluvia are treated separately, as they are very different environmental systems with specific dynamics.
For a summary of the main characteristics of the substratum per region (parent material and soil types), we refer to table 1 and fig. 1.

3.1 The middle Belgium loess region

This area is dominated largely by deeply decarbonated loess deposits with rather poor soils (fig. 1; table 1).

3.1.1 Slope deposits at a regional scale

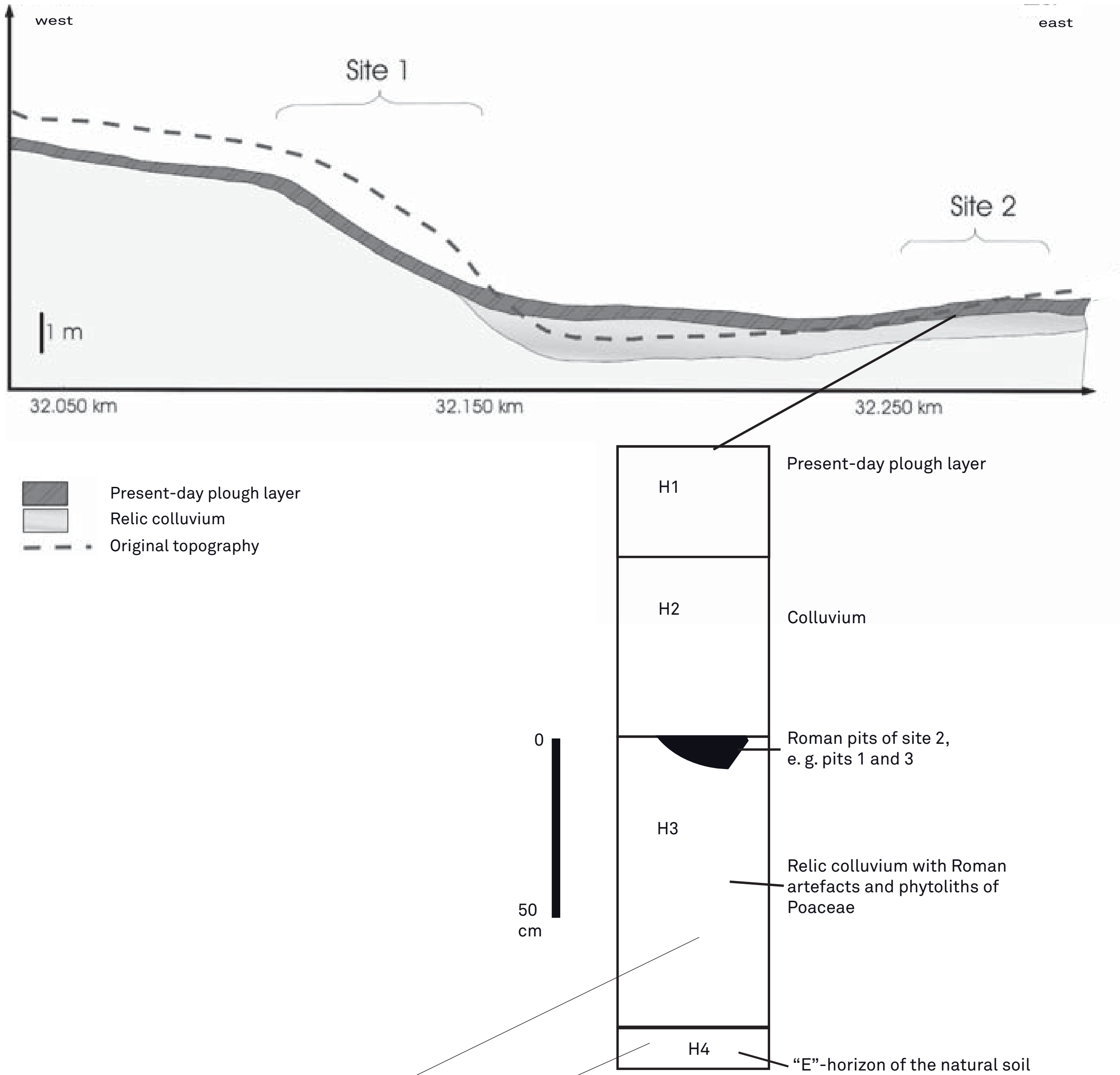
The eminently dominant soils of this area are Luvisols formed on a deeply decarbonated loess. This soil formation is usually attributed to the Tardiglacial and at the very beginning of the Holocene[42]. Due to the rather weak slopes in this area and to the rather continuous vegetation cover in the first part of the Holocene, erosion processes on a regional scale only started through significant anthropogenic impact, from the Neolithic onwards. Two possible older cases are chronologically situated between the mostly tardiglacial soil formation and the occurrence of stable climate and vegetation in the Early Holocene. These are situated in Rebecq and possibly in Taintignies (fig. 2)[43] and show limited erosion-sedimentation events.

⊙ The Landen-Lincent sector
The sites of Landen (fig. 3) and Lincent (fig. 4) are the most representative examples. These sites are situated in two large dry valleys that are juxtaposed and are both filled with Roman colluvium over the complete length of the transversal section of the valley, on an uneroded and unploughed in situ Luvisol. The colluvia are cut by Roman structures in Landen and both contain Roman material. Ard marks, an interpretation which is confirmed by the study of Helen Lewis[44], and traces of woodland clearing by burning of trees (among others Pommoideae and Corylus avellana) are present in Lincent[45]. Micromorphological characteristics which are usually associated with cultivation practices[46] were observed in the relic colluvium of Landen. These combined data enable us to interpret these sites as large cultivated surfaces on which tillage or other types of short distance erosion occurred[47]. Alternative explanations, such as the transport of colluvium in pathways or roads, do not fit with the internal characteristics, with the overall distribution and with the lack of sorting in most sublayers, of the colluvial deposits.

⊙ The Hannut-sector
Situated in the same area, relic colluvia at the sites of Hannut/Cras-Avernas "Village", "Trommelveld" I and II, and "Tommeveld" display very similar morphological and stratigraphical characteristics as in Landen and Lincent, but without the association with former in situ ploughing horizons[48]. They are orange clay-rich colluvia that originate from the Luvisol "Bt"-horizon, and are situated below a darker coloured humiferous active colluvium. The sites of Hannut cover three successive dry valleys and might be dated to the same period as Landen and Lincent (supra), which are situated in the immediate neighbourhood. In the studied sections, thick deposits of the homogeneous orange relic colluvium are buried below thick active colluvium in three of the valley heads that surround a Celtic quadrangular enclosure. The relic colluvia bury an uneroded soil pedon and in one case ("Trommelveld" II) the relic colluvium covers two black surface A-horizons of different ages, situated above and below the *in situ* eluvial E-horizon. At the contact with the relic colluvium, there are some charcoal fragments and reworked remains of the surface A-horizon.

⊙ The Waremme sector
The relic colluvia on the sites of Berloz, Lantremange and Voroux-Goreux have revealed the same morphological and stratigraphical characteristics as the former ones[49]. It is noticeable that the Belgian soil map of the "Hesbaye" area west of Liège shows colluvial valley fills that are particularly large when compared to other parts of Middle Belgium. These very broad bands in the eastern part of the Hesbaye region contrast with the very narrow strips of colluvium/ alluvium in the valleys in the Hainaut province, in the west of the region. This distinction might thus in part relate to massive Roman field erosion in the eastern Hesbaye region.

41 Langohr 1992 and 1994; Fechner & Laurent 1996; Fechner *et al.* 2004; Fechner in prep.
42 Van Vliet *et al.* 1992.
43 Fechner *et al.* 2010.
44 Fechner 2007b; Fock *et al.* 2008.
45 Deligne 2002; Fechner & Schartz 2000.
46 Following Gebhardt 1997.
47 Schrijvers & Van Impe (eds) 2001; Fechner 1998a and 1998b; Fechner *et al.* 1999; David *et al.* in press.
48 Fechner 1998a.
49 Fechner 1998a.



Clay	Fine silt	Coarse silt	total silts	Very fine sand	Fine sand	total fine sands	Medium coarse sand	Coarse sand	Extreme coarse sand	total coarse sands	total sands	Total fine fractions	Ratio fine / coarse silts		Profile	Depth	Inter-pretation
g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg		Unités GiEP			
230	276	433	709	49	7	56	4	1	0	5	61	1000	0,64	Landen	PRef	-0 à 10	
212	287	438	725	51	9	60	3	0	0	3	63	1000	0,66	Landen	PRef	-10 à 20	
219	281	443	724	43	10	53	4	0	0	4	57	1000	0,63	Landen	PRef	-30 à 40	
202	205	472	677	109	10	119	2	0	0	2	121	1000	0,43	Landen	PRef	-50 à 60	
212	206	464	670	105	10	115	3	0	0	3	118	1000	0,44	Landen	PRef	-60 à 70	
203	192	484	676	108	9	117	4	0	0	4	121	1000	0,40	Landen	PRef	-70 à 80	
181	183	535	718	94	6	100	1	0	0	1	101	1000	0,34	Landen	PRef	-80 à 90	
145	187	545	732	113	8	121	2	0	0	2	123	1000	0,34	Landen	PRef	-90 à 100	
128	210	541	751	85	18	103	9	4	5	18	121	1000	0,39	Landen	PX	-5	
156	241	503	744	68	17	85	9	3	3	15	100	1000	0,48	Landen	PX	-15	
142	211	522	733	92	19	111	6	4	4	14	125	1000	0,40	Landen	PX	-35	
145	192	525	717	81	32	113	20	4	1	25	138	1000	0,37	Landen	PX	-55	
209	261	456	717	52	15	67	6	1	0	7	74	1000	0,57	Landen	PX	-90	
213	295	422	717	37	16	53	7	6	4	17	70	1000	0,70	Landen	PX	-105 à 125	
139	286	483	769	59	10	69	7	10	6	23	92	1000	0,59	Landen	PX	-125 à 145 E	
134	251	508	759	67	13	80	10	12	5	27	107	1000	0,49	Landen	PX	-165	E-Bt
187	261	468	729	62	11	73	8	2	1	11	84	1000	0,56	Landen	PX	-190	B22t?
150	242	516	758	70	8	78	6	6	2	14	92	1000	0,47	Landen	20B1		Ap
141	216	542	758	87	7	94	4	3	0	7	101	1000	0,40	Landen	20B1		Colluvions
169	236	494	730	85	5	90	5	5	1	11	101	1000	0,48	Landen	20B1		Colluvions
184	237	503	740	59	4	63	8	4	1	13	76	1000	0,47	Landen	20B1		Colluvions
247	272	420	692	59	2	61	0	0	0	0	61	1000	0,65	Landen	10A3	-70 à 80	

FIG. 3 **Transect and reference profile of the site of Landen « Populieren », with relative dating of the colluvium given by the archaeological materials and structures, both Roman.**

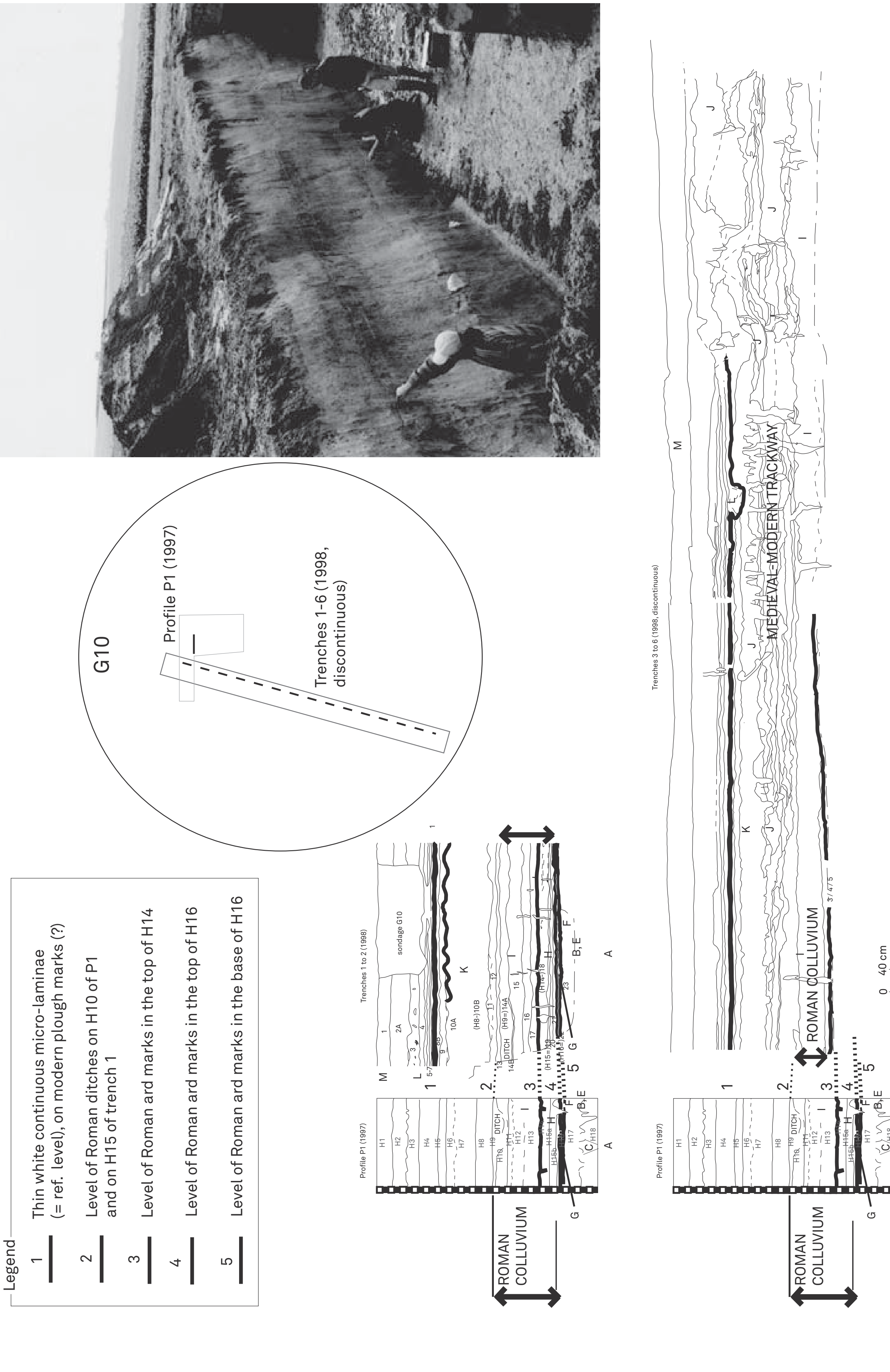


FIG. 4 **Reference profile of the site of Lincent "Couture" II.**

G. Louwagie[50] has mapped occurrences of colour- and/or structure-B-horizons formed in "old colluvium or alluvium" according to the Belgian soil map. These are all situated in the loess belt of Belgium (regions "Middle Belgium loess" and "Middle Belgium sandy outcrops and sandy loess") and are discussed later (see chapter on that second area).

◉ The Leuven sector
In the area of Leuven, as in Huldenberg[51], some palaeogulleys are found in old forests that are protected from significant erosion since at least the 14th century. Some of these gulleys are related to significant erosion/ sedimentation processes leading to the arrival of silty sediments in the alluvial plain of the Dijle River, possibly from the Atlantic onwards[52]. According to detailed mapping, most gulleys found in the nearby Meerdael forest are possibly of Roman and/or Iron Age, and reflect periods of extended land use[53].

3.1.2 Slope deposits on a local scale

Only very superficial and localised erosion and sedimentation events can be associated with pre-Roman occupation. These phenomena did however not yet significantly modify the topography and soilscape.

Surprisingly, one of these example can be attributed to the Early Mesolithic period[54]. This site (Rebecq "Spinoi") is situated in a very shallow valley head on the lower part of a slope, along a small river. An upper colluvial deposit is installed on the Mesolithic occupation level, which in turn covers relic colluvium, and a Luvisol. The Luvisol was almost completely developed, and had been slightly eroded before being covered. The relic colluvium is lacking any, especially micromorphological, indicators of pre-Holocene climatic conditions that would define this deposit as a "colluviated loess" (see above). The uneroded top of the relic colluvium coincides with the occupation level, including some artefacts that were *in situ*. A number of other artefacts were retrieved from slightly reworked deposits which form the base of the overlying upper colluvium. Here the erosion-sedimentation phase is possibly linked to the Mesolithic occupation itself. Micromorphology and palynology also favour the hypothesis that the upper colluvium might be "present-day surface relic colluvium" rather than active colluvium. Both colluvial deposits possibly stem from anthropogenic presence and activities, resembling similar cases on later Mesolithic sites[55]. However, in spite of the lack of indications, we cannot exclude that a disequilibrium in the climatic conditions at the contact between Pleistocene and Holocene is in part or fully responsible for the lower erosion-sedimentation event[56]. It is interesting to note that these erosion-sedimentation processes already affected the largely developed Luvisol. The latter thus existed in the Early Mesolithic and before the colluviation.

Other sites with site-specific erosion are found in Aubechies "Coron Maton", in Remicourt "En Bia Flo" II, in Chièvres "Ferme Taon" and in Tubize "Laubecq". At the first two sites, relic colluvium reflects a clear inversion of the Luvisol originally located higher upslope. The inverted profile includes the displaced dark surface A-horizon. In Aubechies, the original dark surface horizon is preserved below the colluvium, referred to as the "Soil of Aubechies" and interpreted as an Early Neolithic plough horizon[57]. Both the deposits of Aubechies and Remicourt are located a few metres downslope of an Early Neolithic settlement and could be more or less contemporary with these settlements, and related to tillage practices in or on the settlement borders. In Aubechies however, charcoal of *Prunus avium* in the base of this dark colluvium is dated in the Late Iron Age. In "En Bia Flo" II, the dark colluvium is situated in the middle part of the fill of a large Early Neolithic fortification ditch, situated at the base of a long slope on which the Neolithic occupation is situated. As in "En Bia Flo" II, but situated in the neighbouring dry valley, and without any traces of a habitation site, a similar dark relic colluvium is observed in "En Bia Flo" I. It is similarly situated along a west-facing slope, but outside any archaeological structure. However, during the archaeological surveys in light of construction of the high speed train railway here, this whole area revealed a very high density of Early Neolithic sites, one every two or three valleys. The lack of dating evidence for these dark colluvial layers does not allow to classify them as being part of a larger common erosion process. Rather than Early Neolithic erosion, it is more probable that they originate from later erosion-sedimentation of a rather thick Early Neolithic ploughed soil horizon, as has been shown in Aubechies. The preservation of the dark colour is due to the very short transport distance. This hypothesis would indicate the former presence of these ploughed soils on these two west-facing slopes of Remicourt.

At the site of Chièvres "Ferme Taon", relic colluvium from tillage or another short-distance erosion is covering a tilled surface with one evident straight ard mark dating to the 5th century BC, and a surface level with evidence of a stable or a corral of the 1st century AD. This surface horizon below the relic colluvium, which was interpreted as a ploughed horizon, contained charcoal dated to the Middle to Late Bronze Age (^{14}C: 1380-1115 BC) and to the Iron Age (400-210 BC), and some Early La Tène sherds. A detailed soil analytical and micromorphological characterisation[58] provided some useful information for the understanding and definition of relic colluvium. Among other aspects, it was distinguished from the active colluvium by the presence of frequent matrix or unsorted clay coatings (see also below: site of Taintignies). As in the cases of the Somme region and in the Meuse Valley bottom (see below), among others, the relatively old erosion event of Chièvres might possibly or partly be explained by the presence of much more pronounced slopes as compared to the other regional examples.

50 Louwagie 1996.
51 Poesen *et al.* 2003, fig. 11.
52 Bollinne 1976, 160.
53 Vanwalleghem *et al.* 2003. In Moustier, other traces of former agriculture in actual forests include terraces that are most probably made of colluvium (Fechner *et al.* 1994).
54 Fechner *et al.* 2010.
55 See below: region "Somme", where the site of Saleux has colluvium, although it coincides with a very short occupation. For discussion on other impacts of Mesolithic man on the landscape: Lauwers & Vermeersch 1982; Lüning 2000, 36-38; Richard 1995; Leroyer 2001; Vannière & Laggoun-Defarge 2002, 121-2.
56 *Cf.* Van Vliet-Lanoë 1990: Preboreal solifluxion.
57 Mikkelsen & Langohr 1996.
58 Louwagie *et al.* 2000; Fechner *et al.* 1998.

Two other cases with relic colluvium with similar morphologies and stratigraphies as at Chièvres are present in Huissignies and Brugelette, which are also in the larger surroundings of the city of Ath. These sites are however too far from each other and are too badly dated to be considered as reflecting a common erosion/ sedimentation process.

In Tubize "Laubecq" two generations of relic colluvium coincide with the presence of Medieval and post Medieval (10th to 17th century) occupation and agricultural fields on the upper slopes. The latter phase has included the formation of one large accumulation of relic colluvium that is perpendicular to the slope and must have been deposited against a hedge[59].

A number of similar cases, which also might be related to colluvial rather than alluvial processes, are included in the following paragraph.

3.1.3 Fluvial deposits

Only a small number of isolated data concerning relic alluvium are available from preventive archaeological studies[60]. In Tubize "Laubecq", a massive deposition of alluvial clays coincides with the end of peat formation in the valley bottom. This clay deposition started in or after the Roman period, but before the formation of Medieval colluvia (see above).

In the valley bottom of Wasmes-Audemez-Briffoeuil "Cimetière", along a small present-day brook, heavily micro-stratified clay deposits contained large Late Medieval and/or Modern artefacts from the adjacent habitat, situated only a few decameters away on the lower slope[61].

The only certain case of a "present-day surface relic alluvium" of our knowledge is attested in the dry flat-bottomed valleys of the Zonian Forest[62], consisting of a silty laminated alluvial layer, which has been deposited during the Subatlantic, due to reworking of the older alluvium. This layer lies at the present surface and is characterised by the formation of a colour- and structure-B-horizon and a weak clay migration.

The three following examples of deposition in fluvial valley bottoms could be of related to colluvial processes, were it not they are associated with particular topographical contexts. Possibly these concern colluvial deposits, reworked by fluvial or alluvial events. Moreover, these deposits have the same characteristics as the Sub-boreal deposits of Liège and Houplin-Ancoisne located in the neighbouring regions "Meuse Valley floor" and "Nord-Pas-de-Calais", whose contexts might favour an association with relic alluvium in the first, and relic colluvium in the second case (see below).

In Ath/Arbre "Dendre"[63], midway a slope above the river, a fine deposit intervenes between an Early Atlantic surface horizon (^{14}C for the latter: 7520-7070) and a Roman anthropogenic fill. Both the valley bottoms at Brugelette "Bois d'Attre" and Chièvres "Moulin de la Hunelle" are also characterised by a similar thin light grey deposit of silt and fine sand. The site of "Moulin de la Hunelle" is situated in the valley bottom of a small meandering river (the Hunelle), along the present river bed, and predates a buried surface horizon of the Early Iron Age. As in Ath, these deposits are situated next to the present river bed and completely leached of all hydroxides, so they might be alluvium as well as colluvium. In Brugelette, however, there is only a temporary water flow nowadays, and analyses indicate that the colluvium is identical to the underlying eluvial horizon of the natural soil.

A Sub-boreal age of these deposits is compatible with the stratigraphy of the three sites, even if it not possible to be certain.

3.2 Middle Belgium sandy outcrops and sandy loess

The parent material in this region is composed of Tertiary outcrops and secondary aeolian deposits whereby sand and silty loess were mixed, resulting in sandy loess (fig. 1; table 1). Some sites, as at Dion-le-Mont, are situated in the loess belt, but are at least partly situated on and thus also strongly influenced by sandy (Tertiary) outcrops. This specificity explains the distinction from the sites of the previous region. As for the previous area, soils are rather poor.

3.2.1 Slope deposits at a regional scale

As mentioned earlier, the traces of depositions of relic colluvium seem at this stage much more abundant in the areas with sandy loess. For instance, in spite of the great abundance of geoarchaeological studies in the city of Brussels, largely located on sandy outcrops, no evident relic colluvium has been encountered, neither on the sandy slopes of the valleys, nor at the contact with the alluvial valley of the Senne River. In the surrounding sandy areas of the Brabant Province, investigations are probably still too scarce.

⊙ The Ostiches sector

In Ostiches and Papignies, four neighbouring sites are situated in a relatively hilly area with numerous dry and active valley heads and sandy and clayey Tertiary hilltops.

In Ostiches "Hameau du Rec" and in Papignies "Marais de Papignies" relic colluvia had similar characteristics as the examples from Middle Belgium, i.e. displaying the characteristics of a rather clayey orange reworked "Bt" horizon of a Luvisol. Several decimetres of colluvium with Protohistoric sherds were also observed in Papignies "Chapelle de la Cavée", under Roman or Protohistoric ditches. These rather thick and extensive deposits are probably related to agricultural fields rather than to more local phenomena such as settlements or pathways. In Ostiches "Chêne Saint-Pierre" and Mainvault "Embise", some thin colluvial deposition is present respectively below a Roman tomb and below Medieval settlement structures[64]. In these two cases, the thin deposits with some artefacts probably originate from erosion of the occupation level, whereas in Rebecq some erosion was induced by repeated walking (see above).

59 Fechner & Sartieaux 2000; Fechner 1999.
60 The "old alluvium" found in numerous places of Middle Belgium on the Belgian soil map (Louwagie 1996, 9-10, 16-17) would be pre-Holocene, maybe Allerød, although more recent dates cannot be excluded; the palynological studies performed on some of these in Middle and Low Belgium might also allow a dating between the Preboreal or Boreal and the Subatlanticum.
61 Willems 1996.
62 Sanders *et al.* 1986.
63 Fechner & Sartieaux 2000.
64 Fechner & Bécu 2001.

Relation with the Belgian soil map:
As mentioned above the soil map of Belgium indicates a particular soil type, i.e. soils with a "structure- or texture-B-horizon" formed in "old colluvium or alluvium" in some parts of the regions "Middle Belgium loess" and "Middle Belgium sandy outcrops and sandy loess"[65]. Among other areas this is for example the case in the area studied along part of the highway from Brussels to Lille, in the western part of the province of Hainaut. In the field this soil type coincided with relic colluvium. In accordance with the four neighbouring sites in Papignies and Ostiches (see above), excavated along that highway, it is very probable that most of this soil unit is relic colluvium due to a large-scale Roman phase of colluviation. According to Scheys[66] the sites on "old colluvium" would be situated in spring areas and would coincide with actual dry valley heads, as is the case for relic colluvium in the area of South Limbourg in the neighbouring Netherlands. This neighbouring loess area similarly has revealed Roman and/or post-Roman anthropogenic colluvium[67].

This position in valley heads might fit with the cases of Papignies and Ostiches, as well as "Ferme Taon" and Hannut in the region "Middle Belgium loess" (see above), which are also situated in dry valley heads.

⊙ The Dijle-sector
An excavation in Dion-le-Mont revealed a Roman building that was constructed on a thick relic colluvium that filled the sides of a dry valley, containing no artefacts except some fragments of burnt earth (fig. 5)[68].

Notebaert *et al.* (2009) presents a global study of the Dijle-catchment (which includes the former site), based on numerous transects and augerings. The datings in the Nethen subcatchment indicate a "start of colluviation around 7000-6000 BP (5900-4800 BC) with increasing amounts from 2500-3000 BP (1300-500 BC)", but "significant colluvation (...) from Roman period onwards". There might be an important time lag before alluvial deposition was significant in the floodplain, which was mainly after the Early Medieval Period (see below and comparison with works of C. Ballut in the Limagne[69]).

These chronological observations of the colluviation history coincide with the dates (Iron Age/Roman) of the gulleys observed in the forests of the Leuven area (see above: Leuven-sector), but also with the cultivated area of the adjacent Hesbaye area[70]. The site of Dion-le-Mont also included a gulley, located at the bottom of the dry valley and potentially Holocene and man-induced. On the one hand however, a B_t-horizon had formed in its fill which reminds of pre- or Early Holocene soil formation[71]. On the other hand, such a pedogenesis is also observed to a lesser extent in Roman colluvia and mostly depends on favourable chemical conditions[72]. Moreover, the presence of at least five more generations of (post-Roman) gulleys allow the potential attribution of this first gulley to a (pre-) Roman anthropogenic erosion phenomenon.

The lack of characteristics from periglacial environments clearly differenciates all these gulleys from the Tardiglacial gulleys studied in the nearby Zonian Forest[73]. This shows that the

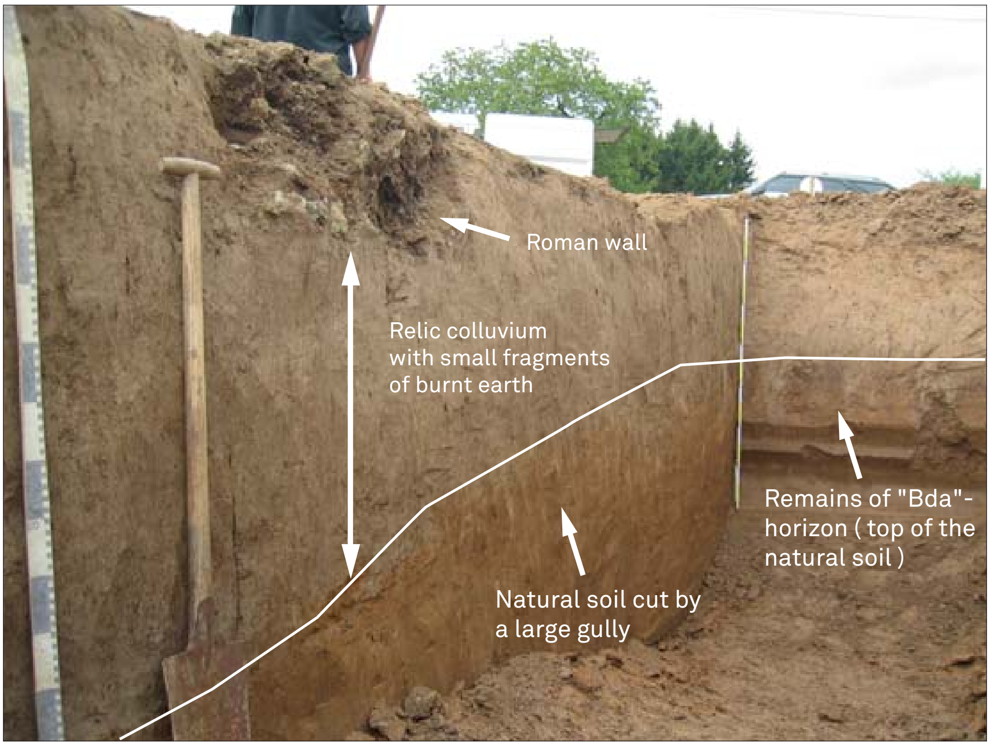


FIG. 5 View of the valley filled with relic, Roman or pre-Roman, colluvium in Dion-le-Mont. Here, it is cut by a Roman wall, elsewhere by a post-Roman erosion gulley.

65 Louwagie 1996; Louwagie & Langohr 1999.
66 Scheys 1955, in Louwagie 1996; Louwagie *et al.* 2000.
67 Bolt *et al.* 1980; Louwagie 1996.
68 Fechner 2004a.
69 Auvergne, France: Ballut 2001; Ballut *et al.* 2003.
70 Bolline 1976, fig. 10.3.
71 Van Vliet-Lanoë *et al.* 1992; Fechner *et al.* 2010; see also above: site of Rebecq "Spinoi".
72 E.g. Louwagie *et al.* 2000: Chièvres and Taintignies, see respectively above and below.
73 Langohr & Sanders 1985; Sanders *et al.* 1986; Huybrechts 1989, fig. 7: before 10.060 BP.

palaeogulleys in Middle Belgium can have different origins and indicates that some of the gulleys of the Meerdael Forest[74] might be of the kind observed in Dion-le-Mont, while other rather recall the naturally formed ones of the Zonian Forest[75].

⊙ The Neufvilles sector
A very detailed study concerns the fill of a river valley in Neufvilles "Gué du Plantin"[76]. At ca. 580 BC and 200 BC, as well as in parts of the Roman, the Merovingian and the Carolingian periods, colluvial deposits were formed. While there is no sign of deforestation in the palynological results for the first of these phases, there are clear phases of forest regeneration from 200 BC onwards.

In Lombise, about 4 kilometers from Gué du Plantin, a dry valley was filled with relic colluvium made of fine sand which contained Protohistoric and Roman ceramics. These deposits were cut by a small ditch with Roman material, and covered by active colluvium[77]. The colluvia and ditch fills were more sandy than the natural soil. The latter, a sandy loess, was very well preserved, with remains of the eluvial horizon ("E") and the dark top of the clay accumulation horizon ("B21t, da") present.

3.2.2 Slope deposits at a local scale

More than 10 kilometers to the south of Lombise and Neufvilles, the exact same situation as in Lombise was encountered in Ville-sur-Haine "Champ du Sablon", with protohistorical material in the ditches and protohistorical and already some Roman material in the colluvium cut by the ditches. About 6 kilometres away, the site of Casteau "Sablon" reveals a similar stratigraphy, but without dating material that can be clearly associated with the relic colluvium[78].

Some other so far isolated sites (Taintignies, Peronnes) have revealed relic colluvium with the same characteristics as in Ostiches and Papignies, and might also be dated to the same period as relic colluvia in the loess region of Middle Belgium (see above: Landen and Lincent). In the less well-dated site of Taintignies, a detailed soil analytical and micromorphological study provided a good characterisation of relic colluvium as opposed to the present-day surface active colluvium on top of it[79]. Among others characteristics, the presence of impure to matrix clay coatings and infillings proved to be typical of the relic colluvium. It represented a typical inverted profile and was interpreted as being the result of short-distance sediment transport.

3.2.3 Fluvial deposits

In Neufvilles (see also above), the first Holocene phase of filling of the river bed consists of fluviatile sands, dating back to ca. 2900 BC and slightly posterior to the Michelsberg occupation of the site (and related to it?). From c. 2700 BC onwards alluvial deposition might be related to a wetter environment and/or change in the vegetation. On the site of Brussels "Rue d'une Personne", a pre-Medieval clayey alluvium was encountered. It was both very clayey and very humiferous which indicates a shallow swamp with some vegetation, possibly in the former flood basin of the River Senne[80]. The alluvium was also cut by numerous puddling and trampling traces of (large ?) mammals, subsequently filled and covered with pure, possibly alluvial (or colluvial) sands[81]. The latter are Medieval or earlier, as they are covered by an accumulation of organic remains dated to the beginning of the Later Middle Ages (^{14}C: 1030-1250 AD, with 95% probability). An Early Medieval age is probable, as this lowland part of Brussels seems little or not to have been occupied before. However, this is difficult to prove, without a more detailed analysis of the basal stratigraphy of this part of the city.

In the upper Mark valley[82], fluvial clays are deposited on top of organic layers, of which the youngest ^{14}C date is 1500/1120 BC or possibly 770/380 BC[83] (both on the border of the valley). In the lower valley, the youngest date for such organic layers is 840/480 BC, but in some sections the initial replacement of the organic facies by fluvial clays seems to have occurred at ca. 5400/4800 and 4600/4050 BC (around 6000 BP).

In the Dijle valley, the "majority of the floodplain deposition took place after the Early Medieval period"[84], thus later than the main substantial colluviation (cf. supra). This important time lag between erosion and floodplain deposition is similar as that indicated by the thorough work of C. Ballut in the Limagne[85].

3.3 Low Belgium

This area is dominated by fine to coarse sandy soils, quite often with a shallow water table (fig. 1; table 1).

3.3.1 Slope deposits at a regional scale

In this region a relative large number of studies are devoted to Holocene erosion/ sedimentation events, which however indicates that most events seem to be either active or pre-Holocene. Much work was also focussed on the study, mapping and quantification of post-occupational wind and water erosion on archaeological sites. Only one of the sites investigated by us involves some earlier man-made erosion-sedimentation. In Vosselare "Kouter", the occupation level related to ditches of the Late Bronze age and Late Iron Age is separated from a Medieval occupation by a probable ca. 25 cm thick colluvial deposit[86]. Concerning water-related erosion, the scarcity of data can be explained by the very flat topography. For wind erosion the scarce amount of data is more surprising, which might show the rarity of such phenomena in the Holocene and of the conditions that enable them (strong winds on a completely bare, extended surface). Several studies furthermore show that former slight elevations were preferred settlement

74 See above and Vanwalleghem *et al.* 2003, 2, 14.
75 Dr. R. Langohr, pers. comm.
76 De Heinzelin *et al.* 1977.
77 Fechner *et al.* 1993, 27, 72-74.
78 Fechner *et al.* 1993.
79 Louwagie *et al.* 2000.
80 E.g. Brown 1997, 17-33, table 1.1.
81 Fechner 1997; On the same site, a Medieval or pre-Medieval ditch is filled with the same pure sands in alternation with humiferous laminations; this phenomenon is however beyond the scope of this article (see 2. Scope and interest), but might confirm the presence of colluvium on this site.
82 Huybrechts 1989.
83 According to the interpretation of the stratigraphical links between adjacent augerings.
84 Notebaert *et al.* 2009.
85 Auvergne, France: Ballut 2001; Ballut *et al.* 2003.
86 Fechner 1992.

locations, avoiding the high water tables in the Bronze and Iron Ages, and in Roman times. Often these elevations are levelled today, mostly due to modern large-scale agriculture[87]. As other topographical changes are limited in these lowlands, colluvium remained thin and later intensive agriculture could easily have destroyed existing colluvial deposits[88].

3.3.2 Fluvial deposits

For the Mark river (not to be confused with the one mentioned in the region of Middle Belgium sandy loess; *cf. supra*), Vandenberghe *et al.*[89] suggest that the increased river load and its sandy character are due to deforestation from the Early Middle Ages onwards. The question whether the phase of river erosion between the Middle Atlantic and the Early Subatlantic has a climatic cause is left to further research by the authors.

3.4 Valley bottom of the Scheldt/Escaut River (France, Belgium)

3.4.1 Slope deposits at a local scale

In Antoing "Crevecoeur", wind erosion seems to have destroyed the microrelief of Tardiglacial sandy river dunes, possibly including most of a Late Neolithic site[90].

3.4.2 Fluvial deposits

In Fresnes-sur-Escaut (Nord, France), at the confluent of the Scheldt and the Haine Rivers, a clayey inundation deposit was encountered[91]. It was a few decimeters thick, and was dated to the Subboreal period or younger. Other important sites with relic alluvium are located in Ramegnies-Chin and in Oudenaerde "Donk". The first site shows floodplain depositions which probably date between the Early Middle Ages and the 16-17th century AD[92]. On the second site, the onset of alluvial clay deposition, after peat formations, is interpreted as the result of an increasing deforestation and agriculture that started in the Atlanticum and could be dated here between 4000 and 2500 BP[93].

For the middle part of the Scheldt, Kiden[94] indicates anthropogenic impact on the river system perceptible from about 5000 BP, and distinct from about 3800 BP onwards. Particularly strong sedimentation is related to soil erosion due to deforestation and agricultural activities in the Roman and Medieval periods. The end of peat formation can be dated on some sites, as in the Kalkense Meersen to 4240 BP (Late Neolithic) and 2320-2050 BP (Late Iron Age), possibly coinciding with the start and acceleration of anthropic deforestation: "as deforestataion continues, the water balance and soil hydrology became further disrupted, pushing back organic accumulation and promoting clastic sediments in the alluvial plain"[95].

3.5 Nord-Pas de Calais (France, similar border area in Belgium)

This area differs from the former ones by a mixture of deeply and undeeply decarbonated loess, some calcareous outcrops, and the presence of a large number of large alluvial plains (fig. 1; table 1).

3.5.1 Slope deposits at a regional scale

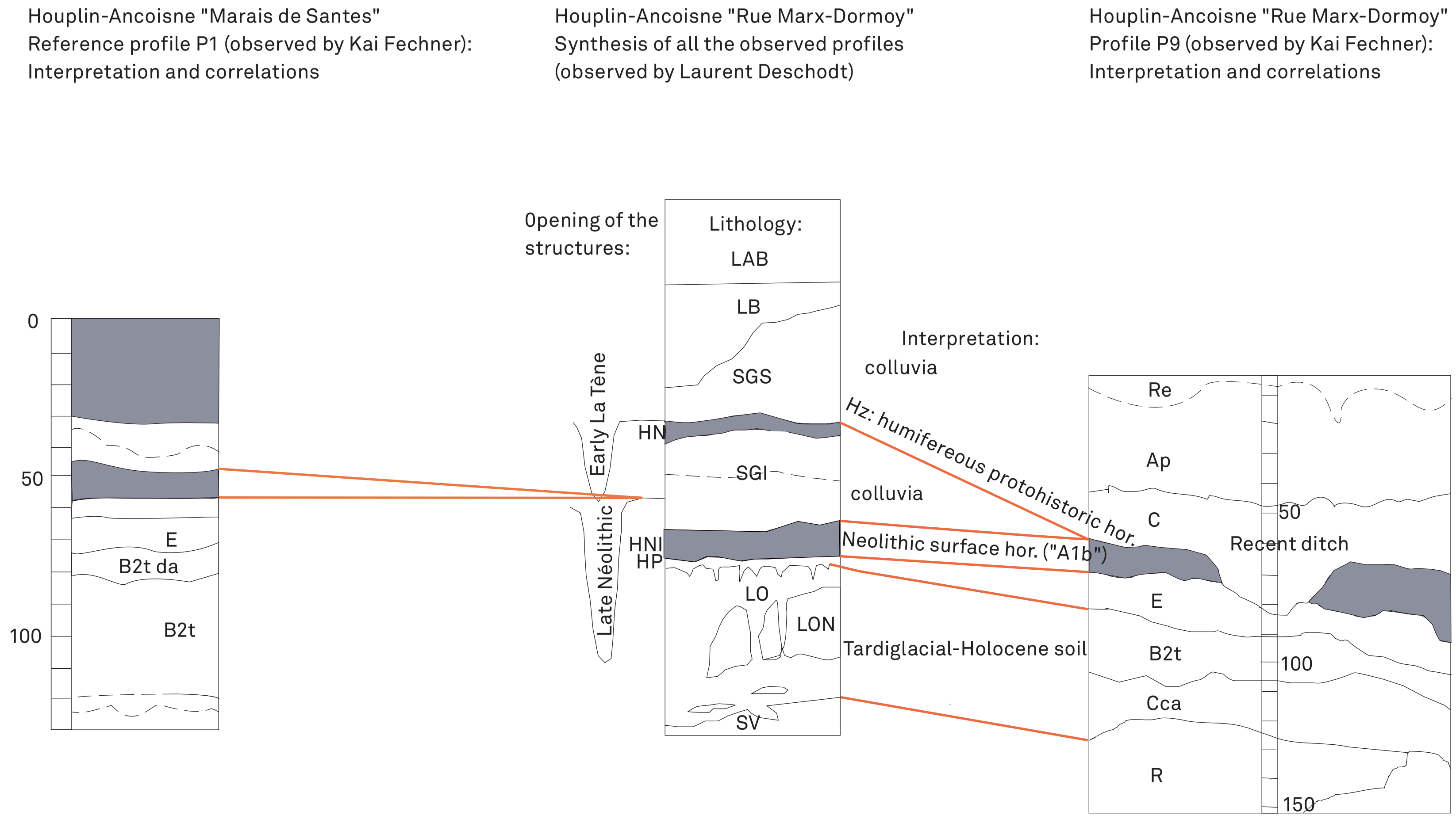
- The Houplin-Ancoisne-sector

A probable colluvial deposit was found associated with and/or posterior to Late Neolithic (Gord-Deule-Escaut group) artefacts on the two neighbouring sites of Houplin-Ancoisne "Rue Marx-Dormoy" and "Marais de Santes" (fig. 6), both located along the River Deulle[96]. Similar deposits were more recently discovered in Carvin "Château d'Eau"[97].

This homogeneous, light grey deposit of fine sand is also present above the Late Neolithic levels, at the first site it is cut by a pit dating to the beginning of the Late Iron Age (fig. 6). The indicator to interpret these sands a having an alluvial origine are the recurrent position along a former river, and the complete gleyification of these deposits. Such a sequence of thin successive deposits and surface horizons might be typical of a Fluvisol. This depositional sequence seems similar with the one described at the site of Croix-Saint-Ouen in the Oise Valley in the Seine Basin[98] (e.g. infra: Tardenous/ Aisne region). These depositions are believed to be anthropogenically rather than climatically induced. This can at least partly be associated with the large-scale impact of (palaeo-) agriculture on the landscape. However, an interpretation as colluvial deposits is more probable, according to micromorphological and granulometrical arguments[99]. On both sites of Houplin-Ancoisne and in Carvin, some thinner deposits of relic colluvium are probably formed during the occupation, on their lower lying borders. It is difficult to discriminate between different causes for this erosion (fields, pathways,...).

These deposits are comparable in morphology and stratigraphic position with those of Brugelette and "Moulin de la Hunelle" in the region of Middle Belgium loess (*cf. supra*), and of Liège in the region Meuse Valley bottom (*cf. infra*). In these cases however, the supposed alluvium is not as well dated as in the two cases of Houplin-Ancoisne. Therefore, we propose to use the latter sites as a reference and to use the term "complex of Houplin-Ancoisne" when the following sequence of three events can be observed: a surface dated to the Late Neolithic, a grey, leached deposit of silt or fine sand, and another surface horizon dated to the Iron Age.

87 E.g. Langohr & Pieters 1985; Langohr & Fechner 1993; Fechner 1992; Langohr 2001.
88 Langohr 2001.
89 Vandenberghe *et al.* 1984.
90 Fechner 2004e.
91 L. Deschodt, pers. comm.
92 Earlier depositions, with levels of the Early Iron Age and the Roman period, coincide with peat, reworked peat and tufa or river bed deposits; Heinzelin & Osterrieth 1983.
93 In the lower parts of the Scheldt Basin, the rise of the water level from the Atlanticum onwards is related to the marine transgression; De Ceunynck *et al.* 1985, 67-69.
94 Kiden 1991.
95 Bogemans *et al.* 2012.
96 In Houplin-Ancoisne "Rue Marx-Dormoy", the deposit includes large lithic artefacts of the Gord-Deule-Escaut group (Late Neolithic), in "Marais de Santes", 14C-dates for charcoal are the same (2877-2579 BC) as in the overlying surface horizon (2859-2473 BC); Fechner 2007a; 2004c; Deschodt 2007.
97 Fechner, unpublished premilinary report.
98 Pastre *et al.* 2002, 39/1.
99 Praud (ed.) in press.



Legend:
Ap : present-day ploughing - B2t : illuvial horizon- C : colluvia - Cca : loess parent material- E : eluvial hor.- B2t da : dark illuvial hor. (B"dark")- HNI : lower neolithic surface horizon - HNS : upper neolithic surface horizon - HP : light, powdery, silty horizon - LAB : present-day ploughing - LB : brown silts - LO : orange silts - LON : orange and black silts- R : substratum, with occasional calcareous fragments - Re : recent upfill- - SGI : lower coarse sands -SGS : upper coarse sands - SV : green sands

clay importation horizon clay exportation horizon dark humus-rich horizon

FIG. 6 **The reference profiles of Houplin-Ancoisne "Marais de Santes" and "Rue Marx-Dormoy" and their correlation.**

3.5.2 Slope deposits at a local scale

Some punctual observations were obtained at the sites of Reques-sur-Hem, Izel-les-Esquerchins and Petit-Fampoux[100]. At the first of these sites clayey silt was deposited between the end of the Iron Age (Late La Tène) and the Roman period. At the second site silts are buried between the La Tène occupation level and a coarser, active colluvium. Relic deposits of brown silt with granules of chalk on this site are post-Roman. These results might indicate that sedimentation is limited here to the period after the Late Iron Age period[101].

Relic colluvium containing Protohistoric sherds was also observed in Asquillies, on the Belgian side of the frontier[102].

Recent investigations in a dry valley at Erre (Pas-de-Calais) have revealed the presence of colluvia that separate the uneroded natural soil formation ("E", Bda" and Bt"-horizons) from a thin occupation surface horizon with (Early Iron Age ?) protohistoric sherds[103].

3.5.3 Fluvial deposits

A one meter thick clayey inundation deposit related to an affluent of the River Scarpe has been studied in Flines-les-Raches[104]. It overlies a Roman surface, thus offering a, however rather vague, *terminus post quem* for this deposit.

The works of Cercy & Deschodt[105] and Deschodt *et al.*[106] at a number of successive excavations in the city of Lille document changes in alluvial deposition in the river Deulle in the Early Roman period that could be anthropogenically-induced. In Lille "Esplanade", a small river was progressively filled with laminated deposits of clay before the Modern Times[107].

Historic data in the Scarpe Valley indicate that anthropogenic impact was the main cause of important inundations in the Medieval period[108].

3.6 Somme (France)

This area is dominated by calcareous outcrops and undeeply decarbonated loess (fig. 1; table 1).

3.6.1 Slope deposits at a regional scale

◉ The Middle Somme sector

A number of Mesolithic sites represent colluvial depositions on the slopes of the Somme River, such as the sites of Saleux, Belloy-sur-Somme "La Plaisance" and Chaussée-Tirancourt "Petit Marais"[109]. The two latter sites are close to each other. At the last of those sites, three phases of relic colluvia are interstratified with well-dated peat deposits, of which the youngest is approaching the Neolithic period (6900 BP)[110]. These cases attest that the Mesolithic colluvial phases of Rebecq (see above) and Liège 'sector DDD' (see below) are not unique, even if the first of these is older and potentially (also) related to deteriorated climatic conditions. In the Somme, the associated forested environments exclude that possibility, leaving Mesolithic anthropogenic impact as the probable cause for slope erosion.

Erosion along the Somme Valley bottom must have occurred more easily thanks to the presence of pronounced slopes and escarpments, as is also the case for instance in Liège "SDT" (see below: 'valley bottom of the Meuse') and to a lesser extent in "Ferme Taon" (see above).

3.6.2 Slope deposits at a local scale

At a local scale, Subboreal to Subatlantic colluvium is mentioned in the stratigraphic sequence of Belloy-sur-Somme "La Plaisance"[111].

3.6.3 Fluvial deposits

It has to be noted that a recent deep augering in the floodplain of the Ancre, an affluent of the Somme, did not deliver any clayey floodplain deposits between sandy, coarse silty and organic to peaty layers, dated from the Mesolithic to Modern Times[112].

3.7 Valley bottom of the Meuse River (France, Belgium)

3.7.1 Slope deposits at a regional scale

◉ The Liège sector in protohistorical times

In the "sector SDT" of the site "Place-Saint-Lambert", relic colluvium of Subboreal age was deposited in a palaeochannel, before covering the whole "sector SDT"[113]. Erosion along that escarpment of the Meuse Valley was probably induced due to the presence of pronounced slopes, as for instance in the formerly described sites of "Ferme Taon" and in some sites of the Somme region.

At one of the other sectors of the site of Liège "Place Saint-Lambert" ("sector DDD"), three depositions of relic colluvium, with some erosion *hiati* in between, precede what is most probably a Roman plough horizon[114] (fig. 7). At least one of these is probably contemporary with the Subboreal deposit of the former sector.

The same could be true with the underlying fill in the same "sector DDD", which is of a colluvial or of an alluvial origin. Here, the Early Neolithic occupation level is cut by one or more temporary river channels of the Légia, where it seems to split in a number of arms before joining the Meuse river. One of these channels is first filled with a thin layer of homogeneous light grey fine sands, followed by alluvial gravels and stones. These fine sands remind of the ones of the Late Neolithic and pre-La Tène I stratigraphies of the two sites of Houplin-Ancoisne (*cf. supra*). The chronology is less precise in Liège, where this phase

100 Kuzucuoglu *et al.* 1991; 1992.
101 Further south in the Paris Basin the same conclusions are obtained by this study, but more recently some Late Bronze Age colluvia have been encountered (J.F. Pastre, pers. comm.).
102 Fechner *et al.* 1993, 37-38, 74-75.
103 Fechner, unpublished preliminary field report: profiles P2 and P3.
104 Ruchard *et al.* 1992; Deschodt 2002; Deschodt *et al.* 2012.
105 Cercy & Deschodt 2011.
106 Deschodt *et al.* 2012.
107 Fechner 2011.
108 Deligne 1998.
109 Ducrocq 2001, 146/2-147/1, 158, 194.
110 Ducrocq 2001, see also Antoine 1997; Antoine *et al.* 2002.
111 Fagnart 1988.
112 Boulen 2013.
113 Van der Sloot *et al.* 2003.
114 Fechner 1996; Van der Sloot *et al.* 2003.

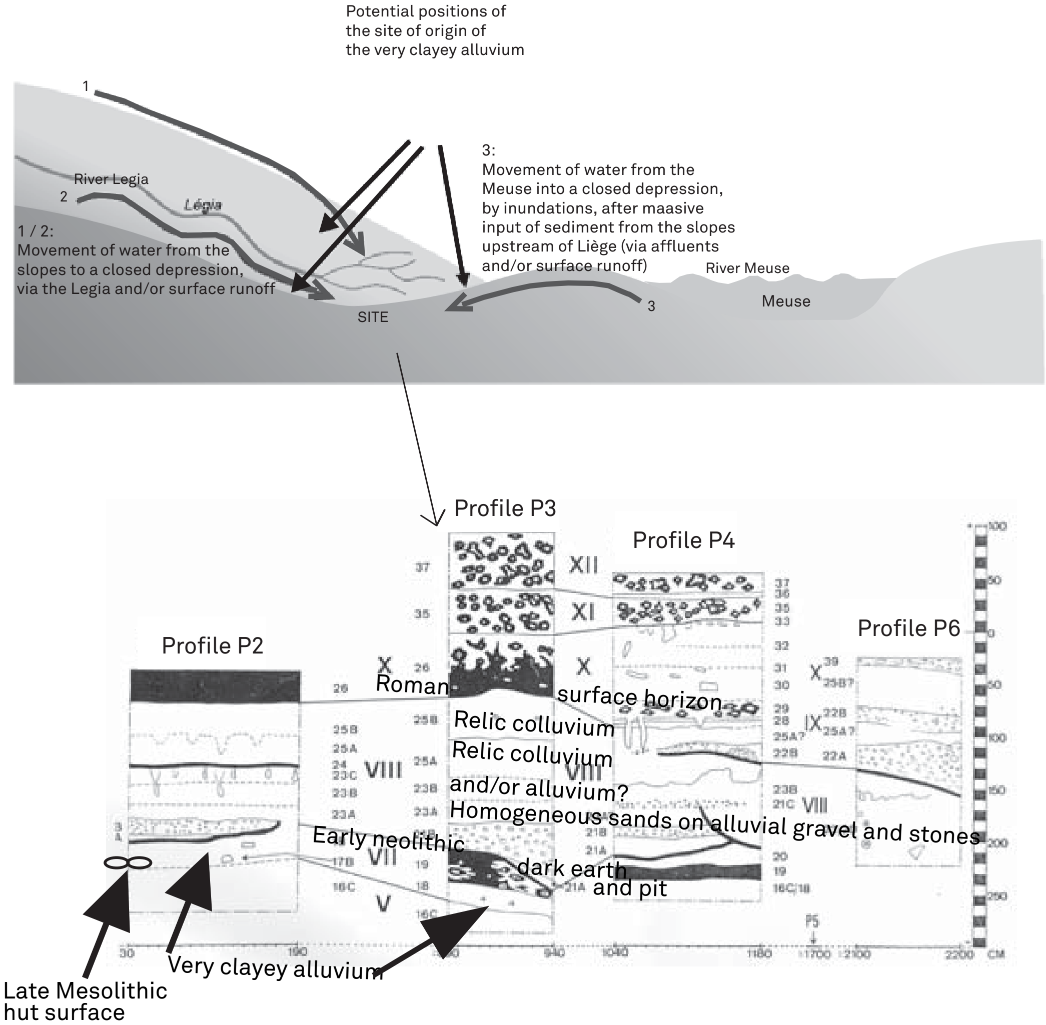


FIG. 7 Litho- and pedostratigraphy of the "sector DDD" of the site Place Saint-Lambert in Liège, including successive alluvial and colluvial depositions.

can be situated in a sequence of events (see above) between the Early Neolithic and Roman surface horizons. However, here a relation with a river channel is much clearer.

3.7.2 Slope deposits at a local scale

In the "sector SDT" of the site "Place-Saint-Lambert", adjacent to a valley with pronounced slopes, a relic colluvium (?) of Boreal age was observed in a former river channel of the Légia[115].

The site of Namur "Grognon", at the exact point of the confluence of the Meuse and the Sambre, presents a silty, probably colluvial, deposit with some artefacts (H2 of profile 1), that separates the Roman from the Neolithic surface horizon[116].

3.7.3 Fluvial deposits

In the "sector SDT" of "Place-Saint-Lambert", a Mesolithic silty alluvium was present in a former river channel of the Légia, followed by a clayey layer on which a Late Mesolithic soil is formed.

In the different sectors of "Place-Saint-Lambert", the floodplain of the Meuse repeatedly shows particular events of alluviation in the Early Neolithic and at a later, undated, pre-Roman period. The first event is characterised by a clay deposit on large parts of the interfluvium between the Meuse and the Légia, and is observed in three different sectors of the site, always at the interface of Late Mesolithic and Early Neolithic occupation levels[117]. In one of the sectors ("DDT"), this deposit cuts a Late Mesolithic occupation phase, and is clearly associated to the first phase of two Early Neolithic phases, before being cut by the second Early Neolithic phase. It is questioned whether the important presence of (often multi-phased) Early Neolithic sites on the surrounding plateaux and steep slopes of the Meuse Valley could have been sufficient to create such an impact on the Meuse depositions[118], and whether we have to look for other origins of this sedimentation phenomenon, for example natural events or more local site-related soil erosion.

Moreover, in the "eastern sector" of the site of Liège "Place-Saint-Lambert", different alluvial phases of the former bed of

115 Van der Sloot *et al.* 2003.

116 Mees 1994; Fechner 1994a.

117 Haesaerts 1985: "east sector"; Remacle *et al.* 2000: "north-west sector"; Fechner 1996; Van der Sloot *et al.* 2003: "sector DDD".

118 A comparable discussion is proposed by Lüning (2000, 32-33) for a number of alluvial deposits on German sites (*cf.* also Semmel 1995 for colluvia), some being even a little older than the accepted Early Neolithic.

the River Légia coincide with the 1st to 2nd century AD, with the Carolingian period and with the 11th century[119]. The latter two deposits were also associated with some input of colluvium.

It can be noted that the comparison of the different sectors of this site doesn't allow many parallels with respect to stratigraphy, except for the overall presence of the Early Neolithic inundation clay. This is due to the fact that the different channels of the alluvial fan of the Légia were active following differing local dynamics, and at differing time spans (fig. 7)[120]. This large-scale process is probably due to an exceptional event originating from the much larger Meuse River, as opposed to the Légia.

Sites like Namur "Grognon", at the interfluvium of the Meuse and the Sambre, also testify to a complex alluvial sequence and might demonstrate the presence of processes similar to the ones described at Place Saint Lambert. Covered by Roman and Late Iron Age surface horizons, the stratigraphy includes deposits of heavy clay with gravel, occasionally containing Neolithic bones and flints. This deposits is situated on another humiferous horizon with a similar granulometry, which coincides with a Mesolithic surface[121]. The sediments below this Mesolithic surface were also already very clayey Indicating a continuity rather than to a change in the nature of sedimentary environment. More detailed geoarchaeological work at these sites is hampered by the of lack larger cross sections with morphological characteristics and stratigraphical relations. The amount of clay is slightly lower in the Mesolithic surface, when compared to the deposits above, which might indicate an evolution towards a more dynamic fluvial environment. A similar evolution may be found locally in Choisy-au-Bac (see below) and in Remerschen "Schengerwis" (see below). At these two sites, the most clayey layers however date to the Neolithic period.

3.8 Ardennes (Belgium, Luxemburg and France)

3.8.1 Slope deposits at a regional scale

Large-scale erosion and sedimentation phenomena seem to be lacking, except at the present-day surface[122].

3.8.2 Slope deposits at a local scale

At the sites of Jemelle "Malagne" and Soumagne/Ayeneux I and II, active colluvium completely covers the Roman and, respectively, Medieval structures, while earlier colluvia are missing. In Baelen "Rue Corbusch", on loess-like materials, a colluvial deposit fills a slight depression on the top part of the slope. It is comprised between a buried surface horizon containing charcoal and a Roman man-made filling related to metallurgy[123].

3.8.3 Fluvial deposits

In Jehay "Chateau de Jehay", a floodplain alluvial clay deposition precedes the Medieval to Modern wooden installations which provided access to a castle[124]. The works of Houbrechts & Petit have shown that human activities (deforestation, agricultural practices, extension of area under tillage) have played a major role in silt accumulations since the 14th century in High Belgium[125].

3.9 Eastern Lorraine (France and Luxemburg)

3.9.1 Slope systems at a regional scale

On the airport of Lorraine[126], south-east of Metz, the studied dry valleys regularly presented a colluvial filling which was associated to Late Iron Age occupation sites. In the Roman period the overall erosion patterns increased, possibly relating to intensifying agricultural practices.

3.9.2 Slope systems at a local scale

On a local scale, the same site also presented some traces of Late Bronze Age erosion, on shallow calcareous soils. In Imling, colluvium was present buried under a Roman villa[127].

In comparison, further south, in the Alsace region, the site of Sierentz[128] shows local erosion patterns that started between the Early Neolithic and the Late Bronze Age.

3.9.3 Fluvial systems

The site of Marsal was the subject of a soil study focussing on indicators of buried alluvium. In two of the augerings done in the present-day flood basin of the salt-bearing River Seille, 8 to 9 metres of alluvial deposits have been encountered. Underneath *ca* 2.5 m of clayey active alluvium, the sequence is dominated by gravelly sands. Two clayey deposits of a few decimetres thickness could be related to relic alluvial depositions. The upper one of these is situated just below salt ovens dating from the Iron Age[129]. At the current state of research it is impossible to tell whether one or both relic alluvial clay layers can be related to an early over-exploitation of the wood resources in the surrounding area[130]. In a third augering, where the substratum occurs deeper, two clayey phases are separated by clayey sands, below a more complex upper sequence.

3.10 Valley bottom of the Mosel River (France, Luxemburg)

3.10.1 Slope deposits at a regional scale

⊙ The Remerschen-sector during historical times
At Remerschen, in an affluent or in a former arm of the Mosel, a Roman surface was formed on a stabilisation horizon

119 Haesaerts 1985.
120 Haesaerts 1985; Fechner 1996.
121 Mees 1994; Fechner 1994a; Defgnée & Munaut 1996.
122 For the forested areas of the Ardennes in Luxemburg, some work on present-day erosion processes has been proposed (Imeson *et al.* 1980).
123 Fechner, unpublished report.
124 Fechner, unpublished observations and field report.
125 Houbrechts & Petit 2003; Gauthier *et al.* 2009.
126 De Decker 1989.
127 Gebhardt *et al.* 2009; Gebhardt & Fechner, in prep.
128 Wolf & Viroulet 1992, 51.
129 Baes 2002.
130 Olivier 2000, 166/1; See also Dufraisse & Gauthier 2002 for deforestation related to salt exploitation much further south in Franche-Comté, from the end of the Bronze Age on.

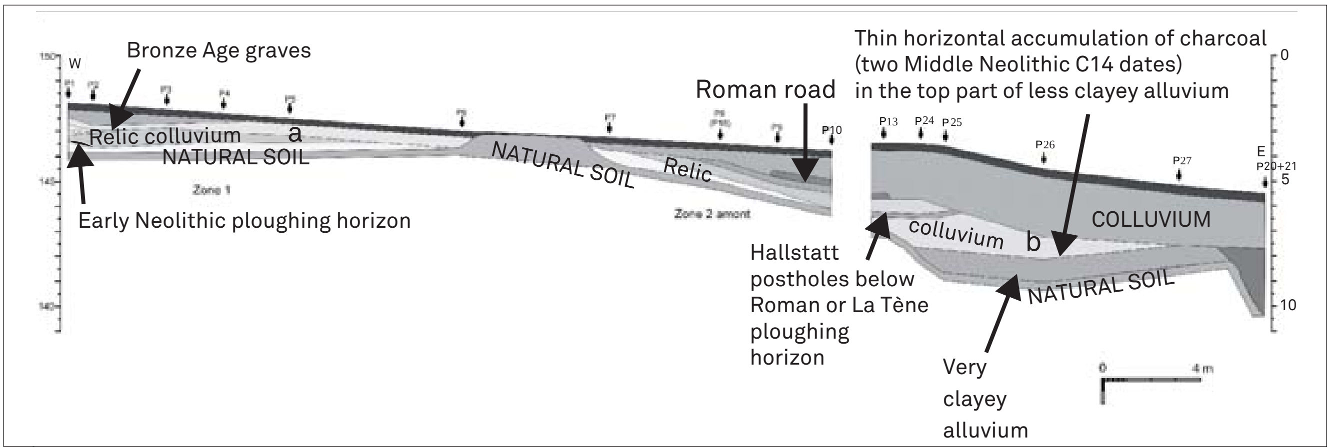


FIG. 8 The long transect of Remerschen "Schengerwis", perpendicular to the river Mosel, includes both relict alluvium and colluvia. Note the two protohistorical phases, one in (a), the other in (b).

on former alluvia and colluvia, which however could not be dated precisely[131].

In the lower part of colluvium which covers the Roman surface, a clay-accumulation horizon ("Bt") developed before being eroded and covered by active colluvium. This soil development might indicate a relatively old, probably Roman or Medieval, age of the deposit (e.g. supra "Ferme Taon" and Taintignies).

In the adjacent German Mosel area, important erosion starts with the Roman invasion, as is confirmed by increased sedimentation from 50 BC onwards and evidenced by varve chronology[132].

⊙ The Remerschen-sector during protohistorical times
Two phases of Iron Age erosion-sedimentation are probably indicative of the presence of larger fields with tillage or another type of short-distance erosion (fig. 8). One of them is also present in the directly adjacent site of Remerschen "Ennert dem Raederbierg"[133]. Protohistoric colluvium might also be present in the nearby site of Remerschen "Ennert dem Wentrangewee"[134] and Wintrange "Quäschwis"[135].

⊙ The Ennery-sector
Two neighbouring sites present nearly identical sequences, consisting of an inversed profile of agrarian colluvium in Ennery, with or below a Late Bronze Age occupation, and Bronze age agrarian colluvium in Ay-sur-Moselle, cut by Late Bronze Age and Early Hallstatt postholes[136]. In Ay-sur-Moselle, the micromorphological study evidences a colluvial deposit, and is interpreted as the result of agricultural activities between the Early Neolithic (upslope occupation with a buried ploughing horizon) and the Late Bronze Age.

3.10.2 Slope deposits at a local scale

The Forêt de Haye, in a meander of the Moselle river, shows erosion below Roman agrarian levees, which possibly dates to the Iron Age period, but could also already be Roman[137].

At the site of Borny, a colluvial deposit is dated to the Medieval period[138].

At Remerschen "Schengerwis" (fig. 8), a particularly old, but very local, erosion-sedimentation event might be due to tillage or another short-distance erosion. This concerns a colluvial layer, which is cut by Late Bronze Age incineration graves, and situated on an Early Neolithic ploughed horizon and structures. The Early Neolithic plough horizon, located in between two Early Neolithic settlement levels, might indicate that part of this deposition occurred already during the Early Neolithic[139]. The interpretation as tillage erosion, rather than erosion caused by natural causes, is based on the distribution of the colluvium.

3.10.3 Fluvial deposits

In Remerschen "Schengerwis" (fig. 8), a particular clayey alluvial filling of the former river bed was observed (profiles 25-27). This filling probably ends in the Middle Neolithic, as indicated by a thin, little less clayey deposit including angular-shaped, densely distributed charcoal fragments (^{14}C: 3790 to 3650 and 4335 to 4079 BC). The horizontal alignment of these fragments argues for little or no displacement and a good association with this stratigraphic level. It is questioned whether this clayey deposit might be related to the Early Neolithic landnam[140] that is attested by the important village situated just upslope of the alluvial deposit. At the same site, but a little further downlope and very close to the present river bed, some clayey, partly laminated sediments are deposited in and/or after the Roman period[141].

131 Brou *et al.* 2009; see also: Kühn 1996, site of Remerschen "An der Leichen".
132 Kühn 1996, 45.
133 Gaffié & Baes 2001; Baes 1999.
134 Baes, unpublished information.
135 Baes, unpublished; Kühn 1996, 36; Brou *et al.* 2009.
136 Gebhardt *et al.*, in press.
137 *Ibid.*
138 *Ibid.*
139 Baes *et al.* 2000; Fechner & Baes in press; Fechner & Langohr 1994; Fechner *et al.* 1997. This process is beyond the scope of the present article (see 2. Scope and interest), but indicates that this part of the site of Remerschen has been favourable to such phenomena very early and at a number of different moments.
140 See also above: the dicussion concerning the site of Liège "Place Saint-Lambert" in the region of the "Meuse Valley bottom".
141 Fechner & Langohr 1994: profiles 21-23, cutting the former clayey alluvia.

Data on both colluvium and alluvium have also been obtained on the other sites of Remerschen and Wintrange (see above).

As in Marsal (above: region Eastern Lorraine), a sudden change in deposition regime from coarser to finer material is documented in Crévéchamps "Tronc du Chêne", close to Nancy. This is dated to 3400/2400 BP[142] and coincides with the Middle Bronze Age to Early Iron Age occupations and a local stabilisation of the surface. From 2400 BP onwards, occasional or increased inundations resulted in the deposition of silt and clay layers with less than 25% sand and almost no gravel. In the adjacent site of Crévéchamps "Sous Velle", it is very probably the base of these fine-textured materials that has been extracted on a large scale in the Roman period[143]. The whole site is covered by a thick deposit of active post-Roman alluvia.

3.11 Western Lorraine (France and Luxemburg)

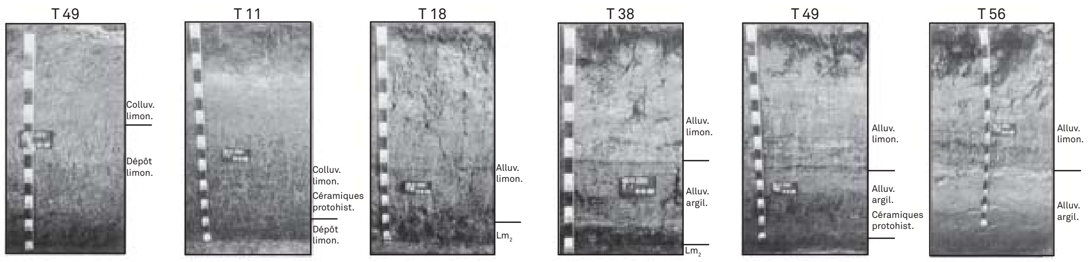
3.11.1 Slope deposits at a regional scale

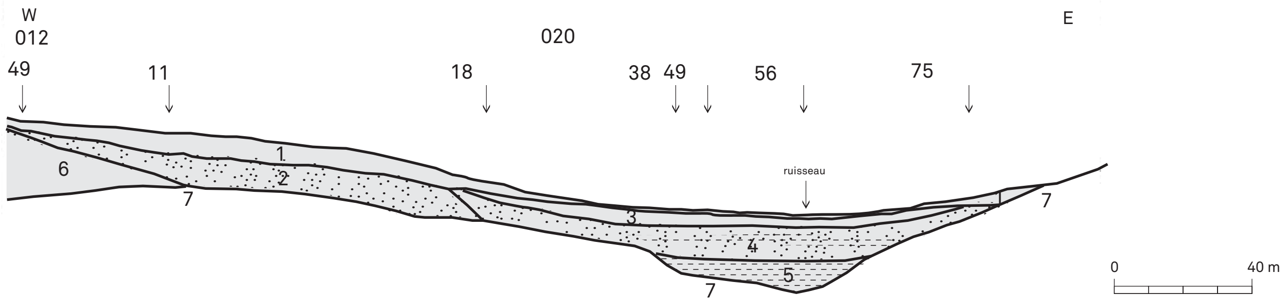
⊙ The Villers-le-Tourneur sector

Louwagie & Langohr[144] and Laurelut & Louwagie[145] have provided a reference study for the detection of tillage erosion phenomena in archaeological contexts, on the successive sites located between Poix-Terron and Villers-le-Tourneur, along the future highway A34 (Reims - Charleville-Mézières). They are indicated further on as "Villers-le-Tourneur". These adjacent sites present a recurrent succession of events, for which detailed soil analytical and micromorphological characterisation provided some unique information. After deforestation phases in the Early Iron Age (Hallstatt), most of the landscape was used as pasture land except for "landnam" phases in the Second Iron Age (La Tène) and the Middle Ages[146]. The colluvium probably results from a combination of tillage with sheet wash erosion. Both are only driven by a short-distance sediment movement and the sheet wash is too limited to produce any significant sediment sorting. In Villers-le-Tourneur, it is noteworthy that the charcoal fragments found in alluvial context have parallels in the vicinity, as well as in hearths associated with the deforestation. The associated sedimentation phases are relatively thin. Synchronous charcoal fragments are also found in the more developed relic colluvial phases, coinciding respectively with the end of the Iron Age and the very beginning of the Roman period, and with the transition from Early to Late Middle Ages, around 1100 AD.

⊙ The Souhesmes sector

At Souhesmes, the study of a small river system with two valley heads and their confluence[147] revealed successive generations of colluvium. A thick colluvial fill also was observed in the neighbouring valley to the west, however without detailed observations. The study at Souhesmes shows that (probably tillage) erosion has started in the Early Roman Age period, following a deforestation phase in the Iron Age period, resulting in orange silty colluvia containing early roman artefacts. Relic colluvium with unoriented gravel and stones, related to the Medieval and Modern periods, covers the whole valley and part of the slopes. These layers are interpreted as the result of tillage erosion. The end of this phase includes the formation of a large accumulation of relic colluvium perpendicular to the slope and most probably formed against a hedge of horizontal stones, which are present at the top of the active colluvium in some profiles. These final phases show some horizontal stones related to erosion and sedimentation in rills. In comparison with the Roman ploughing





1 Medieval and modern colluvium
2 Colluvium with protohistoric and roman material
3 Clayey alluvium
4 Silty alluvium with protohistoric and roman material and iron-rich stratifications
5 Very clayey alluvium, reduced and with decomposed organic remains
6 Clayey -silty upfill
7 Geological substratum (Li as marl)

FIG. 9 Repetitive trend of depositions in the Neieweier Valley (Hellange, south-east Gutland) and its tributaries.

142 Buzzi *et al.* 1993.
143 Fechner *et al.* 2000; Bécu 1998; Koenig in press.
144 Louwagie & Langohr 1999.
145 Laurelut & Louwagie 2002.
146 Laurelut & Louwagie 2002.
147 Béague *et al.* 1998.

TABLE 3
Relic alluvium and colluvium along the transect cut by the future highway from Luxemburg to the German border (going to Saarbrücken) (Baes 2002).

Secteur (s)	Localisation	Altitude (m)	Largeur (m)	Epaisseur (m)	Substrat	Position topographique	Type de dépôts	Témoins archéologiques
42-C-029	*Reikiesschtchen* Hellange	272-280	200	>2,7	Lm_2	Vallée à ruisseau temporaire	alluvions limoneuses et argileuses	céramiques protohistoriques
42-C-018	*Schrondhauf* Hellange	261-262,5	150	>1,5	Lm_2	Vallée à ruisseau temporaire	alluvions limoneuses et argileuses colluvions argileuses	céramiques protohistoriques fosse et briques romaines
42-C-017 42-C-016	*Steemper* Hellange	152-257,5	500	1,55	Lm_2	Vallée à ruisseau temporaire	alluvions limoneuses et argileuses colluvions argileuses	céramiques protohistoriques briques romaines
42-C-012 42-C-020	*Neieweier* Hellange	248,5-250	350	>2	Lm_2	Vallée à ruisseau temporaire	alluvions limoneuses et argileuses colluvions limoneuses	céramiques protohistoriques briques romaines
Non sondé	*Deidebreck*				Lm_2	Vallée à ruisseau		
42-A-008 Aspelt	*Reckwues-Schiechtert* versant ouest	250-254	100	1,5	Lm_1		colluvions limoneuses alluvions limoneuses	occupation protohistorique
42-A-007	*Reckwues-Schiechtert* fond ouest	246-250	350	2	Li_4		alluvions limoneuses	
42-A-003 42-A-004	*Reckwues-Schiechtert* fond central	240-245	500	>2	Li_4	Vallée à ruisseau temporaire	alluvions limoneuses et argileuses	
42-A-002	*Reckwues-Schiechtert* versant est	241-246	150	>2	Li_3		colluvions argileuses couche argileuses remaniée	céramiques protohistoriques briques romaines
42-A-011	*Vallon sec d'Aspelt* Aspelt	244-247	75	>4	Li_3	Vallée à sèche	colluvions limo-sableuses	
Non sondé	*Gander*				Li_2	Vallée à ruisseau		
Non sondé					Li_2	Vallée à ruisseau		

of Champfleury (*cf. infra*: region "Champagne"), a contact with deeper, more stony horizons might partly explain this change in particle size and colluvial sorting. The archaeopedological study also reveals that, from the Later Medieval period onwards, fields were installed all over the valley, covering the areas of the Roman to Early Medieval village. Longer uninterrupted slopes allowed stronger erosion with a transport of larger particles into the valley bottom, through rills or by tillage erosion.

⊙ The Neieweier sector

A synthetic overview of the observations in two valley cuts of the Neieweier in Hellange, studied during the archaeological works for the highway Luxemburg-Saarbrücken, in the area corresponding to south-east Gutland has been presented by Baes[148]. This shows a rather general presence of relic colluvial and alluvial phases (fig. 9). In the secondary valleys of this marly region, two phases of erosion and sedimentation could often be recognised: (1) a very clayey organic alluvium situated in the lower central part of the valleys, covered by (2) a loamy alluvial deposit, often laterally corresponding with loamy colluvial deposits at the valley sides. These loamy alluvia and colluvia are chararacterised by the presence of Protohistoric and Roman artefacts (fig. 9, table 3) and have probably been deposited from the Roman period onwards. In one case, at the site of Aspelt "Galgebierg", this relic colluvium is situated on top of a Late Bronze Age site, without more detailed relative dating.

3.11.2 Slope deposits at a local scale

Local events of erosion have been put in a sequence for the site of Altwies (Luxemburg)[149]. Here Neolithic to Roman occupations alternate with a (pre-) Late Bronze Age and a (pre-)Roman phase of sedimentation. These thin colluvia might also be related to tillage erosion rather than more pronounced erosion

148 Baes 1999; 2002.

149 Baes 2002; Baes & Fechner 2003.

phenomena. The chronological sequence of colluvia however recalls the one of Remerschen, Ennery and Ay-sur-Moselle, in the nearby Moselle valley (*cf. supra*).

At Souhesmes, as in Rebecq "Spinoi", Ostiches "Chêne Saint-Pierre" and Mainvault "Embise", some very thin colluvial deposits containing some artefacts are probably linked with the erosion of the Carolingian occupation level, on which repeated walking allowed sheet erosion.

At the site of Bure[150] (France), an Iron Age plough horizon affects two dry valleys. On top of this horizon, there are rills and a stone layer, most probably related to rill erosion. All these horizons and deposits are comprised between settlement traces of the first phase of the Iron Age and some Late Iron Age structures.

At Vitry-sur-Orne, an agrarian colluvium contains Neolithic material at its base and is cut by a Medieval path. This deposit is supposed to date to the Subboreal period, or for the most part to the Iron Age or even Roman periods[151]. At Bouxière an (agrarian ?) colluvium could also date back to the Subboreal or the earlier Subatlantic period, but is probably mostly Roman[152].

At Saint-Epvre, agrarian colluvial deposits are attested through the whole Iron Age and partly Roman period[153]. The site of Solgne presents an inversed profile of agrarian colluvium from the Roman period[154].

3.11.3 Fluvial deposits

The Neieweier sector (see above, fig. 9 and table 3) provides some combined results on slope and fluvial deposits at a regional scale.

Alluvial deposits in small rivers in the area of Poix-Terron - Villers-le-Tourneur (Ardennes, France) seem to be associated with intensive land-use in the Iron Age (see above).

In the alluvial deposits of the site of Novy-Chevrières (Ardennes, France), a few kilometres downstream the same Vendre River, a small affluent and its springs have been studied. In a former meander of this affluent, a clayey alluvium containing Iron Age artefacts was cut by Roman installations[155].

At Prettingen (Luxembourg), below a surface of the first Iron Age period and buried by 2.3 metres of colluvium, an alternation of colluvia and, mainly, clayey alluvia fills the valley floor of the Alzette for about 8 metres. This sequence includes six layers of organic clay and four more sandy depositional phases, overlying gravelly, possibly Pleistocene, alluvia[156].

In their study of local bogs in Luxemburg, Riezebos & Slotboom[157] mention the possibility that an increase of sand deposits occurring in the alluvium could be due to deforestation from the Early Middle Ages onwards.

3.12 Champaign (France)

In the discussion we include both the limestone lowlands of the "Champagne crayeuse", the slightly hilly and less well-drained areas of the "Champagne humide", and some areas with calcareous loess.

3.12.1 Slope deposits at a regional scale

At a regional scale, erosion becomes more widespread in the Late La Tène and Roman period, however without being widespread. In some cases the soilscape is strongly modified as a consequence of deeper ploughing, mixing the black surface horizon with the calcareous rock[158].

⊙ The Champfleury sector

In Champfleury, the formation of a very heterometric colluvium affects a large dry valley and one of its tributaries. The colluvium is cut by a Late La Tène pit, and is probably the combined result of tillage and other types of erosion, as is a.o. shown by a profile situated further upslope (fig. 10). Malacology and pedological studies on this profile permit to characterise a pre-Roman or Roman plough horizon[159], with deeper ploughing and an important physico-chemical modification by the admixture of the very alkaline and rocky substratum.

⊙ The Saint-Hilaire-au-Temple sector

At Saint-Hilaire-au-Temple (fig. 11), both sides of the river Vesle are covered with multi-phased relic colluvium. On the eastern foot of the slope, the basal part of an inverted soil profile is cut by an Early La Tène pit and covered a Final Neolithic or Early Bronze Age sherd. This basal deposit shows the malacological and pedological characteristics of the underlying surface horizon, except for a slight addition of gravel. At the foot of the western slope, the oldest colluvium is dark and cut by a Roman ditch, which leaves the question open of its synchronicity with part of the colluvium of the eastern slope[160].

3.12.2 Slope deposits at a local scale

On a local scale, tillage erosion or other short-distance erosion phenomena have been found in association with the Middle La Tène occupations of Cuperly "La Perte". Here, colluvia cut by Middle La Tène structures could be either due to tillage erosion or erosion caused by activities in the adjacent settlements[161].

At Bussy-Lettrée, part of a large dry valley is filled by an extended, but rather shallow relic colluvium. This colluvium presents an inverted profile and is probably derived from a plough horizon in the loess on the eastern slope, and only from the natural rendzina soil on the western slope[162]. These relic colluvia are Late or more probably post-Neolithic (the latest ^{14}C-date on charcoal in the underlying surface horizon is 2460-2040 BC).

On the large scale excavation of Buchères (Aube, France), ditches of the Roman period were cutting colluvial deposits, situated on one side of a small affluent of the river (site n°31)[163].

150 Bécu 1999; Boulen *et al.* 1999.
151 Gebhardt *et al.* in press.
152 *Ibid.*
153 *Ibid.*
154 *Ibid.*
155 Fechner 2004d.
156 Baes, unpublished; Cordier *et al.* in press.
157 Riezebos & Slotboom 1978.
158 Fechner & Slachmuylder 2009; Fechner *et al.* 2008; Fechner 2004b; c.
159 Fechner 2004b.
160 Fechner & Slachmuylder 2009.
161 Fechner & Slachmuylder 2009.
162 As in Champfleury and, in other regions, in Souhesmes, the western slope of large valleys was not covered by Pleistocene loess, as they were in the shadow of the dominant winds.
163 Riquier *et al.* 2012.

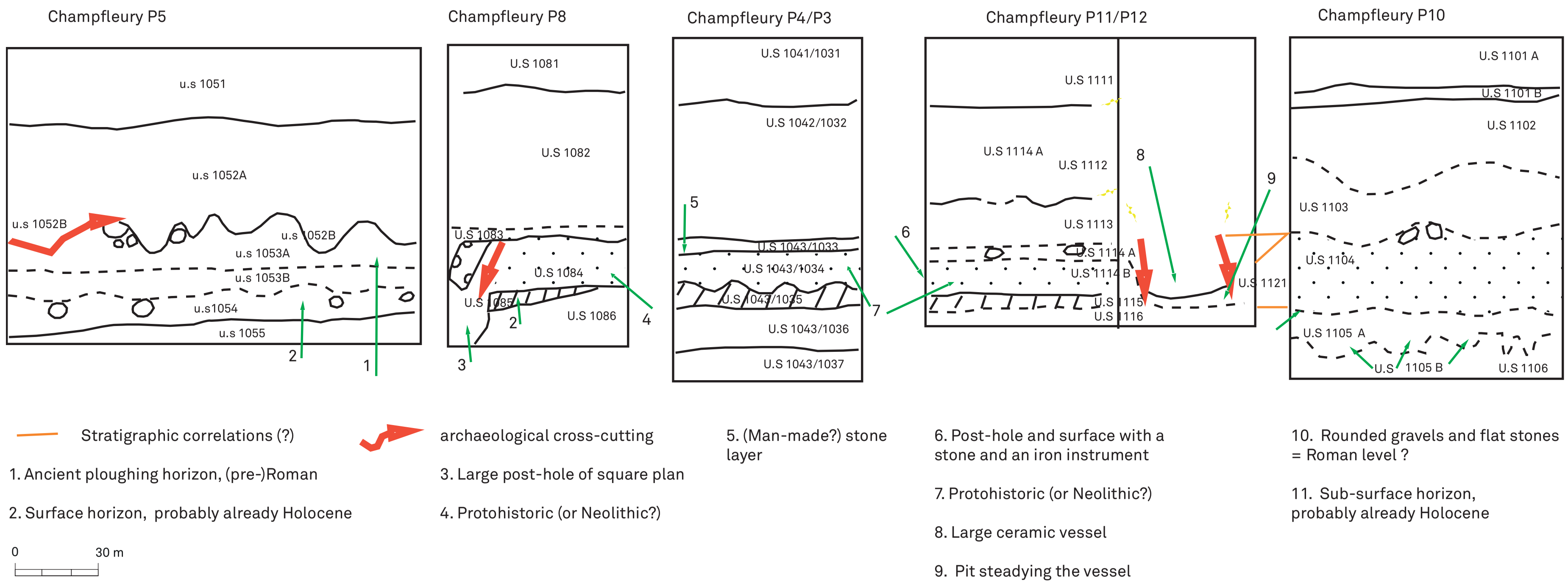
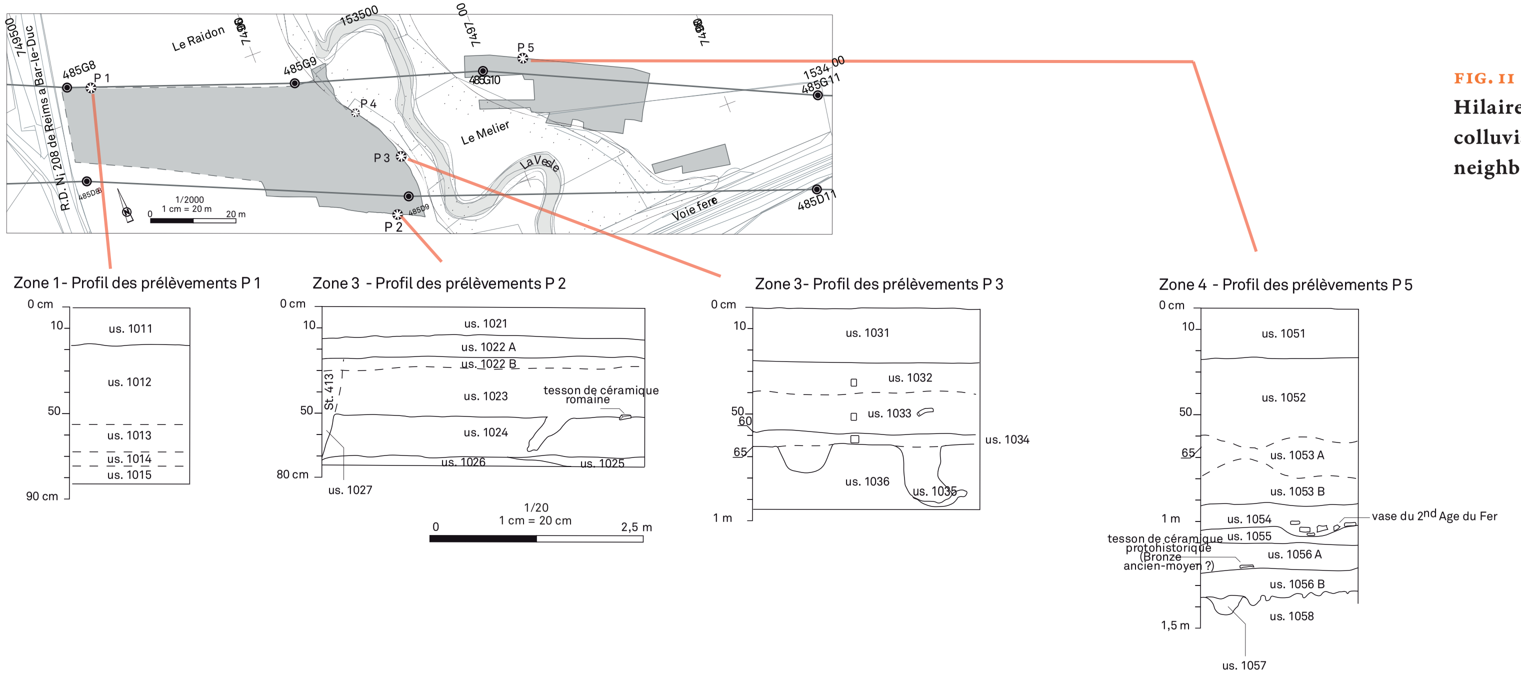


FIG. 10 **The profiles along the catena of Champfleury, all showing the same stratigraphic sequence that includes deposits cut once by Late La Tène, once by Roman structures.**



US 1011 : 0-20 : present-day ploughing layer (" Ap " horizon).
US 1012 : 20- 60/65 : colluvium becoming darker with depth.
US 1013 : 60/65-77 : humiferous horizon (" A1 " horizon), loose.
US 1014 : 75-80/85 : iron-enriched gravel.
US 1015 : >80/85 : gravel.

US 1021 : 0-15 : present-day ploughing layer (" Ap " horizon).
US 1022A : 15-25 : colluvium, beige colored.
US 1022B : 25-30 : colluvium, beige colored, slightly darker (humiferous?).
US 1023 : 30-52 : humiferous colluvium, horizontal sherd of 4 cm diameter at its base.
US 1024 : 52-72 : humiferous horizon (" A1 " horizon), very loose.
US 1025 : 72-75/80 : grey gravel, localized in a pocket.
US 1026 : >72/75/80: gravel.

US 1031 : 0-25 : present-day ploughing layer (" Ap " horizon).
US 1032 : 25-env. 40 : colluvium, beige colored.
US 1033 : env. 40 - 58 : darker colluvium.
US 1034 : 58-65 : humiferous horizon (" A1 " horizon).
US 1035 : 65-70/85 : humiferous bioturbation pockets (" Bbi " horizon).
US 1036 : 70/85->100 : fragmented limestone.

US 1051: -0 H1 = present-day ploughing layer (" Ap " horizon).
US 1052: -25 H2 = grey-brown colluvium (gradual transition), 20-40% gravel (0,3-10mm).
US 1053: -60 H3 = grey-brown colluvium (abrupt base), 20-30% gravel (0,3-10mm).
US 1054: -93 H4 = slightly humiferous colluvium with 40-50 % gravel (0,3-10mm).
US 1055: -105 H5 = humiferous colluvium with 25-40 % gravel (0,3-10mm).
US 1056A : -112 H6A = upper part of a very humiferous horizon (" A1 " horizon) or colluvium, 5-10%, locally 15-30%, of gravel (0,3-12 mm).
US 1056B: -125 H6B = lower, more homogeneous part, with only 5-10% and smaller gravel (0,5-8 mm). At -125 cm: horizontal sherd of 6 x 5 cm (1 cm thick). No asociated biogalleries. Near to horizontal base.
US 1057: -137 H7 = grey to dark grey pockets, abrupt and slightly irregular base, smaller pockets coming from US 1056B (earthworm or root galleries?)
US 1058: -137/ 152 H8 = pure homogeneous gravel, minimum 15 cm thick.

TGV EST EuropZen
Fig. n¡ 3 : TGV Est - Lot 23 B
Saint-Hilaire-au-Temple, "Le Raidon" (Marne)
Profils des prélèvements pédologiques P1, P2, P3 et P5

FIG. 11 The reference profile of Saint-Hilaire-au-Temple, with thick very dark colluvia, possibly due to the immediate neighbourhood of the place of erosion.

At Tagnon (Ardennes, France), a thick deposit of relic colluvium fills the whole extent of a dry valley at its contact with a river valley[164]. Its surface forms the Early Medieval occupation level with its top part containing a large horizontally positioned Roman sherd. It presents everywhere a clear inverted profile that reflects the former presence of decalcified materials (loess?) on a limestone substratum on the surrounding slopes.

A similar situation is encountered in Loisy-sur-Marne « ZAC de la Haute-Voie »[165]. A valley head has delivered dense Medieval traces on top of an orange clayey silt that covers a former surface horizon developed on marl, containing Roman and Iron Age artefacts.

3.12.3 Fluvial deposits

In Avenay "Val d'Or" (Marne, France), a first generation of fine-textured alluvia is most probably cut by the Iron Age ditches[166]. The large scale excavation of Buchères, which included a small river and its affluent, revealed the presence a clayey floodplain deposit from the Roman period (sites n°4 and 25)[167].

3.13 Tardenois and Aisne (France)

3.13.1 Slope deposits at a local scale

The sites of this area often present the direct juxtaposition of soils formed on an undeeply decarbonated loess and soils formed on a calcareous substratum[168]. As noted in Rebecq and possibly in Taintignies (see above, fig. 2), there is one older case at the site of Léry "La Presle" where the natural erosion-sedimentation is again very limited in space and depth (fig. 12). It is to be situated between that soil formation and a surface horizon representing the onset of stable climate and vegetation conditions. These events precede the deposition of Late Mesolithic flint working debris[169].

On a local scale, at the same site of Lhéry, colluviation is rather limited between the Late Bronze Age (attested by 14C-dating of a large charcoal fragment) and the Roman phase of incineration graves that cut this colluvium (fig. 12)[170].

At the site of Goussancourt (Aisne), significant phases of erosion took place before and just after a Merovingian occupation[171].

At Saint-Quentin "Parc des Autoroutes" (Aisne), a multi-phased deposit of dark horizons with Roman and Late Bronze Age occupation phases attests of regular colluvial raising of the surface of a dry valley. This sequence already covers a thin light grey colluvium with some pieces of charcoal[172] on top of an uneroded soil.

Further south, in the Oise valley, regular anthropogenic erosion presumably started inwith the Late Bronze Age[173].

3.13.2 Fluvial deposits

Only information for the adjacent department of the Oise is available.

At the interfluvium of the Oise and Aisne rivers, on the site of Choisy-au-Bac (Oise), a thick multiphased deposit of clayey alluvium is interstratified with Mesolithic, Neolithic and Protohistorical occupation phases[174].

At Saint-Croix-Ouen, in the same Oise departement, Pastre *et al.*[175] have studied alluvia that are contemporaneous with the Late Neolithic colluvia of Houplin-Ancoisne (see above: Nord-Picardie region). The interpretation of the latter site is very important to mention here: « *Vers 4000 BP, la fin du Néolithique (Néolithique final, Chalcolithique) est marquée par le début d'une importante crise sédimentaire qui se marque dans les lits mineurs des grandes vallées par des apports limono-argileux massifs. Dans la vallée de l'Oise, la sédimentation ripuaire à tendance organique, bien datée par des vestiges du Néolithique récent, passe à une sédimentation limoneuse contenant des témoins du Néolithique final de type Gord. Ce changement témoigne d'une première déstabilisation massive de la couverture limoneuse pédogénéisée (sols bruns) des versants. (…)* ». It asks the question of the part of man and of climate in the sediment dynamics in the rivers and on the slopes in the Paris basin[176], as early as the Late Neolithic, as well of possible comparisons between that area and our study areas further north.

4 Discussion

4.1 "The archaeology of erosion-sedimentation": first results at different scales

⊙ *Relic colluvia* (table 4)
For the Middle Belgium, Western Lorraine and Champaign areas, elaborated work on short-distance erosion was amongst others presented by Louwagie[177] and Louwagie & Langohr[178]. By these dominant short-distance erosion-sedimentation processes, the soil-scape and topography of some areas were modified drastically. In Middle Belgium, as erosion reached the heavier, illuviated B_t-horizon at ca. 40 cm depth, with 8-18% more clay (23-28% instead of 10-15%) than the eluvial E-horizon originally lying at the surface, ploughing instruments and drainage ditches had probably to be adapted.

Some units on the published soil maps could be correlated with the colluvia and alluvia studied on individual sites. In the north-western part of the pedo-regions 'Middle Belgium loess' and 'Middle Belgium sandy outcrops and sandy loess', buried colluvium sometimes coincides with soils with "profiles with a structure or colour B-horizon" on the soil map. Some of these colluvial deposits date from the Roman period.

A simple compilation of data from rescue archaeology (table 4) seems to indicate that there are recurrent erosion and sedimentation phenomena in the Bronze/Early Iron Age in area 10

164 Fechner 2003.
165 Fechner 2008.
166 Bécu 2000.
167 Riquier *et al.* 2012.
168 Fechner *et al.* 2008.
169 Fechner *et al.* 2008; Bostyn & Séara (eds) 2011.
170 Fechner *et al.* 2008; Bostyn & Séara (eds) 2011.
171 Hosdez (ed.) 2009; L. Deschodt, pers. comm.
172 P. Lemaire, pers. comm., forthcoming report, K. Fechner, unpublished observations and field report.
173 Kuzucuoglu *et al.* 1991 and 1992; Pastre *et al.* 1997.
174 C. Coussot, INRAP, pers. comm.; Fechner, unpublished report.
175 Pastre *et al.* 2002 39/2.
176 Kuzucuoglu *et al.* 1991; 1992; Pastre *et al.* 1997.
177 Louwagie 1996.
178 Louwagie & Langohr 1999.

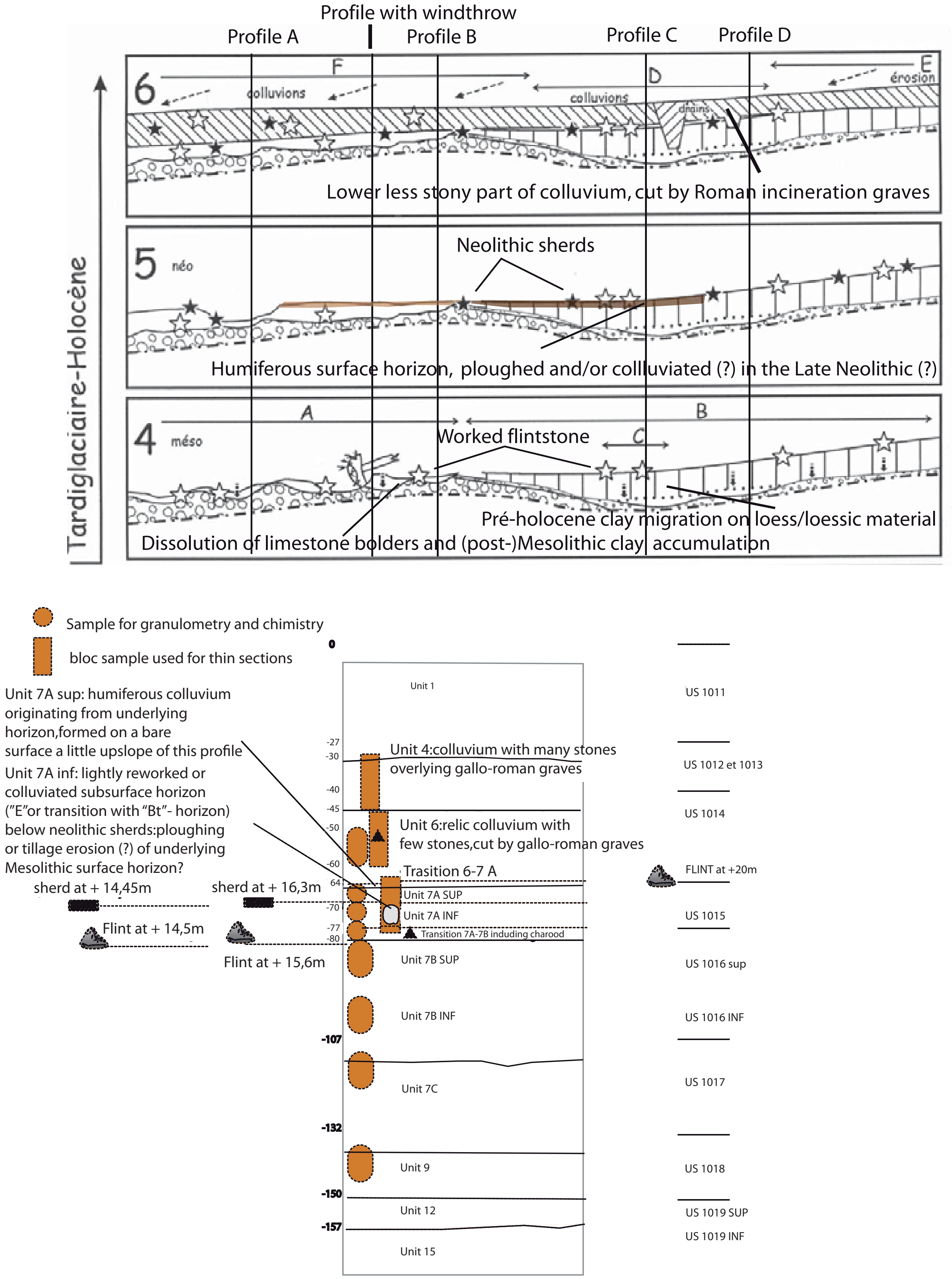


FIG. 12 **Lhery "La Presle": Interpretation of transect 1 by soil analyses and micromorphology (completed after sketch of L. Deschodt)**

(Moselle river), in the Late Iron Age in nearby areas 11 (Western Lorraine), 12 (Champaign and 13 (Tardenois/ Aisne), possibly 2 (Middle Belgium loess with sandy outcrops) and 9 (Western Lorraine), and in the Roman period in areas 1 (Middle Belgium loess area), 2, 9, 11 and possibly 12, in the Medieval period in area 1 (see also table 5). However, these tendencies are derived from a potentially biased dataset (*cf. supra*), and thus need to be confirmed by a.o. off-site data. Moreover, a more detailed analysis of the data is necessary (below).

It appears that in some areas older or more general phases of erosion are present, especially in the subarea with steeper slopes as in Chièvres in the pedo-region 'Middle Belgium loess' or in Papignies and Ostiches in the western part of the province of Hainaut or "Flemish Ardennes", in 'Middle Belgium sandy outcrops and sandy loess', or, finally, in some cases as along the Somme and along the Meuse Valley bottom. On the steeper slopes of some of these two valleys, one could even imagine that wild macro- or microfauna alone might have produced limited erosion in forests, without any

TABLE 4

Catalogue of the better documented cases of significant erosion-sedimentation, per period and per area; in italic and bold: clayey alluvial deposits. In orange: three certain cases per pedoregion and period. In blue: four or more certain cases per pedoregion and period.

Pedo-region	Mesolithic	Neolithic	Bronze/Early Iron Age	Late Iron Age	Roman period	Medieval period
1	(Rebecq ?)			("Ferme Taon" ?)	Landen	Tubize
				(Meerdael Bos ?)	Lincent	***Wasmes-l..-A.-B..***
					"Ferme Taon"	***Tubize***
					Wisbecq	
					Meerdael Bos	
					(Tubize?)	
2		***(Neufvilles?)***	Nethen valley	Neufvilles	Neufvilles	Neufvilles
			(Neufvilles?)	Nethen valley	Lombise	Embise
				(Papignies ?)	Chêne-Saint-Pierre	
				(Dion-le-Mont?)	Dion-le-Mont	
					Nethen valley	
					Papignies	
3		***Oudenaerde-Donk?***	***Oudenaerde-Donk***	***Scheldt river***	***Scheldt river***	
			Scheldt river			
5-6	Somme river	Houplin-Ancoisne I	Erre	(Erre ?)	(Recques-le-Hem?)	***Scarpe river***
		Houplin-Ancoisne II		(Recques-le-Hem?)		
7	***(Namur?)***	***Liège***	(Liège ?)	(Liège ?)		(Liège ?)
		(Namur ?)	***(Liège ?)***			
9				Goin	Goin	
				Varincourt	Bliesbrück	
				(Marsal?)	Imling	
				(Imling?)	Sarrebourg	
				(Sarrebourg?)	Haut-Clocher	
				(Haut-Clocher?)		
10		Remerschen	Remerschen		Forêt de Haye	Borny
		Remerschen	Ennery		Illange	
			Ay-sur-Moselle			
11			Altwies	Villers-le-Tourneur	Souhesmes	Villers-le-Tourneur
				Bure	Solgne	Souhesmes
				Saint-Epvre	Bouxière	
				(Neieweier?)	Neieweier	
				(Neieweier?)	***Neieweier***	
					Novy-Chevrières	
12			St.-Hilaire-au-Temple	Chamfleury	Cuperly	Loisy-sur-Marne
			(Cuperly?)	Cuperly	(Tagnon ?)	(Tagnon ?)
				St.-Hilaire-au-Temple	***Buchères***	
13			(Lhéry ?)	(Lhéry ?)	(Lhéry ?)	
			(Saint-Quentin?)	Saint-Quentin	Saint-Quentin	

intervention of man[179]. It should be noted that Denny & Goodlett[180] report on tree-falls producing erosion-sedimentation phenomena, however at a limited scale.

◉ *Relic alluvia* (table 4)
They reflect regional, rather than local, effects of a climatic and/or anthropic impact, as they are usually the result of (and thus secondary to) a phenomenon that took place elsewhere. The early Neolithic ages (*cf.* table 4) of the alluvial clays in the sites of Remerschen, in the Mosel Valley, and Liège, located in the Meuse Valley, are remarkable and probably stand for sites or area(s), further upstream, that had an abnormally intense anthropogenic occupation. On a supra-regional scale, and however based on little data, there are possibly three main phases of early alluviation in the study area: in the Early Neolithic, the Late Neolithic and the Late Bronze Age. These results might confirm the idea of Bravard & Magny[181] that this alluviation could coincide with increased anthropogenic impact on the landscape, but that this however remains difficult to prove through individual cases. In order to confirm some trends, the built up of a larger dataset is necessary. These trends will then have to be confronted with climatic and archaeological data in order to distinguish between anthropic and climatic triggers of erosion, sediment transport, and sedimentation.

4.2 "Erosion of archaeology": impact on site conservation studies and reconstructions

The knowledge of the extent and depth of pre-modern soil erosion is an important starting point for the evaluation of the state of preservation of Holocene open-air sites. This evaluation of the impact of erosion on sites contributes to the understanding of the excavation data and allows the approximative reconstruction of the surface level of the occupation, and thus of the depth and importance of the structures.
The present study states that the prehistorical, even La Tène and Roman, erosion phenomena were limited in depth and extension and limited to well-defined zones. This observation allows us to evaluate the post-occupational erosion of the majority of sites, as it confirms that we are entitled to use the present-day state of erosion for the reconstruction of the level of the former occupation surface (and amount of abrasional destruction) of the large majority of pre-Roman and Roman archaeological sites in the study area.

4.3 First attempts of analyses and synthesis of the raw data

Going beyond the raw data, a first attempt of analysis and synthesis is proposed in table 5. However, this attempt is also derived from a potentially biased dataset (*cf. supra*), and will need to be confirmed by a.o. off-site data. Table 5 classifies the most significant data obtained in the limits of this study per period and geo-region, and, as far as possible, by importance and possible types of past erosion-sedimentation traces. The most significant sectors of erosion-sedimentation, with more than two synchronous events, are indicated in bold characters. The hypothetical character of most of the erosion-sedimentation types imposes a differentiation between better interpreted and less well interpreted types (between brackets and with a question mark), but the difficulty of attribution to a type does not justify to exclude the sites from the table.

Where possible, the appointment to a certain erosion-sedimentation type is based on the following criteria (table 5):

I. The most significant erosion-sedimentation is present on more than one place (more than one adjacent valley or more than one slope in one valley), coinciding with what is indicated in this article as a "sector". When the information is accessible, it can be associated with synchronous traces of cultivation, based on direct or indirect information (large distribution of erosion-sedimentation, lack of any traces of settlement).
II. When synchronous traces of settlement are present, this is interpreted as the probable main cause of the erosion-sedimentation
III. Local erosion is not or not yet associated to equivalent discoveries in the adjacent valleys and limited to a restricted area, for instance one slope. Here too, it sometimes can be associated with synchronous traces of cultivation, based on direct (or indirect information) (large distribution of erosion-sedimentation, lack of any traces of settlement).
IV. Here too, when synchronous traces of settlement are present, the presence of the latter can be proposed as probable main cause of the erosion-sedimentation.
V. Very localized erosion-sedimentation is sometimes found in the middle of a dense settlement or a cemetery, as a layer that is particularly thin and containing (micro-) artefacts.
VI. The accumulations of fine-grained alluvial deposits are listed, but not all or not directly related to human action.

In the present state of research, mainly based on recent archaeological surveys and revealing several trends, two sectors with recurrent earlier erosion-sedimentation phenomena appear in the Somme region (Late Mesolithic colluvia) and in Nord/ Pas-de-Calais (Late Neolithic colluvia near or in settlements). After some Late Bronze Age colluvia in the Mosel valley and in neighbouring sites in the Western Lorraine, there are a larger amount of Iron Age, often Late La Tène, large-scale erosion sedimentation events in parts of the Tardenois/Aisne area, Eastern Lorraine, the Mosel valley, the Western-Lorraine and Champaign (in this last region, especially in the north-west, associated with soils developed on limestone) (table 5: in blue and in grey). Note that all these areas are largely dominated by nutrient-rich soils (fig. 1). There is an equivalent phenomenon during Roman times in parts of the Middle Belgium loess area and in parts of the Middle Belgium loess area with sandy-outcrops (table 5: in green). These areas originally present nutrient-poor soils.

The other important events related to colluvium and erosion might be isolated and related to local human impact, for example associated with Early Neolithic occupation in the Mosel region. The exact chronology of important colluvia situated between the Neolithic and Iron Age surfaces in Nord/ Pas-de-Calais (Erre), between Neolithic and Roman surfaces in the Meuse (Liège) and

179 **Hazelhoff *et al.* 1981; Imeson 1976; Imeson & Kwaad 1976; Imeson *et al.* 1980.**
180 **Denny & Goodlett 1956.**
181 **Bravard & Magny 2002.**

TABLE 5

Interpretation of the results: regional tendencies as reflected mainly by recent archaeological survey, without yet confronting them with all other types of approaches in the study-area. In green, the sites on nutrient-poor soils according to soil map in figure 1, that are mostly attested from the Roman period onwards. In grey, sites on nutrient-rich soils in Champaign and in the Tardenois/Aisne area that date from the Iron Age and later. In blue, sites on nutrient-rich soils of Lorraine and the Mosel valley that are present from the Late Bronze Age onwards.

Chronology according to Vanmoerkerke in Fechner & Slachmuylder 2009; Gebhardt *et al.*, in press.	I. Probable field erosion sectors	II. Probable local field erosion	III. Probable settlement erosion sectors	IV. Probable local settlement erosion	V. Very localized erosion in settlement/ graveyard	VI. Important deposits of fine-grained alluvium in the flood-plain
Pre-Boreal (ca. 9200 -8300 BC)				(Middle Belgium: Spinoi ?)		
Boreal (ca. 8300-6900 BC)						(Meuse: Liège ? Namur ?)
Ancient Atlanticum (ca. 6900-5000 BC)			**(Middle Somme sector: Late Mesolithic colluvia?)**			(Meuse: Liège ? Namur ?)
Recent Atlanticum (ca. 5000-3500 BC)		(Middle Belgium: Dyle valley?)		(Middle Belgium: En Bia Flo II?)	Mosel: Remerschen Early Neolithic settlement	Meuse: Liège
Subboreal (ca. 3500-800 BC)	**Moselle: Ennery-sector: inversed profile of agrarian colluvium in Ennery, Bronze Age agrarian colluvium in Ay-sur-Moselle**	M.B. sandy outcrops: Nethen valley: increasing amounts of colluvium from 2500-3000 BP (1300-500 BC) Meuse: Liège Subboreal colluvium Mosel: Remerschen colluvium below Late Bronze graves W. Lorraine: Altwies colluvium below Late Bronze graves (Tardenois/ Aisne: Saint-Quentin ?) (Tardenois/ Aisne: Lhéry ?)		**Nord Pas-de-Calais: Houplin-sector: Late Neolithic settlements**		M.B. sandy outcrops: Neufvilles Scheldt: Oudenaerde-Donk
Pre-Roman Subatlanticum (ca. 800-50 BC)	**E. Lorraine: Goin sector: Late Iron Age colluvium** **Mosel-sector: Remerschen sector: two Iron Age colluvia, one protohistorical and some (Pre-)Roman colluvia** **W. Lorraine: Neieweier sector: pre-Roman colluvium** **W. Lorraine: Villers-le-Tourneur sector: erosion of the end of the Iron Age** **Champaign: Chamfleury-sector Late La Tène erosion**	(Middle Belgium: Ferme Taon ?) Nord Pas-de-Calais: Erre Meuse: Liège (Pre-) Roman colluvium E. Lorraine: Imling rill erosion before colluvium Moselle: Forêt de Haye erosion below Roman agrarian levees W. Lorraine Bure rill erosion and colluvium W. Lorraine: Saint-Epvre agrarian colluvium, through the whole Iron Age Tardenois / Aisne: Saint-Quentin Tardenois / Aisne: Lhéry initial colluvium	**Champaign: Saint-Hilaire-sector**	M.B. sandy outcrops: Neufvilles E. Lorraine: Varincourt fortified settlement Champaign: Cuperly		Middle Belgium: Mark river Scheldt: Scheldt river E. Lorraine: Marsal ? W. Lorraine: Villers-le-Tourneur

Chronology according to Vanmoerkerke in Fechner & Slachmuylder 2009; Gebhardt *et al.*, in press.	I. Probable field erosion sectors	II. Probable local field erosion	III. Probable settlement erosion sectors	IV. Probable local settlement erosion	V. Very localized erosion in settlement/ graveyard	VI. Important deposits of fine-grained alluvium in the flood-plain
Roman Subatlanticum (ca. 50 BC-400 AD)	**E. Lorraine: Goin-sector Mosel: Remerschen sector: Roman coilluvia W. Lorraine: Villers-le-Tourneur sector: colluvium at the beginning of Roman period W. Lorraine: Souhesmes-sector: (Early) Roman colluvium W. Lorraine: Neieweier sector: Roman colluvium Champaign: Chamfleury sector: Roman colluvium**	M.B. sandy outcrops: Neufvilles M.B. sandy outcrops: Dion-le-Mont M.B. sandy outcrops: Nethen valley Meuse: Liège (Pre-) Roman colluvium E. Lorraine: Bliesbrück agrarian colluvium. E. Lorraine: Imling rill erosion before colluvium E. Lorraine: (Pre-) Roman agrarian erosion in Sarrebourg E. Lorraine: Haut-Clocher dark agrarian colluvium with protohist. Material Moselle: Forêt de Haye erosion below Roman agrarian levees W. Lorraine: Solgne inversed profile of agrarian colluvium W. Lorraine: Bouxière (agrarian ?) colluvium Champaign: Buchères Roman colluvium Tardenois/ Aisne: Lhéry colluvium	**Middle Belgium: Landen sector Middle Belgium: Hannut sector Middle Belgium: Dyle sector M.B. sandy outcrops: Lombise-sector M.B. sandy outcrops: Ostiches sector Champaign: Saint-Hilaire-sector**	Mosel: Illange colluvium that is rich in artefacts	Middle Belgium: Wisbecq M.B. sandy outcrops: Chêne-Saint-Pierre	Scheldt: Ramegnies-Chin Scheldt: Scheldt river (Nord Pas-de-Calais: Lille) Easterrn Lorraine: Bliesbrück Champaign: Novy-Chevrières Champaign: Buchères
Post-Roman Subatlanticum (ca. 400 AD-ca. 1200 AD)	**W. Lorraine: Villers-le-Tourneur sector: beginning of the Late Middle Ages (around 1100 AD)**	Middle Belgium: Tubize	Moselle: Borny colluvium	M.B. sandy outcrops: Neufvilles	Middle Belgium: Embise	Middle Belgium: Wasmes-les-Audemez-Briffoeuil
	W. Lorraine: Souhesmes-sector: Carolingian rills and colluvium and Late Medieval colluvium	Champaign: Loisy-sur-Marne			Western Lorraine: Souhesmes carolingian palissade	W. Lorraine: Villers-le-Tourneur

in Western Lorraine (Vitry-sur-Orne), between Late Bronze Age and Roman surfaces in the Tardenois/Aisne (Saint-Quentin, Lhéry), between Iron Age and Roman surfaces in Eastern Lorraine (Sarrebourg, Haut-Clocher, Imling), and in the Moselle (Forêt de Haye) remains to be defined. In these cases, the younger of these two chronologies has been considered as the most probable one, until more local information is gathered.

It has once again to be stressed that the confrontation with off-site data (augerings, geomorphological transects,...) still needs to be done, and that such data are under-represented in this paper. However, the few cases in this article where data from the flood-plains are compared with data from surrounding sites (table 5) prove the value of this exercise. In the Western Lorrain region, the sector of Villers-le-Tourneur allows to draw some parallels between Iron-Age colluvia and fine-textured alluvium. The same is possible for the Roman period in Buchères (south of the Champaign region) and in Bliesbrück (Eastern Lorraine), as well as possibly for earlier periods in Middle Belgium (Oudenaarde-Donk), in the Meuse (Liège) and in the Moselle (Remerschen).

5 Conclusion and perspectives

The table of synthesis is a first attempt to summarize the results of a work in progress. Data are to be completed, and interpretations might evolve. Nevertheless, this method of grouped presentation of the main results allows to reveal regional tendencies as reflected mainly by recent archaeological surveys, without yet confronting them with all other types of approaches in the study-area. This lack of synthetical confrontation withholds us at this stage from proposing interpretations on the causes of these tendencies.

The appreciation of more regional trends has led us to strongly modify our initial impressions that were based on some individual sites. In order to understand the evolution of the anthropogenic impact on the palaeo-environment correctly, a regional approach including a sufficient number of well-documented sites will be needed. Only this approach will provide us with adequate regional sequences that can serve as an interpretational and taphonomic framework for both archaeologists and palaeo-environmentalists. Provided map and tables illustrate that some areas have not been investigated as much as others. Moreover, data are often only published in local and thus less accessible papers and reports.

The examples quoted in this article indicate that only some cases have been studied in such a way that more detailed questions on the exact environment and its evolution could be answered. This fact advocates the extension of detailed studies, involving topotransects and adequate soil physico-chemical and micromorphological studies. Along with this aspect, the means provided for absolute dating of colluvia and alluvia in the study area are mostly scarce. The impact of climate change on an increase of alluvial and colluvial depositions can indeed be important[182]. It is however difficult to detect such trends and to distinguish them from anthropic impacts, as long as the well-dated deposits are too few.

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182 E.g. Van Geel & Magny 2002; Bravard 1997 for the Subboreal and Subatlantic of south-eastern France; Van Geel *et al.* 1996 for the period of 2750 to 2450 BP.

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This ninth volume of the *Relicta Monografieën* is a collection of papers based on the lectures presented at the conference '*the Archaeology of Erosion, the Erosion of Archaeology*', hosted by the Flanders Heritage Agency in Brussels on April 28th-30th 2008. The conference sought at bringing together approaches and methods for the study of taphonomic processes on the scale of landscapes and regions, and the interaction of these processes with the archaeological record. As such a selection of studies passed the scene, involving a.o. geology, pedology, remote sensing, computer-based landscape modelling, and of course archaeology. This multi-disciplinary approach proved to be a fruitful ground for debate and interesting discussions, leading to the main conclusion that the complexity of landscape and archaeology 'intertwinement' can indeed only be unravelled by combining this multiplicity of approaches. The papers in this volume are a reflection of this wide-ranging 'toolkit'. As case studies they present important insights and intakes for both the study as well as the management of cultural landscapes and the archaeological record.

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