INTERDISCIPLINARITY BETWEEN HUMANITIES AND SCIENCE

A FESTSCHRIFT IN HONOUR OF PROF. DR. HENK KARS

editors
Sjoerd Kluiving, Lisette Kootker
& Rita Hermans

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Contents

Preface

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This festschrift for Professor Dr Henk Kars highlights Henk's great interdisciplinary drive and vision which has characterised his career and the work he inspired in his division within the Vrije Universiteit (VU). The papers delivered at a packed meeting in a former Church, high in a tower in the VU, included contributions from the two of us, which we in the lieu of formal papers, are recognised in this preface.

It was a brave move for Henk to establish an Institute of Geo and Bioarchaeology in Amsterdam, and the publication series which supported this. The group, which to my great regret the VU decided to close, performed remarkable feats on a shoestring budget, not least of which are the range and quality of the undergraduates and graduate students that they trained. Henk has influenced two generations of researchers, in areas so broad they are beyond the limit of comprehension. Further, International Symposium of Biomolecular Sciences (ISBA) started by Henk has taken over from a rival Ancient DNA series to become *the* meeting place for Biomolecular Scientists, although it had no such intention when Henk first launched it at the VU in 2004. Henk frankly decided it would be useful to hold a meeting highlighting the developments of biomolecular archaeology as a means of attracting Dutch students to the courses held by the VU. Although there were very few Dutch voices at the meeting, researchers flooded in from all over Europe, and a symposium series was born, to be held next by Kerstin Liden in Stockholm in 2006. At the Stockholm meeting hearing so many researchers discuss new ideas on lactase persistence and dairying, the EU project LeCHE was born. In 2008 we brought the meeting to York, then Copenhagen in 2010, Beijing in 2012, Basel in 2014, and we meet again for the seventh ISBA in Oxford this year, 2016.

He and his students, Miranda Jans and Hege Hollund have made inexorable progress in understanding the survival of bone in the archaeological record, and as he moves on to new directions, he leaves a field in rude health and at a period in which it is growing more rapidly and extending its tendrils ever further into the discipline of archaeology. Much as Henk envisaged as he moved from ROB to the VU, archaeology is becoming a truly interdisciplinary area of research, and is more vital, relevant and engrossing for that.

Matthew Collins

'Bone corrosion' these two words were my introduction to Henk Kars. Angela Gearney, who was a then postdoctoral researcher working with me had been approached to add more of an archaeological focus to an EU project that Henk had devised building on corrosion of bronze artefacts. It was my first introduction to Henk (which also means Eva) and to the complexities of EU funding and EU grant management. I thank Henk for both. The bone 'corrosion' or bone diagenesis project that Henk initiated and that we gratefully rode the coattails was great fun, and sucked me into a research project from which I have never been able to fully wrest my interest. Henk was a superb manager, he knew how to reach consensus, how to drive a project forward, and how to deliver a project on time. Although I am not so about the latter bit – which seemed to rely a little too much on the coordinator doing all the work.

In my view the project was responsible for launching my research career. Furthermore, Henk is solely responsible for me becoming involved in large European research projects, and it is entirely appropriate that I am typing this on the Eurostar on route to a meeting with our desk officer ahead of the start of an EU project. What is more *really* we discovered something! I was very sceptical that we would find anything, so many sites, too many variables, but with careful work from them team we began to piece together a pattern of survival which seemed to make sense. With Miranda Jans, carefully documenting histological changes in bones, Colin, managing the endless mercury porosimetry data and Christina, putting it all together, we could identify three diagenetic trajectories, and these identified more than 60% of the variance we measured. What is more they made sense. Broadly speaking, one (time) attacked the collagen, another (soil chemistry) attacked the bone and the third (the gut flora) attacked Trojan like by getting via the blood vessels into the bone, itself. More significantly in cases which broke this rule, we were alive to the exception and wanted to know why. Which of us on the team can forget the still unexplained case of Apigliano, a small deserted Medieval village in Tuscany, who bones looked to all intents and purposes as if they had come from a fossil site. It is a rare example of completing a project drawing conclusions and drawing a line under the research, our contribution done. I still teach bone diagenesis by teaching about the project and the discovery of our three trajectories, during this my first European project.

Henk has drawn on his experience in working with the then Rijksdienst voor het Oudheidkundig Bodemonderzoek (ROB) and the particular archaeology and geology of the Netherlands in which the draining of the polders revealed much archaeology, a lot of it sunken. Henk, perhaps persuaded by the sheer number of sunken artefacts became interested in preservation in situ. He became a key member of the Preservation of Archaeological Remains In Situ (PARIS) group, hosting a very enjoyable meeting at the VU. Indeed, I fondly recall the many meetings we had at the VU, the Archaeometry meeting in 2000, was the springboard for me to establish BioArCh at York, where Mike Richards and I speculated on how the future of archaeology would emerge as biological sciences made an ever increasing impact. This was the subject of my *Reuvenslezing* essay, my invitation to that most enjoyable Reuvensdagen was something else for which I am sure I am grateful to Eva and Henk.

Kerstin Lidén

Although I had heard of Henk and his work previously I first met him in person at the first ISBA meeting in Amsterdam. The work that I was most aware of was of course his bone diagenesis project described above by Matthew, since it also included Swedish collaborators from Riksantikvarieämbetet (RAÄ), but also since soil chemistry in archaeology has a long history in Sweden. I also knew the work of his wife Eva, who had worked as a professional archaeologist at RAÄ in Stockholm, Sweden. At the meeting in Amsterdam Henk approached me and asked if I was willing to host the second ISBA meeting, which I gladly accepted. At that meeting we had an excursion to Birka, the Viking Age settlement outside Stockholm. This was also the start of a long collaboration between VU and Stockholm University (SU). The collaboration was based on an agreement that within our master programmes in archaeological sciences there should be an exchange of teachers and exchange of students. Originally it was supposed to include also York but it turned out to be administratively difficult for the Brit's to take part in the agreement so we continued with only VU and SU. It meant that every second year we hosted students from Amsterdam I Stockholm for a week and every second year our students went to Amsterdam. At these meetings the students had to present their theses and to take active part in the discussions after the presentations. It also included excursions to different archaeological sites around Amsterdam and Stockholm, this last year, when students from Amsterdam came to Stockholm, they took part in our seminar excavations at Broby, a Viking Age settlement with rune stones and burials. Although we lacked proper funding for this exchange, we somehow always managed to fulfil the expectations from the students. Taking part as teachers from Stockholm were beside myself also Sven Isaksson and Lena Holmquist. For me personally Henk has also been an important person since he was one of two evaluators for my position as full professor in Archaeological Science in Stockholm, so I can only back up Matthew's claim that Henk launched Matthew's career by saying he definitely launched my career as well.

Interdisciplinary collaboration between the Humanities and Sciences

Fifteen years of Geo- and Bioarchaeology teaching and research at the Vrije Universiteit Amsterdam

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Introduction

In 1999 the Faculty of Earth and Life Sciences of the Vrije Universiteit in Amsterdam founded the Institute for Geo- and Bioarchaeology for Research (IGBA). At the same time, the Institute founded an interdisciplinary study program entitled 'geo- and bioarchaeology', which was developed by Professor Henk Kars, attracting and inspiring a modest number of bachelor and master students, as well as PhD students from both the Netherlands and abroad.

Now, fifteen years later, in response to low student numbers, the study program has been cancelled by a faculty wishing to economize, thereby reducing research opportunities (Kluiving & Kars, 2014). In this paper, delivered on the retirement of Prof. Dr. Henk Kars, a) we review what has been accomplished in the fifteen years of research collaboration between geology and archaeology at the VU, b) we introduce ten papers between science and humanities that form the backbone and introduction of this Festschrift to Prof. Dr. Henk Kars, and c) we discuss what future prospects exist for research and teaching geo- and bioarchaeology in the Netherlands and beyond.

Almost half a century ago Colin Renfrew declared that "every archaeological problem starts as a problem in geoarchaeology" (Renfrew, 1976). Geoarchaeology has developed in the current and pre-last decennium internationally, shown by the growth of interdisciplinary sessions between culture and nature at various large conferences. The department of Geo- and Bioarchaeology (AGBA) of the Vrije Universiteit has organised a significant number of international conferences and symposia, and has manifested itself as the university where interdisciplinary research is executed at the interface of geology and archaeology: the 33st *International Symposium on Archaeometry* (ISA, 2002; Kars & Burke, 2005), the 1st *International Symposium on Biomolecular Archaeology* (ISBA, 2004), the 3rd conference *Preservation of Archaeological Remains In Situ* (PARIS, 2006; Kars & van Heeringen, 2008), and the 1st and 3rd international *Landscape Archaeology Conferences* (LAC2010, LAC2014). Moreover, we have been guest editors of five special volumes dedicated to themes of Landscape Archaeology, Geoarchaeology, and Soil as a Record of the Past (Quaternary International, 2012, 2015; Catena, 2015, 2016; SoilD, 2016).

What is geoarchaeology?

Definitions that have often been cited in the literature suggest that geoarchaeology addresses archaeological research questions using methods and techniques from the earth sciences (Butzer, 1973; Engel and Brückner, 2014). In the early days of this emerging interdisciplinary research field the focus was on understanding the physical environment and landscape setting of the archaeological remains and the (pre-) historic landscape.

Nowadays the original definition of geoarchaeology has been widened with the application of earth sciences going beyond simply the reconstruction of the archaeological-historical landscape. Furthermore, archaeological knowledge is now being used to inform questions addressing earth science research and the relationship between natural processes and human influence. Over the past fifteen years, the AGBA Institute has contributed in many ways to academic debates in geoarchaeology. The following list of themes, research questions and publications of staff, PhD and MSc students illustrate the multi-faceted role of the IGBA in contributing to the interaction of earth sciences and archaeology (for a more complete description see Kluiving & Kars, 2014).

Georchaeological prospection and Geo-ICT applications

Identification and geoprospection of the remains of past settlements and graveyards can be undertaken by coring and through remote sensing analysis (Sueur, 2006; Waldus & Van der Velde, 2006). Magnetometry has been successfully applied to map archaeological features including ditches and hollows, as well as iron-rich anomalies within the soil caused by metalliferous objects and high temperature alteration caused by other processes such as burning (Kattenberg, 2008). Novel geochemical techniques have also been used to detect organic residues associated with settlement, such as proteins derived through the decay of human and animal material (Oonk, 2010).

The geographical distribution of sanctuaries on the hill tops of Crete, Greece, including sight lines and other spatial characteristics, have been systematically analysed in GIS (Soetens, 2001). 3D-modelling of the geological and cultural

Figure 1. Landscape reconstruction in the Fayum Oasis, Egypt: PhD student Annelies Koopman investigates the dynamic landscape of the northern shore of Lake Quarun using sediment-stratigraphic methods. Below the surface of the contemporary desert, a hidden landscape has been revealed comprising past lake shorelines Aeolian, Wadi, and deep and shallow lake deposits as well as charcoal hearths (Koopman et al., 2015).

Figure 2. Investigation of storm layers in the Late Medieval clays of Schokland: correlation of geological and historical data (Van de Biggelaar et al., 2014; photo: Hege Hollund).

setting of the city of Bergen, Norway, demonstrates its significant heritage value (De Beer *et al.*, 2012). Using stratigraphic modelling, the relationship between high densities of artefacts and the spatial variability of non-erosive, stable surfaces has been established (Gkouma *et al.*, 2011). Statistical analyses have produced probability maps explaining surface structures and indicate the preferential location for settlement in a landscape (Fernandes *et al.*, 2012).

The archaeological-historical landscape

What was the landscape like at a particular archaeological period and locality in question, and how did people use this landscape? The natural landscape can vary considerably in shape and over time at any given place, influenced by the dynamics of sedimentation and erosion, soil formation, as well as volcanic, tectonic and other processes. How do cultures relate to these natural forces in terms of land use and experience? Under the banner of landscape archaeology the AGBA has carried out many research projects in diverse Mediterranean regions, including Italy, Greece, Turkey and Egypt (Kluiving *et al.,* 2011, 2016; Groenhuizen *et al.*, 2015; Kluiving, 2015; Koopman *et al.*, 2015: Fig. 1). Within a geoarchaeological PhD project in Flevoland, The Netherlands, four discrete time windows of human history within the past 250.000 years demonstrate highly variable landscape conditions influencing as well as determining cultural history (Van den Biggelaar *et al.*, 2014, 2015; Van den Biggelaar & Kluiving, 2015; see also Van den Biggelaar *et al.*, this volume). In order to reconstruct the paleo-landscape and to investigate whether evidence of Roman waterworks could be detected, geoarchaeological coring campaigns were carried out to gain insights into the sedimentology, chronology, stratigraphy and geoarchaeology of the eastern Netherlands river area (Verhagen *et al.*, 2016).

Studies of human-induced 'natural' disasters in the south-western Netherlands have included the reconstruction of flooding of an entire Medieval landscape, and has provided insights which have allowed advice to be given to designers recreating cultural landscapes for future development (Kluiving *et al.*, 2006; De Kraker & Kluiving, 2010). Novel approaches include a) palaeoclimate reconstructions based on historical documents such as crop yield records that can be correlated to past monthly temperatures (De Kraker & Fernandes, 2013), b) potential of correlating temperature fluctuations and trends with historical storm episodes to inform storm potential under scenarios of future climate change (De Kraker, 2006), c) to establish insights in historical land use in polder areas to sustainable coastal management given rising sea levels (De Kraker, 2011). It is significant to note that the last 3000 years of sea level rise in NW Europe cannot be constrained by geological data, but by archaeological and historical data instead (Kluiving *et al.*, 2013).

Which natural resources have been used in the past?

How did humans obtain minerals, rocks and ore, for direct use as well as for the production of ceramics, metals and glass? An MSc student of Archaeometry undertook an analysis of *La Tene* bracelet fragments found in The Netherlands, which demonstrated that the rough glass had its provenance in Egypt (Van der

Figure 3. Landscape archaeological research in eastern Flevoland: MSc student Mark Groenhuijzen is coring into Pleistocene sands, a project related to the 'Nieuwland Erfgoedcentrum' PhD research 'Biography of the New Land' (photo: Don van de Biggelaar).

Figure 4. Groundwater level, flow and chemical composition, especially the oxygen content, determine the preservation potential of invisible heritage within the subsurface. Groundwater monitoring is needed to identify changes in hydrological parameters, caused by e.g. construction and the potential impacts of reduced groundwater on the conservation of archaeological deposits.

Laan, 2013). The economic significance of iron extracted from bog iron on two Dutch push moraines on the Veluwe has also been indicated by Moerman (1928). Recent estimates based on the number of iron slags suggest production of around 55.000 tonnes of crude iron ore, indicating the largest early medieval iron production centre in North-West Europe. The early historic iron production process involved winning of solid iron by using small charcoal heated ovens that reached temperatures of 1200 °C, facilitating the conversion of iron oxide to metallic iron (Laban *et al.*, 1988; Joosten, 2004). Since Roman times salt recovery from peat in the Lowlands has been an almost daily practice. During the Middle Ages, as a result of increasing urbanisation, the peat was not only an important fuel source, but continued to be exploited for salt with excavation and extraction having a major impact on the landscape (De Kraker & Borger, 2007).

Our soil as a repository of invisible heritage

Conservation of archaeological remains *in-situ*, demanded by many statutory governing institutions, urges questions to be addressed related to the physical preservation status within soils and sediments. Knowledge of the mechanisms of degradation and decay of materials such as bone, wood, and metal is essential and the processes operating within the soils and sediments, including the geochemical and hydrological regimes and groundwater movements, which all influence conservation capacities considerably (Huisman, 2009). Conservation should not be considered static, but as a dynamic process, at which in spatial design the conservation of cultural heritage is preserved in nature development projects. Next to contributions from the earth sciences, historical geography is also important (Bloemers *et al.,* 2010).

Bioarchaeology

While in the past the degradation of bone was not considered to be a big problem, nowadays this view has changed due to the rapid developments of research in ancient DNA that demands good preservation. Two PhD projects within the Institute have studied degradation mechanisms in a variety of bone types and soil conditions across a range of European countries (Jans, 2005; Hollund, 2013; see also Kootker & Davies (this volume) for more references on bioarchaeology and bone analysis). A separate research theme related to bioarchaeology considered human evolution, in particular, Neanderthal behaviour. The evolution of cognitive development using archaeological data from the Early- and Mid-Palaeolithic contexts has proved more promising, following the so called bottom-up approach (Langbroek, 2012).

Archaeology contributing to earth science

Archeo-seismology is a good example of where archaeological knowledge is a key component of earth science research. Archaeological find spots in tectonically active areas like the Mediterranean can provide important clues about timing and intensity of earthquakes in prehistory, when historical sources are scarce and

Figure 5. Archaeologists and senior field technicians take the course Soil Science and Geology for archaeologists (www.scholingarcheologie.nl) on the location of the Wekeromse Zand, central Netherlands.

measuring instruments were not available. Internal structural deformation of the Roman theatre of Pinara, Southern Turkey, have been captured and visualised using laser altimetry, providing a measure for the extent and intensity of earthquakes that originated along the local fault zone (Yerli, 2011).

Many other examples illustrate that where the results of radiometric dating of geological deposits are lacking or scarce, relative dating of archaeological remains can provide a chronological framework for landscape evolution across a variety of research projects (*e.g.*, Kluiving *et al.,* 2013, 2016; Kranendonk *et al.,* 2015; Vos *et al.,* 2015; Verhagen *et al.*, 2016).

Interdisciplinary research

Within the relationship between earth sciences and archaeology the landscape is centre stage. For earth science practitioners the term landscape is almost self-evident in terms of meaning 'natural'; for archaeologists, landscape has a different, wider meaning that is equally as valid. Cultural landscape features comprise anthropogenic phenomena such as infrastructure and housing, but can also include intangible and invisible elements that contribute to the perception of the landscape (Kluiving *et al.,* 2012; Kluiving & Guttman, 2012; Bloemers *et al.*, 2010). Both visions of landscape can contribute to each other, so consequently many projects now take a multidisciplinary approach. The challenge for the future is to develop increasingly larger scale projects between geology and archaeology that are truly interdisciplinary. Key to achieving this aim is that the research questions considered should be posed by both disciplines, which goes beyond traditional approaches where one is only an auxiliary discipline for the other. An example of such an overarching research question is undoubtedly related to the fact that we are currently moving beyond the 'natural' climate of the Holocene interglacial and have moved into the Anthropocene (Kaplan *et al.,* 2009; Ruddiman *et al.*, 2008; Ruddiman, 2013; Smith & Zeder, 2013). Human impact on the environment has increasingly outweighed the flow of natural processes interacting with the earth's lithosphere, atmosphere, biosphere and hydrosphere (Waters *et al.*, 2016).

Ten research papers in this Festschrift

In this Festschrift we present ten research papers written by former colleagues, post-doctoral and PhD students that encapsulate all the themes discussed previously. The papers range from pure archaeometry, to bioarchaeology, landscape archaeology and historical geography and illustrate the width and strength of geo- and bioarchaeology.

Jan Kolen & Barbara (chapter 2) discuss the true enigma of European landscape archaeology and summarize findings and common opinions that may re-activate the debate about the nature and origins of the cultural landscape among scholars of prehistoric hunters and gatherers. They conclude that the evidence is far from complete and coherent, proposing a new systemic and focused approach and research strategy while calling on the assistance of Henk himself.

Guus Borger & Sjoerd Kluiving (chapter 3) describe and reconsider the most relevant historical and geological data pertaining to the discharge and supply of water to the 'Wet Heart' of the Netherlands during the past millennia. Based on data such as the evidence for the earliest peatland cultivation and reclamation they date the outlet of the Almeer to the Wadden Sea, developed as a tidal channel, to the 8th century AD, almost a millennium later than the latest geological interpretation (Vos, 2015).

Kootker & Davies (chapter 4) review the current state of human bioarchaeological isotope geochemistry research in The Netherlands. With examples of many case studies in the Netherlands they comment on the on-going methodological developments in isotope research that are improving our understanding of the archaeological record. Many of the on-going developments are allowing smaller samples to be analysed, resulting in either less sample destruction or the capability to analyse new sample types.

Marco Langbroek (chapter 5) describes the recent find of a Neolithic polished axe made of quartzite from the Naarder Eng (Huizen, the Netherlands) and the implications of this find for the so-called 'Quartzite Palaeolithic' of the Naarder Eng. Field observations reported here suggest that the site is situated on a localized outcrop of quartzite cobbles originally derived from the ice-pushed deposits at this locality. This quartzite procurement site may well have been in use during the Neolithic, i.e. during the mid-Holocene.

Adrie de Kraker (chapter 6) discusses strategic inundations during the Eighty Year's War and how archaeology is preserved after reclamation of the landscape in Zeeuws-Vlaanderen (southern Netherlands). The author combines history, historical geography, physical geography, archaeology and aerial photography to reconstruct late medieval landscape, its settlements and main infrastructure.

Ineke Joosten and Maarten van Bommel (chapter 7) report on archaeometric analyses using ultra-high performance liquid chromatography and scanning electron microscopy to determine colorants and the condition of fibres and the possible use of a mordant. Bog finds from the Bronze Age and late Iron Age were compared to pieces of fabric from the sandy soil of a large Early Medieval cemetery of Rhenen and a piece of cloth from a 17th century shipwreck found in the sea near Texel.

Dauven *et al.* (chapter 8) study the variation in $\delta^{13}C$ and $\delta^{15}N$ ratios in collagen from a single human femur, and between different bones of the same skeleton, in order to estimate the range of isotopic variation in archaeological isotope studies. Results show that the choice of sampling position is significant and important, with implications for the use of a subdivided femur as an international standard for isotopic measurements. Measuring a wider range of skeletal elements of the same individual, and plotting them as standardized isotopic scores, potentially gives considerably more insight into individual life histories than rib-femur spacing.

Don van de Biggelaar *et al.* (chapter 9) discuss the landscape development and evidence for hominin activity in Flevoland (central Netherlands). It is demonstrated that the area consists of a stacked stratigraphic sequence of different landscapes with (possible) traces of hominin activity dating back to the period 220-170 ka (MIS 7/early MIS 6). During each of these four time periods the study area was characterised by a different environmental setting and specific evidence of hominin activity.

Jan Verhagen *et al.* (chapter 10) report on the Linge, a water body in the central Netherlands, comprising a western part which is a natural branch of the Rhine delta, and an eastern part which is largely artificial. Analysis of data from historical maps, oral history, other documentary sources and Digital Elevation Model maps reconstructs how the natural water course and drainage channels developed in the area from late medieval times until the present. It is assessed whether the Linge channel originated near Lobith or that this possibility should be rejected.

Merriman *et al.* (chapter 11) suspect that the mineral corrosion products which form on the surface of archaeological copper alloy objects might provide a suitable locus for the preservation of organic residues. This may offer new insights into the ritual or mundane use of copper vessels. Results of this study have the potential to open up the possibility of extending the study of the use of vessels via the identification of organic residues to include metal forms.

Does geoarchaeology have a future in The Netherlands and beyond?

The scientific legacy of fifteen years of Geo- and Bioarchaeology teaching and research at the Vrije Universiteit has had an important impact in the Netherlands and the demise of both the Institute and its study programme clearly exposes the future ability of the country to undertake multi- and interdisciplinary research bridging the sciences and humanities. The Institute created a huge synergy between research and teaching, which has delivered a vast quantity of knowledge, which was not possible following traditional research frameworks (Kars & Burke, 2015; Kars & van Heeringen, 2008). Future interdisciplinary research is strongly embedded in CLUE+, such as the LAC conference series (Kluiving *et al.*, 2012, Kluiving & Guttmann, 2012, Bebermeier *et al.*, 2012, 2013), as well as the International Association of Landscape Archaeology (www.iala-lac.org), and interdisciplinary research sessions at the European Geosciences Union (Kluiving *et al.*, 2015a, 2015b, 2016; Kluiving & Borger, 2015). The reforming structural bachelor, master and doctoral training developed by the Institute will continue after AGBA's closure as seen in:

a. regular geoarchaeology Erasmus+ courses for (R)MA and PhD students archaeology in the ARCHON research school (www.archonline.nl);
b. the start of an interdisciplinary intra-university bachelor minor in Geoarchaeology at the Vrije Universiteit in the academic year 2016/2017: www.vu.nl/minorgeo);
c. the emergence of Science and Geoarchaeology in the ACASA (UvA/VU) bachelor and master programmes;
d. post-academic training of geology, historical geography and soil science to practitioners and professionals working at the nature-culture interface (www.scholingarcheologie.nl) (Figure 5);
e. geoarchaeology Master's research projects at the Faculty of Earth and Life Sciences;
f. interdisciplinary PhD and Master's projects in the Research School of Humanities, and
g. Geo- and bioarchaeology are embedded within the CLUE+ research cluster combining top researchers from a wide variety of academic disciplines to jointly investigate central concerns of contemporary society, of relevance to all social domains and at all geographical scales (www.clue.vu.nl).

Now, at the culmination of Henk Kars's career we conclude that fifteen years of geo- and bioarchaeology at the Vrije Universiteit have delivered a sustainable synergy between training and research in the interdisciplinary field between geology, archaeology, biology and historical geography. We have demonstrated that investments in interdisciplinary collaborations between the humanities and the sciences in this period clearly support tracks to future developments in this field in the Netherlands and beyond.

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The first cultural landscapes of Europe: A true enigma[a]

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Introduction

Henk is known for his broad interest in archaeological and geological topics, ranging from petrology and Palaeolithic archaeology to cultural landscapes and heritage management. Of these, even within the wider research community, Palaeolithic archaeology and the study of cultural landscapes are rarely combined. There are a few exceptions though, such as the recent and interesting volume on "Perceived landscapes and built environments: the cultural geography of late Paleolithic Eurasia" edited by Vasil'ev *et al.* (2003). Another, earlier and seminal article on the topic is Binford's "Isolating the transition to cultural adaptations" (1989). Apart from these exceptional studies, the issue of the origins and long-term history of European cultural landscapes remains confined to disciplines with a later historical interest, such as historical geography and landscape ecology.

In part, this is due to the fact that the idea of "landscape" itself is so strongly tied to historical North-western Europe, where it developed during the Middle Ages within a specific context of people's relationship to the land (Olwig, 1996). It is furthermore closely related to the history of visual representation (including the invention of perspective and cartography), enlightenment science and western convictions about human-nature relationships. In this specific context, the landscape came to refer to a sense of territoriality, visual perception and domination over nature (and others). However, we can safely assume that these values did not characterize human living space in the same way or to the same degree in deep history. It comes as no surprise, therefore, that historical geographers and historical ecologists predominantly localise the origins of the "classical" European cultural landscapes in the earlier part of the Middle Ages, leaving the task of exploring alternative concepts for the land use of earlier (prehistoric) societies to archaeologists.

When taken in a broader sense, as an intentional cultural ordering of space ("cultural geography") and a cultural specific spatial organisation or form of land use, the origin of the cultural landscape is commonly related to the land use and spatial perceptions of anatomically modern humans. An example is Binford's (1989) earlier mentioned, seminal article about the transition to modern cultural adaptations. Binford makes a crucial distinction between a "cultural geography" and "niche geography". According to this model, a cultural geography results when populations operate out of central places into an environment, as modern populations do. It stands for societies that construct or modify their environments, by means of creating residences, settlements and home bases, to “serve their needs and then exploit their natural setting in ways that sustain both themselves and their cultural construct” (Binford, 1989). Cultural geographies facilitate social interaction and the spatial organisation of technologies. Not surprisingly, Binford places them after the appearance of anatomically modern humans. A niche geography, on the other hand, is characteristic of animals, such as non-human primates, and the earliest hominids, who “do not ‘construct’ and environment to serve their needs but instead move within their natural environment among the places where they may obtain resources essential to their biological success” (Binford, 1987). The underlying behaviour is not technologically aided, but is primarily mobility-based and is not spatially organised around home bases or (other central places). Binford sees Lower and Middle Palaeolithic land use as primarily reflecting this type of geography.

Despite the challenging character of Binford’s hypothesis, it has never figured prominently in debates about the nature and origins of the cultural landscape. In this paper, we briefly summarize some findings and common opinions that may re-activate this debate among scholars of prehistoric hunters and gatherers. We conclude that the evidence is far from complete and coherent, asking for a more systematic and focused approach.

Human architecture

In search of the earliest “built environments”, Palaeolithic archaeologists are inclined to look at on-site structures, such as dwellings and constructed hearths first. For many years it was believed that the oldest dwelling structures dated to at least 300.000 years ago. Supposed “convincing” examples of Early and Middle Palaeolithic dwelling remains and hut structures were excavated *e.g.* in beach deposits at Terra Amata near Nice (a late Middle Pleistocene small oval hut with convex palisades of stakes and a central hearth; De Lumley, 1969a), at the Early Palaeolithic travertine site of Bilzingsleben (oval stone rings and hearths; Mania *et al.,* 1980), in the Grotte du Lazaret – also near Nice (a “Rissian” age *cabane* with stone ring near the rock wall; De Lumley, 1969b), in Early Weichselian loess deposits at Rheindahlen and Ariendorf in the German Rhineland (small circular structures, partly inferred form the local distribution of lithic artefacts; Bosinski *et al.*, 1983; Thieme, 1983), and at late Middle Palaeolithic sites in the Ukraine, such as Molodova (circular bone heaps with peripheral hearths and artefact concentrations; Klein, 1973). However, with the growing popularity and methodological improvement of taphonomic research, most of these claims were contested because of three main problems:

- Most interpretations of spatial configurations as “dwellings” did not or insufficiently take into account the often complex taphonomic histories of sites, features and on-site distributions of materials (*e.g.*, Terra Amata and Lazaret: Villa, 1978, 1982, 1996);

Figure 1. A reconstruction of a Palaeolithic hut. Photo: Michal Maňas.

- Some presumed dwelling structures appeared to be partial "outcomes" of an unwarranted selection of excavation data (*e.g.*, Bilzingsleben: Kolen, 1999);
- Some phenomena might represent human-made structures though not necessarily reflecting the ground plans of dwellings or huts (Lazaret, Molodova).

Two decades ago, it was suggested (Kolen, 1999) that many Middle Palaeolithic "dwellings" and "huts", including Lazaret and the well-known Châtelperronian circular and stone-lined structures at Arcy-sur-Cure (Farizy, 1990), could best be described as "Centrifugal Living Structures" (CLS). These are rather flat and uncovered configurations of waste, similar to the nest-like architecture of non-human primates but more complex, though not really being deliberately "built". Apparently, many of these echoed the same basic principle: the ordering of space outwards from a central position and the (re)arrangement of materials accordingly. It appears that Neanderthals made the semi-circular structures by situating themselves in the middle and moving natural materials, waste and tools outward while executing domestic tasks. The structures furthermore seem to bespeak "fluid" life histories in which this centrifugal cleaning, use, rearrangement and reuse constituted continuous sequences (Figure 1).

From this alternative perspective, the first convincing dwelling structures appeared late, somewhere between 30,000 and 20,000 BP., such as the Perigordian regular stone rings with multiple-used central hearths at Vigne Brun (Villerest) in France and Ohalo II in Israel (Nadel *et al.,* 2004). From this same period we also find sites with high-investment and relatively durable on-site facilities for the making and maintaining of fires, such as well-constructed hearths (*e.g.*, Stratzing/Krems; Abri Pataud) and possible kilns (Dolni Vestonice), even in large numbers and from materials that were imported from elsewhere (Klisoura).

A basic assumption of these and similar hypotheses is that we, as archaeologists, are able to make a clear distinction between deliberately and intentionally built facilities -that is “true” architecture- and rather unplanned outcomes of dwelling, nesting, working etc. This does, however, not work out that straightforwardly in archaeological interpretation. Even philosophical and sociobiological reflections on the differences between human and animal architecture struggle with this distinction. Moreover, in the last two decades, several new, well-documented and more convincing cases of dwelling structures from the late Middle Palaeolithic have been published from several sites. One of these is a former tent structure from La Folie near Poitiers, where a French team of archaeologists excavated a circular structure with limestone blocks, hearth place and posthole, associated with a lithic assemblage belonging to the Mousterian of Acheulean Tradition (Bourgignon *et al.*, 2002). This and other finds again shed new light on the rather well-developed Châtelperronian stone rings of Arcy-sur-Cure, as well as stone aligned hearth constructions from the late Middle Palaeolithic, such as Vilas Ruivas in Portugal (Kolen, 1999). The idea that Neanderthals already constructed deliberate on-site structures is also supported by the fact that the earliest human burials date from the late Middle Palaeolithic as well (Pettit, 2011). The new evidence indicates that Neanderthals, long before the arrival of anatomically modern humans, may well have created cultural landscapes through erecting architecture – be it in simple forms. The earliest examples may even date back as far as c. 100,000 BP.

Human fire ecologies

Although the American geographer, Carl Sauer, addressed the issue already in the 1940s, the impact of prehistoric hunter-gatherer fire ecologies on the earth’s surface remained largely unexplored until a few decades ago. Sauer even claimed that the first human fire ecologies initiated the “birth” of cultural landscapes. According to him, the earliest “interface” between the two was the subtle way in which hunter-gatherers influenced the vegetation (Sauer, 1963 [1925]). This shows that for Sauer the natural foundation did not one-sidedly determine the human uses of the landscape. In his view, cultures work with nature to create a cultural landscape that becomes the material expression of specific cultural processes. For over a century, archaeologists and ecologists in Europe focused on the role of the earliest farming communities in the opening up of the Holocene forest by means of *swidden* farming, shifting cultivation and the associated use of fire technologies. But it took until the 1980s – that is more than half a century after Sauer’s observation – before the impact of prehistoric hunter-gatherers on land cover was fully realized as well in archaeological circles.

From recent research it appears that, at least in large parts of Central and Western Europe, early Neolithic farmers inhabited semi-open landscapes that were already partly created by Mesolithic hunter-gatherers (Frirdich, 2005). Similarly, late Mesolithic communities in particular made use of fire ecology as a response to the deciduous forest becoming increasingly dense and therefore less productive, although most researchers will now accept that this was practiced throughout the earlier stages of the Mesolithic as well (*e.g.*, Bos & Urz, 2003; Scherjon *et al.*, 2015). Palaeo-botanical research, supplemented by the systematic analysis of other environmental proxies, such as (micro) charcoal data, and ethno-historical and experimental observations, strongly suggest that early Holocene woodlands were subject to periodic human disturbance of this kind. By thinning the forest matrix locally by using fire, hunter-gatherers manipulated the vegetation and its succession, in this way improving conditions for edible plant foods and game. These new insights raise the question when exactly humans started to influence land cover in "off-site" situations using fire, either intentionally as a landscaping tool or by accident (Daniau *et al.*, 2010).

It is acknowledged that one of the earliest reliable indications for the use of fire as a "landscaping" tool comes from the early Mesolithic site of Star Carr in Yorkshire, England (Mellars & Dark, 1998; Scherjon *et al.*, 2015). For the Palaeolithic, however, positive evidence is scanty and disputable. Roebroeks and Bakels (2015) suggest that fire may have been used off-site in the surroundings of the Neumark-Nord Eemian lakeside settlement, as occupation and human-induced charcoal signals nicely fit in with vegetation with a more open nature – whereas normally the Eemian interglacial land cover in the area was densely forested. If caused by human intervention, this could be one of the first examples of intentional landscaping using fire, although at a small spatial scale. However, recent analysis of Atlantic marine sediment cores near France and Portugal by Daniau *et al.* (2010) suggests that we don't have clear evidence that human employed extensive fire use for ecosystem management before the Holocene. Overall, the current evidence indicates a relatively late introduction of human fire ecologies in Europe at the start of the Holocene, thus creating and managing mosaic ecosystems that we could well interpret as cultural landscapes.

Symbolic markings of place

It is acknowledged in disciplines like archaeology, anthropology, geography and psychology that landscapes are not only constituted and transformed physically but also socially, mentally and symbolically at the same time. Tuan (1974, 1977) coined the term "topophilia" to denote the emotional attachment to place and a strong sense of home that is almost universal among human societies. In this sense landscapes, as extensive and dynamic networks of meaningful and valued places, actively shape human relationships and symbolise the human measure of space. Landscapes and specific places therein may represent or activate principles of descent and inheritance (Bloch, 1995), reflect personal life histories, contain spirits and hidden forces, or express the constitution of the human body as such (Tuan, 1977; Küchler, 1993). In all these cases, the activity of marking a living place fits in with the more general process of humanising and socialising space: "space is a society of named places, just as people are landmarks within the group", says Levi-Strauss (1966). In many societies this is to be taken literally. For the Pintupi of Australia's Western Desert (Myers, 1986), for example, named places and sacred sites

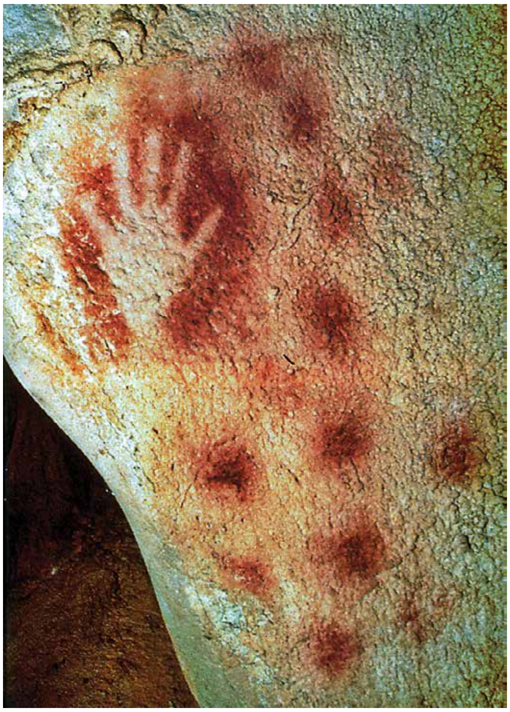

Figure 2. Palaeolithic hand stencils (negatives) from the Pech Merle cave in southern France. Photo: Public domain, French Ministry of Culture.

contain generative power and actually shape and define relations of kinship. These relationships between people and place are seldom perceived in a straightforward way as an appropriation of landscape by the human actors themselves. For many hunter-gatherers, "land owns people" (De Coppet, 1985), or the environment is perceived as "giving" and caring, like a parent (Bird-David, 1990).

There is some disagreement among experts about when roughly, human societies started to shape and perceive their living environment in this sense – that is as a social and symbolic landscape with networks of meaningful places. Binford, in his earlier mentioned seminal publication (1989), links the emergence of social and symbolic landscapes to anatomically modern humans, whereas others (Henshilwood & D'Errico, 2011) see much earlier outlines of symbolic behaviour in Neanderthals that would or could have created similar relationships and interactions between people, objects and places. Among the most convincing indications for an early human attachment to place are, of course, natural landmarks and sites that have been marked by painting and/or carving figures. Recent dating programs have shown that the earliest examples of parietal art in Europe may well date back to at least 40.000-37.000 years. In El Castillo Cave in Spain, hand stencils, dots and round figures were made around that time (Pike *et al.*, 2012), causing some researchers to conclude that even Neanderthals may have been their makers (Figure 2).

The well-known and almost exemplary Palaeolithic hand depictions are particularly interesting from this point of view, as they seem to belong to the oldest symbolic markings of places in Europe, Asia and Australia. They are inherently different from other categories of Palaeolithic artistic expression because they are actual traces of the human body. They are found as stencils (produced by placing the hand on a wall and blowing pigment over it), as prints (produced by dipping the hand in pigment and pressing it on a wall), as dots (made with the fingers), or as striations (produced with the hand in the soft eroded walls of caves). The first examples were discovered at cave sites such as Lascaux and Gargas in France and Altamira in Spain. More recently well-preserved paintings were discovered at sites such as Chauvet and Cosquer (Clottes, 2003). The hand stencils from El Castillo may now be surpassed in age by a site outside Europe: Leang Timpuseng Cave on the Indonesian Island of Sulawesi (c. 39,000 BP; Aubert *et al.*, 2014), where a large number of colourful hand stencils as well as animal figures were painted on the cave wall. Where absolute dates or relative chronologies are available for sites with hand depictions in Europe or Asia, the hand depictions seem to belong to the earliest horizon of parietal artistic expression in the areas or at the sites concerned. In addition, their primordial significance is indicated by their "direct", embodied and -apparently- iconic (in the sense of Peirce: Atkin, 2013) nature.

Places with hand depictions may have differed significantly in terms of accessibility, indicating their position in the social landscape. In some regions, scenes with hand depictions are clearly and easy to access (Northern Coast, Australia), whereas in other regions (such as south-western Europe) they were often produced in small-scale settings and highly uncomfortable positions (Pettitt *et al.*, 2014). Yet in all cases, while making the hand depictions, individuals and groups left something behind of themselves -literally – before moving to elsewhere, thereby creating and maintaining durable personal and collective relationships with remote places (Kolen, 1999).

The fact that hand depictions, dots, finger flutings and striations often mark the first occurrence of placemaking through visual symbolism, not only highlights the primordial nature of hand painting practices (Dobrez, 2013), but also indicates that the places concerned were initially considered as an extension of the human body and therefore remained highly personal and "embodied". This may shed new – critical – light on the view that the earliest "cultural geographies" (Binford, 1989) should be understood essentially as ecological and functional adaptations – as huge spatial technologies that were meant to cover an extensive social network and a large number of different biotopes (*e.g.*, Binford, 1989). It cannot be denied, however, that the earliest forms of placemaking through visual symbolism, that apparently emerged in Europe around or shortly after 40,000 BP, changed the environment into a true social landscape that facilitated people in communicating with each other where face-to-face contact was difficult to realise or deemed undesirable.

The first cultural landscapes: a true enigma

In this overview we briefly indicated that the "beginnings" of the cultural landscape varies with the perspective adopted. When looking at on-site constructions, such as dwelling structures and built stone-lined hearths, we see a number of very early examples of constructed space pointing at Binford's "cultural geography". Several of these predate the arrival of anatomically modern humans in Europe, and some may even indicate that Neanderthals have been "building" for over 50,000 years before they actually had a chance to "imitate" the well-developed dwelling structures of moderns – as some researchers have suggested. Yet, when adopting an ecological perspective on the impact of human land use on vegetation at the scale of biomes, more particularly as a result of intentional human fire ecologies, human-made landscapes seem not to have evolved before the Holocene, although we cannot exclude the possibility that this occurred at a local or incidental scale already during the Middle Palaeolithic (Scherjon *et al.*, 2015). A social and symbolic perspective – again – creates a different picture, with the first symbolically marked places approximately emerging around 40,000 years ago.

Some theoreticians have argued that demarcating architecture and the cultural environment from an evolutionary perspective does not make much sense, at least not if defining "humanness" or its claimed superiority is the main goal. "Compared with the termite's skyscraper", Tuan (1977) rightly observes, "the…shelters of human beings look crude. If humans nonetheless claim a certain superiority, the claim must rest on grounds other than architectural achievement" (see Ingold, 2000 for similar arguments). But to be sure, the quest for the origins and deep historical development of the first "human" cultural landscapes of Europe is not primarily or solely about whether or not some animal populations, be they beavers or bowerbirds, built architecture or organised living space at the same level of complexity as us. Instead the principal question is twofold. First: why did cultural landscapes appear so late in the history of humankind as a human form of niche construction? And second: why do we see cultural landscapes "emerging" at different moments in time when we adopt architectural, ecological and social-symbolic perspectives? These questions have kept us busy for three decades by now, especially in the light of the "discovery" of, and interest in landscape approaches within the archaeological discipline as a whole since the 1990s. Instead, these questions still confront us with a true enigma today – an enigma that deserves a solid research agenda, including long-term perspectives, geographical comparisons, interdisciplinary thinking about human niche construction and new hypotheses. Henk, will you join us?

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Endnotes

[a] This article is based and inspired on a series of other publications and the preparations for recent research proposals, notably Kolen 1999, Kolen & Renes 2015, and Oosterwijk 2012.

The Wet Heart of the Netherlands

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Abstract

According to Vos *et al.* (2011) and Vos (2015), a tidal channel between Lake Flevo and the Wadden Sea was already developed by the last centuries BC. This new vision has far-reaching consequences for the commonly accepted view on the landscape and occupation history of the areas around the former Zuiderzee. Therefore, in this paper the most relevant data describing the discharge and supply of water to the Wet Heart of the Netherlands are reconsidered. Classical authors refer to this body of water as Lake Flevo and in medieval times it is named Almeer. In addition, current knowledge about the earliest peatland cultivation around the later Zuiderzee is considered. Given the age of the start of peatland reclamation and the indication of the Almeer as *stagnum*, stagnant water, around the mid-8th century, it is likely that the outlet of the Almeer to the Wadden Sea developed as a tidal channel in the third quarter of the 8th century. This conclusion is confirmed by peat growth on Schokland which continued until around 1200 ± 50 BP.

Introduction

The Wet Heart of the Netherlands (Figure 1) has become a key area for investigating the landscape history and occupation of the north-western part of the country. Undeniably, the development of a channel to the Wadden Sea has led to a lowering of the water level in Lake Flevo/Almeer, and consequently to improved drainage of the surrounding areas. It is uncertain, however, when and how this outlet developed and this discussion is hindered by the considerable erosion that occurred subsequently in the Zuiderzee area. In order to reconstruct past landscape configurations in that area, it is essential to understand the processes and activities that occurred around the margins of the area. Recent research has significantly

Figure 1. Location of the Wet Heart of the Netherland and the situation of the locations, regions and water courses mentioned in this contribution. Key: A. The western subsector of the Wet Heart; B. The eastern subsector of the Wet Heart.

increased our knowledge of those regional processes and improve our insights into the landscape changes in the Wet Heart of the Netherlands during the first millennium AD (Figure 2a) and this paper provides a synthesis of this work.

In response to the decreased rate of Mid-Holocene sea level rise an increasing part of the lowland area of the Netherlands was covered by an extending peat layer initiated from the 4th millennium BC onwards. At the same time, the tides and waves, augmented by strong winds, caused a northward transport of sediments that had been supplied by the rivers Rhine and Meuse. As a result, a largely closed coastal system of beach ridges and sand bars developed along the western coast of the Netherlands, allowing peat formation to continue behind it. The area of Pleistocene sediments around Texel functioned as a suspension point for the coastline. The discharge of river water and surplus precipitation from the hinterland maintained some gaps in de coastal barrier. At high tides the margins of the peat area could have been flooded by saline waters temporarily, though once these had receded, peat growth continued. However, overtime, some tidal inlets silted up, only to be replaced by others as the rivers found new courses to the coast from the hinterland.

In contrast, east of the area of Pleistocene sediments around Texel, coastal processes resulted in a different type of coastal zone morphology, in response to different geomorphic processes. Firstly, along the coast of the northern part of the Netherlands the amount of sediment was very limited; secondly, the development of a largely closed coastal system was prevented by the easterly transport of sediments. Therefore, the tidal flow could easily fan out in all directions and the tidal inlets were more dynamic than in the western part of the Netherlands. Although peat started to grow around outcrops of the Pleistocene subsoil, the extent of the peatlands was limited by the influence of the sea.

In the north the coastal dynamics were determined by the fixed volume of the tidal flow that entered the Wadden Sea from the North Sea. When one of the tidal inlets extended, the accommodation space behind that inlet expanded at the expense of neighbouring inlets. Behind the inlets with a decreasing amount of tidal movement, the formation of peat could increase, but behind any expanding inlet the rims of the peat area were covered by a layer of clay. As a consequence of increasing tidal range movements, however, not only did the flood inundations become higher across the area, but the effects of the lower tides extended too. Increased tidal retreat during lower tides improved the drainage of the peat areas, even at an extended distance from the tidal inlet. In contrast during tidal surges the dried-up top layer of the peatlands, its subsoil and any associated vegetation were eroded across considerable distances inland.

These natural processes have already been influenced by humans from the second half of the first millennium AD onwards. At that time, the Dutch coastal zone belonged to medieval *Frisia* (Henstra, 2012), with the densely inhabited Frisian-Groningian terp area as a core region. Craft and trade resulted in prosperity and a degree of circulation of currency that was exceptional in Europe (Slicher van Bath, 1965; Knol, 2005). In Groningen and Friesland the reclamation of the peatlands started well before 1000 AD (Knol, 2008; Mol, 2011) and probably by around 700 AD (De Langen, 2011; Groenendijk & Vos, 2013).

In West-Friesland the reclamation of the peat area also started before the 11th century. At Torp, near Den Helder, the oldest indications of habitation date from the 7th/8th century (Besteman & Guiran, 1986). Furthermore, in the Utrecht list of goods, which dates from before ca. 860 AD (Henderikx, 1987), royal tithes are mentioned in *Norhtuualda* between Texel and Medemblik (OSU I, nº 49; Henderikx, 1987). The location of this *Norhtuualda* is uncertain, but the name probably refers to Noord-Scharwoude (De Cock, 1965). Moreover, the oldest way of spelling of the place-names Wognum, Ursem, Mijzen and Etersheim is referring to the word 'heem', a type of toponym that is known to date from the 10th century or earlier (Blok, 1965, 374). Hence, the colonization of the peatlands as demonstrated by these villages must have started before this time.

The process of peatland reclamation started by lowering of the local water table by the digging of ditches. This improvement of the drainage system caused peat desiccation and shrinkage, in turn resulting in a lowering of the landsurface level. As a consequence, in the long term the land became more vulnerable to the influence of the sea.

In Roman times Lake Flevo was already extending through the erosion of the peatlands. Plinius the Elder, who served as a young officer in *Germania* around the middle of the 1st century AD, recounts stories about Roman warships that anchored there at night and were forced repeatedly to engage in battle against trees on peat islands floating within the lake. In his view, the wooded shoreline of Lake Flevo became eroded by water currents whipped up by the strong winds sending large expanses of land, held together by the trees and their roots into the lake (Plinius, *Naturalis historia* XVI; Byvanck, 1931).

Although Plinius notes two lakes and situates them in the territory of the Chaucians, it is generally assumed that they were the predecessors of the later Zuiderzee. Mostly, historians attribute the Dutch coastal zone to the Frisians and the coastal area of Lower Saxony to the Chaucians, but the border between these tribal territories cannot be established precisely (Van Es, 1972). Decisive for the location of these lakes is the strategy of the Romans in their campaign against *Germania*. On the one hand, the valleys of the tributaries at the right bank of the river Rhine functioned as an approach route, and on the other hand the *insula Batavorum*, the central Dutch river district, was used as an operating base. The shipping route along the northern Rhine branch, Lake Flevo and the Wadden Sea, made it possible to penetrate *Germania* through the estuaries of the great rivers (Van Es, 1972). To execute this pincer movement, Lake Flevo was of strategic importance. Therefore, Roman ships will have passed and anchored there regularly. The recent find of wood dating from about 70 AD (Van Heeringen *et al.*, 2014) in southern Flevoland, in combination with a basalt stone transported from the German Rhine Massif (Linthout, 2015) proves that Lake Flevo was sailed by Roman ships.

Until recently it has been assumed that the tidal channel between the Almeer and the Wadden Sea dates from the early Middle Ages (Zagwijn, 1986; Schoorl, 1999). During the silting up of the estuary of the Oer-IJ from about 500 BC onward, the water level in Lake Flevo gradually rose and drowned parts of the surrounding peat area. The reclamation of the peat areas that drained into Lake Flevo/Almeer could only have started after the water level of that lake was lowered by the opening up of the tidal channel to the Wadden Sea.

Vos *et al.* (2011) and Vos (2015), however, have questioned the older opinions regarding the development of the tidal channel between Lake Flevo/Almeer and the Wadden Sea (Figure 2b). According to them, the origin of the open connection between Lake Flevo and the Wadden Sea is directly related to the silting up of

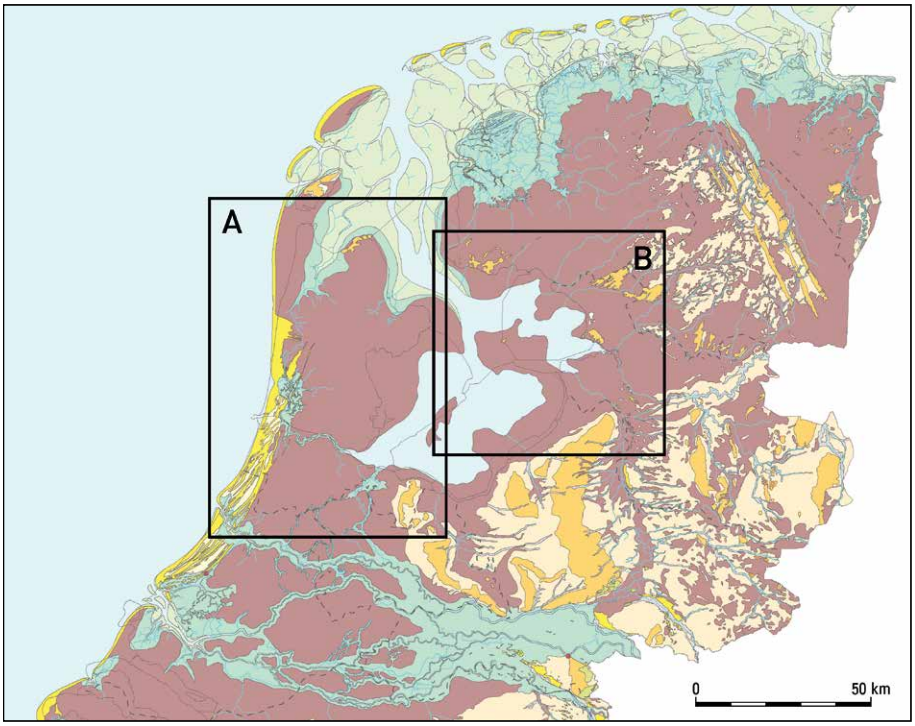

Figure 2a. Overview of the palaeogeographic map in the central and northern Netherlands of 100 AD (after Vos & De Vries, 2013).

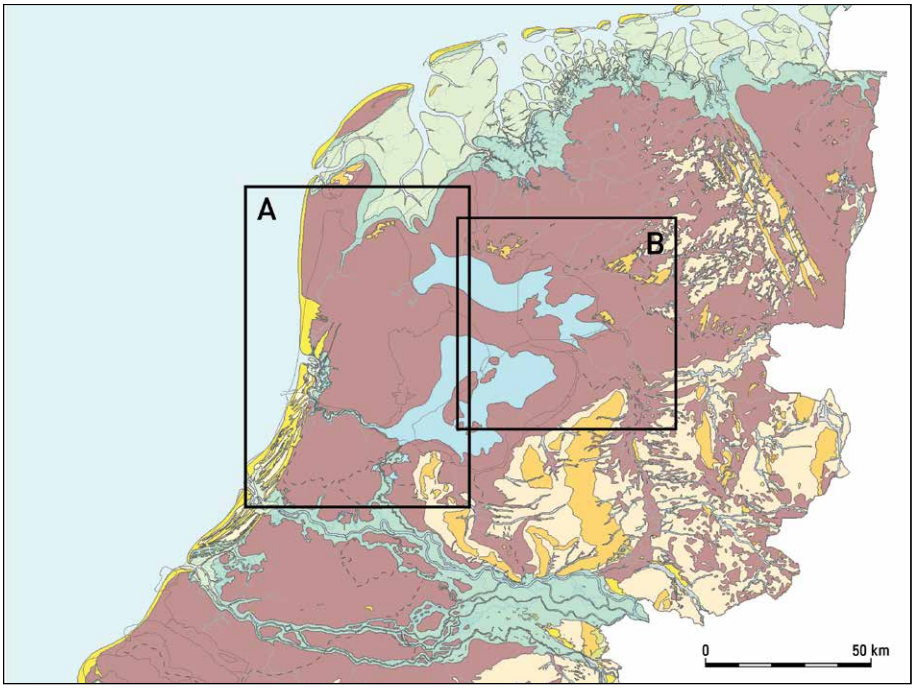

Figure 2b. Overview of the palaeogeographic map in the central and northern Netherlands of 500 BC (after Vos & De Vries, 2013).

the Oer-IJ estuary from around 500 BC onwards. From his reconstruction of the geographical situation at that time, it appears that Vos envisages a substantial opening. This new view demands a reconsideration of the available data concerning the history of landscape and settlement of the territories bordering the later Zuiderzee. In this paper, the main features of the discharge from, and water supply to, the Wet Heart will be discussed and some facts relating to the beginning of the reclamation of the peatlands bordering the Zuiderzee will be reviewed.

The discharge from the Wet Heart

In the coastal zone the water balance is determined by the supply of water from the hinterland and the discharge into the sea. In the first millennium AD the Wet Heart of the Netherlands was drained by the Oer-IJ and the Vlie. The Marsdiep did not attain this function until later. About 800 AD the Abbey of Fulda was endowed with a complex of goods *iuxta fluvium Maresdeop* (OHZ I, 1970). Although the noun *fluvius* refers to flowing water, it is likely that this stream only discharged into the sea, because of the components *mare* and *deop* in the name (Schoorl, 1999). After the Carolingian period the Marsdiep expanded its influence in an easterly and southerly direction. Until recently, it was assumed that this opening in the coastline developed into an important tidal inlet shortly after the Almeer developed an open outlet to the Wadden Sea (Schoorl, 1999).

The Tidal Inlet of Bergen must be mentioned, although it had silted up many centuries before the start of the CE. Initially the influence of this tidal inlet reached into the present Noordoostpolder and enabled the Overijsselse Vecht to drain seawards (Cleveringa *et al.*, 2007, 70). Calibration of older ^{14}C dates has proved that the closure of the Tidal Inlet of Bergen started about ca. 3500 cal BP (Bos *et al.*, 2009). From 2500 BC onwards this tidal inlet silted up rapidly (Vos, 2008, 83). As a result, the tidal amplitude decreased and the banks along the creeks in the sea clay area of West-Friesland became habitable during the Mid Bronze Age (Roessingh, 2011). Further to the east, however, the peat area extended due to the worsening of the drainage system and the steady influx of water from the Overijsselse Vecht. In some locations in that extensive body of stagnant water peat was growing in an oligotrophic environment (Van den Biggelaar *et al.*, 2014). Afterwards, the water of the Overijsselse Vecht will have drained in a northernly direction to the Wadden Sea (Vos, 2015).

The area of the Oer-IJ estuary (Figure 3) has been researched extensively and in some places in great detail (Vos, 2015). For a long time, this tidal inlet was of great importance to the drainage of the southern part of the Wet Heart. Nevertheless, between 550 and 400 BC the influence of the sea in the Oer-IJ estuary decreased. About 400 BC the process of silting up of this tidal inlet started and in Roman times the Oer-IJ estuary had been closed off from the sea by a low coastal barrier (Vos, 2008, 91). Only during heavy storms was the sea able to overtop this barrier, depositing storm sediments behind it (Vos, 2015). Using OSL the storm layers near Castricum have been dated to 163 ± 106 AD (Vos, 2008) indicating that the floods must have continued into the second century AD (Vos, 2008; Vos, 2015).

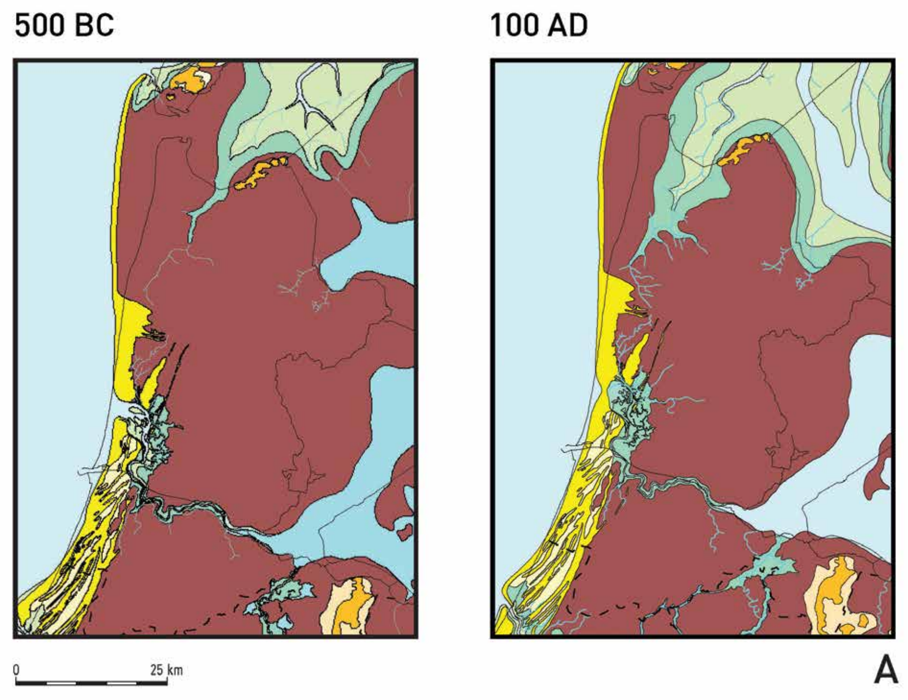

Figure 3. Details from the palaeogeographic maps of the Netherlands of 500 BC and 100 AD in area A (after Vos & De Vries, 2013).

The causal connection between the closure of the Oer-IJ and the development of an open outlet of Lake Flevo/Almeer to the Wadden Sea is still under discussion. On the one hand Vos (2015, 98) states that the Oer-IJ lost its function as a discharge route from the hinterland because of the development of a tidal channel between the lake district in the central part of the Netherlands and the Wadden Sea. On the other hand, however, he presents the closure of that tidal inlet as the reason for the development of that outlet (Vos, 2015). This brings us to the core question of this paper. It is undisputed that the development of that outlet was crucial to the possibilities for discharge of the peat areas around the later Zuider Sea. It is unclear, however, whether this development should be placed in the centuries before or after the start of the CE.

The genesis of the tidal inlet of the Vlie is mostly unknown. It is assumed that even before the Roman period a tidal channel existed between Texel and Wieringen, which discharged in a northeasterly direction through the Vlie (Vos, 2015). This channel enabled the early medieval habitation in the northern part of Noord-Holland (Diederik, 2002) and later on, gave rise to the deposition of a layer of sea clay in the peat areas between Texel and Petten (Schoorl, 1999). The presence of a Roman war fleet on Lake Flevo suggests that there was a navigable connection to the north at that time. However, that does not imply anything about the size of this waterway, and neither is it certain that this connection passed through the Vlie.

The water in the Lake of Wervershoof was still fresh in the Carolingian period, and rye was cultivated in its near vicinity. Subsequently, the deposition of a layer of clay started in a calm environment and it appears that the flood did not disrupt human habitation. Pollen and diatoms indicate an increasing marine influence, but the lake did not become more brackish at this time (Besteman, 1974, 59). However, salt-tolerant vegetation must have been present at a short distance from the early medieval settlement in Medemblik (Besteman, 1989). Furthermore, in the *Vita Bonifatii*, which dates from the mid-8th century, the Almeer is referred to as *stagnum*, stagnant water (Rau, 1968; Schönfeld, 1955), a term that does not indicate a strong tidal movement.

Water supply to the Wet Heart

In the first millennium AD, Lake Flevo/Almeer was supplied with water from various directions and sources. From north to south, streams carried excess precipitation from higher ground and peat areas in Drenthe and Friesland, the Overijsselse Vecht, the Gelderse IJssel, the streams of the Veluwe massif, the Eem and the Utrechtse Vecht. The supply of water from most of those streams must have been constant, although this does not apply to the Gelderse IJssel and the Utrechtse Vecht.

The classical authors know the Rhine as a river with two or three branches, but do not mention the IJssel. Nevertheless, Blink (I, 1892) regards the IJssel as a part of the Rhine system because of a former connection between these two rivers. At times of massive discharge, the water of the Rhine formerly flooded the natural levees on the right bank of the river near Rees. Flooding the lower parts of the fields, the outpouring water of the Rhine found its way to the Oude IJssel. Therefore, the existence of river clay and flood basin clay of Roman date in the IJssel valley and the adjacent stream valleys (Janssen & Van den Hazelkamp, 2007) cannot be seen as an argument to conclude that the IJssel has been a river of significant size in Roman times. The absence of natural levees of any significance along the old course of the IJssel (Makaske *et al.*, 2008) proves the opposite.

It is still under discussion at what time the IJssel at Westervoort was first connected to the Lower Rhine or one of its predecessors. Recent research has resulted in two different dates being put forward. Makaske *et al.* (2008) date the development of a direct connection to the Lower Rhine between ca. 600 and 900 AD, but according to Volleberg and Stouthamer (2008) this development goes back to about 350 AD. If the origin of the outlet of Lake Flevo/Almeer to the Wadden Sea dates from the centuries before the start of the CE, then the increased flow of Rhine water through the IJssel did not have any impact on this event. Both dates exclude this.

After the Lower Rhine had become directly connected to the IJssel valley, the lower parts of the existing peatlands were covered by organic and inorganic sediments. The smooth transition from peat to silts and clays proves that the breakthrough at Westervoort was not the outcome of one catastrophic flooding event caused by extremely high water of the river Rhine (Makaske *et al.*, 2008). Eventually, however, that breakthrough caused the development of an entirely new river course. Locally the province boundary marks the old course of the river IJssel (Spek *et al.*, 1996), and to the west of Vorchten this can be recognized in the land division for over more than 3 km (Heslinga, 1949). In 814/815 AD, an otherwise unknown location is referred to as *ubi Hisla flumen confluit in mare* (Künzel *et al.*, 1989). The term *mare* indicates that the influence of the tidal movement was noticeable on the Almeer at that time.

The development of the new course of the IJssel was accompanied by a changing pattern of sedimentation. As a result, a delta area developed near Kampen, the Kamper Island. The date of initiation of this island is based on a rise of cereals (Cerealia) and cornflower (*Centaurea cyanus*) in the pollen curve. Formerly this rise was assigned a date to the 12th/13th centuries, but nowadays it is dated at the end of the early Middle Ages, around 800 AD (Spek *et al.*, 1996).

Recent research has increased our knowledge about the history of the Utrechtse Vecht. The origin of this river is an avulsion of the Kromme Rhine near Utrecht of about 1000 BC and from that time the Rhine partly discharged through the Angstel and Amstel to the Oer-IJ estuary (Bos *et al.,* 2009). The current course of the Vecht below Loenen was initiated about 500 BC and afterwards became the main branch. At the same time or shortly after, not only the activity of the river Vecht decreased (Bos *et al.*, 2009), but the Oer-IJ estuary also silted up (Bos *et al.*, 2009; Vos, 2015). It seems probable that the flow of water from the Rhine through the Angstel/Amstel has extended the life span of the Oer-IJ estuary (Bos *et al.*, 2009, 371). Until, or even after Roman times the Rhine discharged through the avulsion near Utrecht (Bos *et al.*, 2009), but probably only during high water levels (Bos *et al.*, 2009).

The reclamation of the peat areas bordering the Zuider Sea

In the northern part of the Netherlands, the peatlands discharged to the Wadden Sea. In Sneek it was proved that the growth of the peat continued until about 400 AD and locally a thin layer of reed peat could be dated to the 6th century AD (De Langen, 2011, 81). To the south of Sneek, the reclamation of the peat had already started by about the middle of the 8th century, and probably even earlier (De Langen, 2011). From 900 AD onwards people moved further into the peat area and reached the Tjeukemeer in the mid-11th century. Based on the available historical data, it has been assumed that further to the south, in Lemsterland, the Stellingwerven and the Kop van Overijssel, the cultivation of the peatlands started slowly around the mid-12th century (Mol, 2011). However, Mol (2011) has convincingly argued that the reclamation process must already have been started in the late 10th and early 11th centuries in the peat area between Kuinre, Blankenham and Vollenhove.

In 966 AD, Emperor Otto I not only gave half the island of Urk and a manor (*curtis*) to the Abbey of Saint Pantaleon in Cologne, but also the meadows and pasturelands on the other side of the river Nagele (*ultra amnem Nakala*) as far as an otherwise unknown location called *Vunninga* (OSU V, nº 3028). Mol (2011) located the river Nagele and the homonymous island to the east of Urk. Therefore, he assumes that there must have been more peatlands to the northeast of the Nagele that had already been cultivated before the mid-10th century.

In the Middle Ages a lot of land was lost on both sides of the estuary of the Gelderse IJssel due to the enlargement of the Zuider Sea. This would largely have consisted of peat that had been formed after the Tidal Inlet of Bergen had started to close. In Waterland, peat formation was able to continue undisturbed into the 8th century (Willemsen *et al.*, 1996), and on Schokland, the top of the peat can be dated to ca. 1200 ± 50 BP (Van den Biggelaar *et al.*, 2014). From the area where the peatlands were drowned, a number of toponyms are known from historical documents. Ens is already mentioned in 793 AD (Künzel *et al.*, 1989) and Bant somewhere in the first half of the 10th century (Künzel *et al.*, 1989). Biddinghuizen is named after *Bidningahusum*, recorded in 793 AD, but the location of this village in the Zuider Sea area is debatable (Künzel *et al.*, 1989). The same restriction applies for the settlement Ark to the northeast of Nijkerk, which is mentioned in 855 (Künzel *et al.*, 1989).

The strip parcelling of land in the Vecht estuary is strikingly irregular. The arrangement suggests that the peat area has been reclaimed systematically and the irregularity suggests an old age. Since the very regular opening up of the peat areas in the Vecht region started around 1050 AD (Buitelaar, 1993), the exploitation of the area around the estuary can be dated earlier. A somewhat comparable parcelling pattern is found along the lower course of the Diem, somewhat to the west, where the start of exploitation dates to the 11th century (Van Smeerdijk *et al.*, 2009). Despite long-standing archaeological research, only two isolated finds from the early Middle Ages are known from this region. To the south of Weesp, a pottery sherd is known that probably dates to the 7th/8th century, and along the river Gaasp a sherd from the 8th/9th century was found (Schmitz, 1987). If the name Muiden is indeed of ingweonian origin, then the exploitation of the peat areas around the Vecht estuary could be older (Rentenaar, 1978). However, according to Künzel *et al.* (1989) the name comes from the Old Dutch word *mutha* (= estuary/mouth).

Discussion

Emperor Augustus designated the river Elbe as the future eastern border of the *Imperium Romanum*. Because of that decision, the Rhine-Meuse delta also appeared on the horizon of the Roman military command and the region later received interest from historiographers. Consequently, the number of toponyms and water names mentioned in classical sources is rather large, certainly in comparison with the adjacent regions that were part of the Roman empire for a much longer period of time (Stolte, 1963).

In the Wet Heart of the Netherlands, Lake Flevo is the first to command attention. The name Flevo only appears in the writings of Pomponius Mela. He speaks of an *ingens lacus … Flevo dicitur*, a gigantic lake named *Flevo* (Mela, *De chorographia* III; Byvanck, 1931). The other classical authors more consistently refer to *Flevum*, so it must be assumed that Mela made a mistake in the reproduction from his source (Stolte, 1964). It cannot be established whether the name *Flevum* refers to a specific lake or to a collection of lakes (Figure 4). Plinius (*Naturalis historia* XVI, 5; Byvanck, 1931) explicitly speaks of *duos … lacus*, but elsewhere he mentions 'lakes', just like Tacitus (Stolte, 1964). The word *lacus* can also refer to ‘water’ in a more general sense. The Roman visitors would have been surprised by the dominance of water transportation in the coastal area, and the term *per lacus* may have reflected this surprise.

Mela not only describes the condition of Lake *Flevum*, but also gives a description of the northern Rhine branch. Without further indication of the location, he states that the Rhine divides into a left and right branch *haud procul a mari*, not far from the sea. He describes the first part of that right branch as *angustus et sui similis*, narrow and equal to itself, but further downstream the banks move wide apart, *ripis longe ac late recedentibus*. At this point the Rhine is no longer a river, *non amnis sed ingens lacus*, but a gigantic lake that according to him is called *Flevo.* Important is the addition *ubi campos implevit*, where it flooded the fields. That addition can be interpreted as an indication that the water level in Lake Flevo increased some time before, possibly as a result of the silting up of the Oer-IJ estuary. A more precise indication of time is not possible. Pomponius Mela finished and published his book in late 43 or early 44 AD (Romer, 1998), but his sources are unknown.

It seems out of the question that the higher water level in Lake Flevo was responsible for the decreased water discharge through the northern Rhine branch. Mela notes *non amnis* at the transition from the narrow river course to Lake Flevo. Downstream of that point, this Rhine branch was no longer a river. According to the unknown source Mela used, upstream from this transition the Rhine apparently still clearly had the characteristics of a river. The renewed peat formation in the Vecht area (Van Dinter, 2013) may have been initiated by the rising of water levels of Lake Flevo as indicated by Mela. Since the start of that peat formation is dated to the late 3rd or early 4th century AD, it has to be assumed that the water level in Lake Flevo increased further after the 1st century AD.

If the higher water level in Lake Flevo was the result of the decreased discharge through the Oer-IJ, then it was a gradual process. The development of the floating islands covered with standing trees that the Roman warships encountered cannot be explained by this. Only increased water levels with significant energy for intense, short period of time could explain peat soils being torn from the lacustrine shoreline. Such events more likely indicate the influence of the sea than an increased discharge of the rivers. This brings us to the question about the age of the tidal channel between Lake Flevo and the Wadden Sea.

After the Tidal Inlet of Bergen had closed, the water of the Overijsselse Vecht will have drained away to the Wadden Sea. The gradual decrease of the drainage through the Tidal Inlet of Bergen would have led to a higher water level in the hinterland and the drowning of the lowest parts of the peat area, which is completely consistent with Mela’s description. Eventually the water level would have risen to such an extent that it would have been possible for waters to discharge to the north via in a natural outlet. During heavy storms a large amount of saline water from the Wadden Sea would have entered the inland lake area, and this may have created those floating islands. However, the first indications for brackish conditions in the Wet Heart of the Netherlands appear to date from many centuries later. Apparently, the coastal configuration around the outlet of the

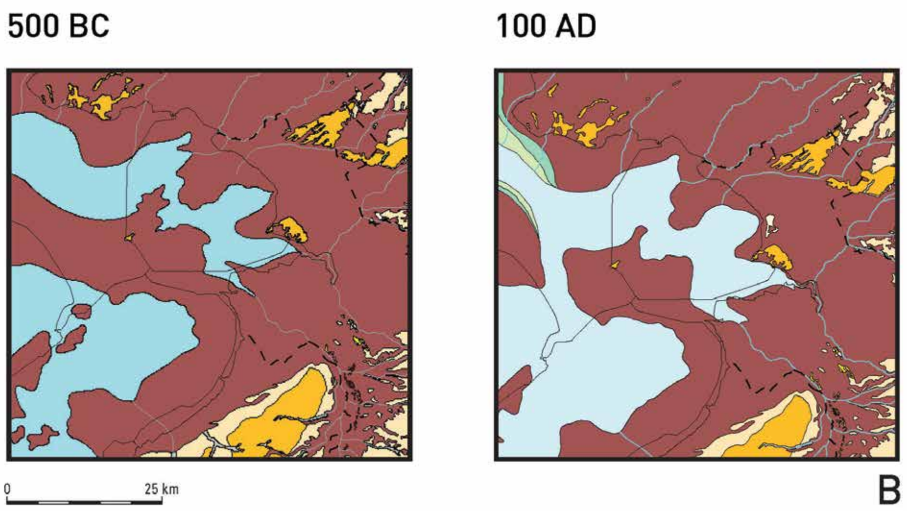

Figure 4. Details from the palaeogeographic maps of the Netherlands of 500 BC and 100 AD in area B (after Vos & De Vries, 2013).

Overijsselse Vecht into the Wadden Sea was such that a large volume of freshwater could accumulate in the region, despite the tidal movement.

In the Roman period, the Overijsselse Vecht must have still drained through the Vlie. After all, Tacitus (*Annales* II, 8; Byvanck, 1931) describes one of the trips taken during the campaign against *Germania*; the fleet sailed to the river Ems in one stretch, *lacus inde et Oceanum usque ad Amisiam flumen*, via the lakes (or: waters?) and the sea. Assuming that the fleet had reached the *lacus* along the northern Rhine branch, a navigable connection must have existed between Lake Flevo and the North Sea in the first quarter of the 1st century AD. A voyage along the Vlie seems most likely, but use of the Oer-IJ cannot be excluded.

During the expedition against *Germania*, a *castellum* with a defendable harbour was constructed on a side branch of the Oer-IJ, near the modern town of Velsen (Hessing, 1998, 99). Since the fort was built outside the power sphere of the Romans, strategic considerations would have been decisive in the choice of location for that fortification. This would not only have involved flight routes for the garrison, but also for the fleet. It is therefore almost certain that in the first quarter of the 1st century AD, a navigable waterway existed between this side branch of the Oer-IJ and the North Sea. The fact that the docks had to be repaired several times after being damaged by erosion (Hessing, 1998, 99) also suggests an opening to the North Sea. Nevertheless, from the 2nd or 1st century BC onwards the Oer-IJ changed into a fresh waterbody and the tides lost most or all of their influence (Vos, 2015). Therefore, in Roman times the still extant opening in the coastline will mainly have functioned as an outlet for the excess precipitation of the hinterland. As a consequence, the silting up of the estuary must have led to a rise in water levels, not only in the Oer-IJ, but also in the waters draining into the sea through the Oer-IJ. This establishes a *datum post quem* for the flooding of the fields around Lake Flevo recorded by Mela.

Around the year 28 AD, *castellum* Velsen I suffered a severe attack (Hessing, 1998). Tacitus (*Annales* IV; Byvanck, 1931) reports a charge by rebellious Frisians on the *castello qui nomen Flevum*, *litora Oceani*, located on the shore of the ocean. If this *castellum Flevum* is identical to Velsen I, then the Oer-IJ was also referred to as *Flevum* by the Romans. After the archaeologically documented attack Velsen I was retaken and significantly extended, but nevertheless was abandoned shortly afterwards. This did not happen because the side branch of the Oer-IJ had lost its strategic importance, because around 40 AD a new fortification was built just a short distance away (Hessing, 1998). This fortification, known as Velsen II, would have been evacuated after Emperor Claudius designated the Rhine as the frontier in 47 AD. Velsen II has not been excavated, but the location was partially investigated geoarchaeologically during the construction of the Velsen Tunnel (Morel, 1988). During these investigations, it was established that the upper one-and-a-half metre of the profile of the southern part of the Velsen Tunnel consists of a strongly eroded and reworked stratigraphy, in which mixed archaeological material from the Roman period and the Middle Ages (ca. 800-1400 AD) is found (Morel, 1988). The landscape surrounding Velsen must have been the focus of powerful erosive processes in the time when the IJ was an off-shoot of the Zuider Sea.

In the northern parts of Noord-Holland, West-Friesland and Kennemerland indications of peatland cultivation in early medieval times are concentrated in the west of those regions. In the northern part of Noord-Holland and West-Friesland this early habitation may have been connected to improved drainage due to an increased tidal movement through the Vlie. In that case, however, the drainage of the peat must have been enabled by the tidal channel running from the Vlie in a south-westerly direction through the western part of what is now known as the Wadden Sea. Obviously, the strengthening of the natural dynamics of this tidal system is unrelated to the development of the open connection between the Almeer and the Wadden Sea. Nevertheless, increasing activity of the Vlie tidal inlet may have influenced the dynamics of that connection.

The early medieval habitation in the southern part of Kennemerland can be facilitated by the improved drainage of the IJ through the Almeer and the Vlie. The peat areas in the northern part of Kennemerland and Geestmerambacht, however, draw little benefit from that drainage system. Based on the distribution of archaeological finds from the Roman period, Diederik (2002, 15) has reconstructed a drainage system to the east and north of Schoorl. Probably, the early medieval occupation of the northern part of Kennemerland and Geestmerambacht is also related to this system. If this supposition is true, then the early reclaimed peat areas in the more southerly parts of Kennemerland could also have drained in this way.

The region between Kuinre, Blankenham and Vollenhove now appears as a coastal zone along the former Zuider Sea. According to Mol (2011) this region was reclaimed from the small rivers draining the western part of the Drents Plateau. That landscape change indicates the extent to which formerly cultivated peatlands were drowned by the later enlargement of the Zuider Sea.

The lowering of the water level on Lake Flevo from 500 BC as postulated by Vos must have had consequences for the drainage of the peat area formed in the IJssel Valley. Due to a lowering of the water level, a process of peat shrinkage started that could have had far reaching effects upstream. If high water levels on the Rhine have been decisive in the development of the connection near Westervoort, then a lowering of the surface level of the land in the IJssel Valley is of secondary importance.

Below Deventer the IJssel did not belong to the domains. The adjacent settlements possessed both the right of accretion of land in the riverbed and fishing rights until the middle of the river (Van Engelen van der Veen, 1924). This proves that the new course of the IJssel developed only after the royal domain rights had been settled. Since the start of the Frankish expansion in this region dates to after 700 AD, the new course of the IJssel must have developed after this date. Another indication for such a late date is the fact that the deposition of sediments along the new lower course of the river did not start until around 950 AD (Makaske *et al.*, 2008).

Of special importance is the description of the Almeer as *stagnum* in the *Vita Bonifatii*. This hagiography, written in Mainz by the priest Willibald, is dedicated to the bishops Lullus of Mainz and Megingoz of Würzburg. Since Megingoz' successor was ordained as Bishop of Würzburg between 763 and 769, the *Vita Bonifatii* must date before 769 AD. The commission for writing this hagiography came from Bishop Lullus (Rau, 1968). He accompanied Boniface on his travels from the summer of 737 onwards, and acted as the missionary's scribe between ca. 741 and 751 (Rau, 1968). Bishop Lullus would have been an important source to Willibald on the life and works of Boniface, but through him he would also have obtained information from other companions of the very passionate missionary. The description of the Almeer as *stagnum* in the *Vita Bonifatii* could be disregarded as an empty figure of style, but it is likelier that this is the reflection of a contemporary observation. In that case, the open connection from Lake Al to the Wadden Sea must date after the middle of the 8th century. This conclusion is confirmed by the date of the top of the peat on Schokland (Van den Biggelaar *et al.*, 2014).

Apart from the date *post quem* the question about the *ante quem* arises. Assuming that Ens, which is mentioned in 793 AD (Künzel *et al.*, 1989), concerns a reclaimed peat area, then the drainage of the peat around Urk must have improved significantly as early as the third quarter of the 8th century. This is approximately the period in which salt water from the Almeer penetrated the Waterland peat region. The proxy indicators of saline waters found there suggest that the Almeer was becoming brackish certainly in the 9th, and possibly already in the 8th century (Willemsen *et al.*, 1996). This process may partly have started earlier, but the influence of salt water around the Lake of Wervershoof was also first noticed in the Carolingian period (Besteman, 1974). These data make it unlikely that the tidal channel between the Wadden Sea and Lake Flevo/Almeer developed in the centuries BCE.

If it is true that the tidal movement did not significantly affect the Almeer until the third quarter of the 8th century AD, then the history of origin of the Gelderse IJssel must also be reconsidered. Spek *et al.* (1996) date the start of the formation of the Kamper Island at around 800 AD, but according to Makaske *et al.* (2008) the deposition of sediment along the new course of the IJssel did not start until around 950 AD. That indicates receding erosion from the old estuary of the IJssel and so the question arises as to what the meaning was of that erosion process to the development of the connection between the IJssel and Lower Rhine near Westervoort.

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Bones, teeth and invisible tracers

The current state of human bioarchaeological isotope geochemical research in The Netherlands

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Abstract

Stable and radiogenic isotopes have successfully been applied to archaeological remains for over 30 years. In the last decade improved instrumentation, sample preparation techniques and theoretical understanding has resulted in isotope geochemistry maturing into an invaluable tool in archaeological science. Prior to 2008, isotope analysis, other than radiocarbon (^{14}C) dating, was only sporadically applied to Dutch archaeological human remains, but since that time a large number of studies have built up an invaluable database. This article provides a brief overview of the current state of bioarchaeological isotope research in The Netherlands. It comments on on-going methodological developments that are improving our understanding of the archaeological record and suggest that we are entering exciting times for isotope archaeology both in an academic and commercial archaeological context.

Introduction

> *Bioarchaeology: bio|archae|ology, pronunciation bʌɪəʊɑːkɪ ˈɒlədʒi*
>
> *The study of bones and other biological materials found in archaeological remains in order to provide information about human life or the environment in the past.*

Initially used as a reference to archaeozoology, Grahame Clark introduced the term ‘bioarchaeology’ in 1972 (Clark, 1972). Nowadays, the term is widely used to cover all biological remains from archaeological sites, including the fields of palaeoparasitology, archaeobotany, archaeozoology and physical anthropology. Within the field of bioarchaeology a subdiscipline of biomolecular archaeology developed from the mid-1970s onwards; since that time the biomolecular content of archaeological artefacts could be analysed. One particular method revolutionised the way we use (bio)materials to gain in-depth insight into our past and enhanced the potential of organic and inorganic archaeological remains: isotope geochemistry.

Albeit isotope analysis is not a panacea, it is nowadays a widely applied technique in archaeological and forensic sciences and is one of the most dynamic fields with new innovative applications continually being developed and validated. But despite its international success and proven potential, a geochemical approach to understanding ancient migratory patterns and palaeodiet is, to date, only occasionally applied on Dutch cultural heritage. Although research on concentrations of elements was pursued quite regularly in the ‘80s of the previous century (*e.g.*, Runia, 1985), isotope research was long-time neglected. The Royal Netherlands Academy of Arts and Sciences (KNAW), as well as the National Archaeological Research Agenda (NOaA) acknowledge this missed opportunity and appealed for more interdisciplinarity between archaeology and archaeological science (Cavallo *et al.*, 2006; KNAW, 2011).

The reason behind the low number of isotope projects that focus on the assessment of palaeodiet, or on residential mobility appears two-folded. Contract archaeology (responsible for circa 90% of all archaeological excavations in the Netherlands: a direct consequence of the 1992 Valletta Treaty; Beukers, 2009) lacks a strong bridge with archaeological science and the resources to fund the widespread application of the relatively time-consuming and hence expensive techniques. In order to increase the application of isotope geochemistry in archaeology within the Netherlands, contract archaeology needs to make bioarchaeological research a stable component of their scientific method, which will lead to a marked increase the scientific output (Van der Velde, 2011). However, the implementation of isotope geochemistry in Dutch archaeology can only be achieved if the (local authority) archaeological advisors and archaeologists are acquainted with the (im)possibilities of the technique and comprehend the potential added value of isotope geochemistry for their archaeological project. Hence, it is vital for both archaeologists and specialists to recognize and fill this knowledge gap. This goal can be reached by the transfer of knowledge, which can be achieved by organising national symposia on the application of isotope research in archaeology, and the publication of informative articles in national professional magazines.

The huge impact that isotope geochemistry has had to bioarchaeology in the last decade has led to a gradual increase in the uptake of the techniques by the commercial archaeology. To aid in stimulating application of isotope geochemistry to archaeology within The Netherlands this contribution aims to present an overview of the current state of bioarchaeological isotope research in The Netherlands and provide an overview of existing data sets that ultimately can facilitate comparisons and hence a more holistic interpretation of regional and temporal trends in diet and migration in the archaeological record.

Isotopes in archaeology

> *Isotope: iso|tope, pronunciation ˈʌɪsətəʊp*
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> *Each of two or more forms of the same element that contain equal numbers of protons but different numbers of neutrons in their nuclei, and hence differ in relative atomic mass but not in chemical properties; in particular, a radioactive form of an element.*

Although the German philosopher Ludwig Andreas Feuerbach did not mean that his famous quotation "Der Mensch ist, was er ißt" (Eng.: "Man is what he eats"; Feuerbach, 1863-4) had to be taken literally, it was adopted by Victor Lindlahr, an American health food pioneer, in the 1920s and translated into "You are what you eat". Nowadays, this 20th century citation forms the premise on which isotope biogeochemistry is based: You are isotopically what you eat, but sometimes modified through known biochemical processes that operate within the body. The principle behind isotope biogeochemistry relies on the fact that different foods can have distinctive isotopic compositions (Schoeninger and DeNiro, 1982; DeNiro, 1985; Schoeller, 1999; Daux *et al.*, 2008; Guiry *et al.*, 2012). These principles form the basis upon which isotope research for diet reconstruction and provenancing studies have been developed.

Palaeodiet

The first carbon (C) isotope study with the specific aim to assess palaeodietary aspects of ancient human lives was conducted in 1971, but published more than 10 years later in 1982 (Van der Merwe, 1982). In 1973, a few years after Van der Merwe's research, a seminar at the State University of New York at Binghamton led to new analyses of human remains from various archaeological sites in New York to assess the introduction of maize. This research was published in 1977 and was quickly followed up by two more papers (Van der Merwe and Vogel, 1977; Van der Merwe and Vogel, 1978). The proportion of the isotope ^{13}C in relation to ^{12}C, or the δ^{13}C value in apatite or collagen, reflects the isotopic composition of consumed C3-based plants (temperate grasses and trees), C4-based plants (subtropical grasses, *e.g.* maize in the New World and millet in Europe) and vegetation that use crassulacean acid metabolism (CAM plants: cacti, succulents and epiphytes, *e.g.* vanilla; DeNiro and Epstein, 1981; O'Leary, 1981; Sealy *et al.*, 1987; Ambrose, 1991). The introduction of nitrogen (N) isotope analyses (^{15}N/^{14}N, or δ^{15}N) as a tool to assess the trophic position of the food consumed by humans and animals developed a few years later, in the early '80's (DeNiro and Epstein, 1981; DeNiro and Schoeniger, 1983; Ambrose and DeNiro, 1986). This method is based on the enrichment of the δ^{15}N of humans and animals relative to their food source due to isotopic fractionation during metabolic activities and tissue protein synthesis (*i.e.* the non-linear transfer of isotopes, favouring ^{14}N over ^{15}N in nitrogen elimination through urea synthesis; Katzenberg 2000).

Carbon and nitrogen isotopes are now well-established and invaluable tools not only for the assessment of palaeodiet (*e.g.*, Redfern *et al.*, 2010; Cassady, 2012; Mays and Beavan, 2012; Vika and Theodoropoulou, 2012), but also for the determination of patterns of breastfeeding and weaning age (*e.g.*, Wright and Schwarcz, 1998; Balasse and Tresset, 2002), and the investigation of animal husbandry (*e.g.*, Millard *et al.*, 2011; Towers *et al.*, 2011; Hammond and O'Connor, 2013). In addition, sulphur isotopes ($\delta^{34}S$) are used to provide supplementary palaeodietary evidence to $\delta^{13}C$ and $\delta^{15}N$ measurements, but compared to the carbon and nitrogen isotopes, this method is still in its infancy (Richards *et al.*, 2003; Nehlich, 2015). In contrast to carbon and nitrogen isotopes, sulphur isotopes reflect the sulphur isotope composition of ingested foods, which depends on the geological bedrock, atmospheric precipitation and active soil-dwelling microorganisms (Richards *et al.,* 2003). In particularly coupled with the previous mentioned isotopes, sulphur isotopes may be used as reliable indicators of marine protein consumption, or reflect coastal location (due to the 'sea-spray' effect).

Palaeomobility

From the 1980s onwards, the concept of mobility has been subjected to research and debate. The original models of migratory patterns in (pre)history were based upon the spatial dispersal of cultural artefacts, with the best known proxies for the analysis of migration being the distribution of typological identical artefacts and the merging of typological groups (Burmeister, 2000; Theuws, 2009). The use of typology to trace ancient migration patterns, however, has led to an active debate about the extent to which the archaeological record represents the actual movement of people or the diffusion of materials and ideas (*e.g.* Childe, 1925; Burmeister, 2000; Hakenbeck, 2008). A new perspective on this debate, and a possible tool to develop a method to identify migratory patterns, is provided by the archaeological subdiscipline of archaeological science. Even though the isotopic study of mobility seems to be tightly bound to archaeology, it does not fall exclusively within the realm of archaeology; stable and radiogenic isotope research has proven its value in many environmental migration studies and historical and forensic cases (Pye, 2004; Wassenaar *et al.*, 2008; Degryse *et al.*, 2012; Hillaire-Marcel *et al.*, 2013; Font *et al.*, 2015).

The isotopes of lead (Pb), neodymium (Nd), oxygen (O), and in particular strontium (Sr) have been extensively used as tracers of origin. These isotope systems act as geochemical signatures that can enable researchers to source organic and inorganic remains to specific geological or geographical regions (e.a. Pye, 2004; Bentley, 2006; Schwarcz *et al.*, 2010). Organic tissues such as fabrics (e.a. Frei *et al.*, 2009a; Frei *et al.*, 2009b, but see Von Holstein *et al.*, 2015), wood (Horsky 2010), keratin (e.a. Meier-Augenstein and Kemp, 2009; Font *et al.*, 2012), ivory (Van der Merwe *et al.*, 1990; Rijkelijkhuizen *et al.*, 2015), shell (e.a. Eerkens *et al.*, 2005) and in particular (fossilised) human and animal bone, dentine and enamel (e.a. Schweissing and Grupe, 2003; Pye, 2004; Bentley, 2006; Britton *et al.*, 2009; Copeland *et al.*, 2010; Schwarcz *et al.*, 2010 and references therein) have been subject to isotope analysis to study migration, specifically on the individual level. In addition, isotope research has proven to be a valuable tool for tracing the provenance of raw materials for pottery, metal and glass, providing solid evidence for trade or exchange of artefacts (e.a. Brill, 1970; Pye, 2004; Henderson *et al.*, 2005; Degryse and Schneider, 2008; Huisman *et al.,* 2009; Degryse *et al.*, 2010; Pryce *et al.*, 2011; Thibodeau *et al.*, 2013).

Figure 1. Well preserved collagen, the organic component of bone. Photo: L.M. Kootker.

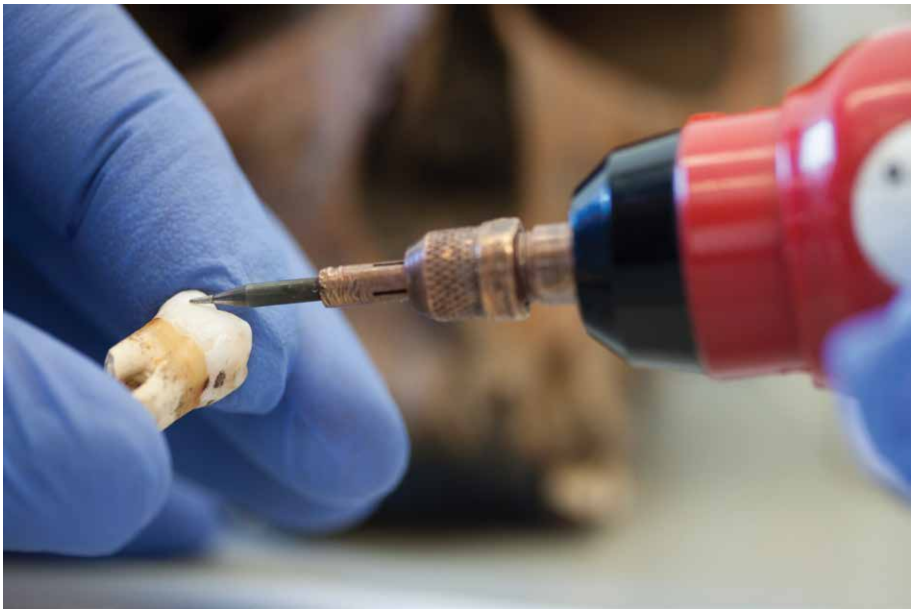

Figure 2. Sampling a human molar using a diamond-tipped dental burr. Photo: L.M. Kootker.

The Dutch context: From aDNA to isotopes

> *DNA: DNA, pronunciation diːɛn ˈeɪ*
>
> *Deoxyribonucleic acid, a self-replicating material that is present in nearly all living organisms as the main constituent of chromosomes. It is the carrier of genetic information.*

Even though Lex T. Runia published an article about the application of strontium and carbon isotopes in 1985 (Runia, 1985) and analysed 62 individuals himself less than two years later (Runia, 1987), it was the find of the skeletal remains of a young child in Eindhoven in 2002 that ushered a new era in Dutch archaeology. Nico Arts, municipal archaeologist in Eindhoven, reached out to forensic scientists at the Catholic University of Leuven (UCL) in Belgium to investigate whether the child's remains yielded DNA. And they did. This exciting find was the starting point of one of the most ambitious archaeological projects ever initiated in The Netherlands: the establishment of a major human ancient DNA databank. Enthused by preliminary results and successes in Eindhoven, fellow archaeologists approached Professor Peter de Knijff, head of the Forensic Laboratory for DNA research (FLDO) of the Leiden University Medical Centre (LUMC), and responsible for aDNA analyses, to conduct aDNA analyses on other sets of ancient human skeletal remains. Amongst these workers was Tim de Ridder, municipal archaeologist in Vlaardingen (S-H). He was able to obtain financial aid for the execution of DNA analyses on 11th century human remains from Vlaardingen and their potential modern descendants. The aDNA results, however, raised more questions than they answered: who were these medieval inhabitants of Vlaardingen, what did they eat and where did they originate? Tim de Ridder therefore contacted Henk Kars in 2008, which lead to a collaboration between Institute for Geo- and Bioarchaeology and the Vlaardingen Archaeology Office (VLAK) and resulted in the first two commercially executed archaeological isotope investigations in The Netherlands after Runia's pioneering work in 1987 (Runia, 1987; Van de Locht and Kars, 2008a; 2008b). During that same period, Professor Leendert Louwe Kooimans, Leiden University, coordinated the research programme 'From Hardinxveld to Noordhoorn – From Forager to Farmer', funded by the Netherlands Organisation for Scientific Research (NWO). This project (2003-2008) focussed on the transition in subsistence strategies during the Mesolithic and Neolithic in The Netherlands and integrated stable and radiogenic isotope analysis on Middle Neolithic populations in Schipluiden and Swifterbant to help answer the research questions (Smits and Van der Plicht, 2009; Smits *et al.*, 2010). Thus, by the end of 2008 carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$), strontium ($^{87}Sr/^{87}Sr$), oxygen ($\delta^{18}O$) and in some cases sulphur ($\delta^{34}S$) and lead ($^{206/207/208}Pb/^{204}Pb$ and $^{207/208}Pb/^{206}Pb$) isotope analyses were executed on dozens of ancient human and faunal remains. The Dutch archaeology had finally entered the era of biomolecular archaeological science.

Isotope archaeology and Dutch cultural heritage

> *Heritage: heri|tage, pronunciation ˈhɛrɪtɪdʒ*
>
> *Valued objects and qualities such as historic buildings and cultural traditions that have been passed down from previous generations*

To date, several studies have stressed the potential of the Dutch geological subsurface and its archaeological records to allow successful research on migratory patterns and to assess palaeodiet. An extensive, but possibly far from complete overview of all archaeological projects in The Netherlands where stable and/or radiogenic isotopes have been applied to human remains is given in table 1 and figure 3. The list contains 50 archaeological sites within The Netherlands or within the Dutch marine territories. Surprisingly, the isotope results from only seven archaeological sites have been published in peer-reviewed journals or as book chapters (Lanting and Van der Plicht 1995/6; De Muynck *et al.*, 2008; Smits and van der Plicht, 2009; Smits *et al.*, 2010; McManus *et al.*, 2013; Schats *et al.*, 2014), although other publications are in preparation. The data of most other projects are published in bachelor, master or PhD theses and dissertations, and in grey literature. The latter category includes archaeological site reports, popular books and internal reports. A selection of theses, dissertation and grey literature is, however, available in online (academic) repositories and databases (*e.g.*, University of Amsterdam – dare.uva.nl; Leiden University – openaccess.leidenuniv.nl; Vrije Universiteit Amsterdam – dare.ubvu.vu.nl; archaeological site reports – easy.dans.knaw.nl). These academic repositories are part of the national NARCIS archive (National Academic Research and Collaborations Information System – www.narcis.nl), an initiative of the Dutch universities to publish their research results in open access as much as possible. In addition, data from six archaeological sites have yet to be published.

Despite the limited number of projects, the number of isotopic analyses is high. Isotopic research into palaeomobility has been conducted on more than 570 ancient human individuals; palaeodietary assessments have been applied to at least 400 individuals. Moreover, isotope analyses have been conducted on human material that cover most archaeological periods in The Netherlands, spanning from the Mesolithic period (8.800-4.900 BC) to the modern era (>AD 1500). The geographical distribution of the investigated sites is biased towards the Holocene marine and fluviatile clay regions (Figure 3). Only a few archaeological sites are situated in the Pleistocene sand and loess districts, such as Eindhoven, Maastricht and Oldenzaal. The sample coverage is unequally distributed across The Netherlands due to:

			Bioarchaeological research			
Province	Site	Period	Diet	Mobility	Reference	
-	North Sea	Mesolithic	x		A/G	Hebels, 2014; Storm *et al.*, 2014; Smits, 2015
Flevoland	Swifterbant	Neolithic	x	x	P	Smits and van der Plicht, 2009; Smits *et al.*, 2010; Baetsen and Kootker, 2013
Friesland	Hogebeintum	Early Medieval	x	x	P	McManus *et al.*, 2013
Gelderland	Beuningen	Iron Age		x	A/P	Geerdink, 2012; Kootker and Geerdink, 2012; Kootker *et al.*, in prep.-a
Gelderland	Geldermalsen	Iron Age		x	A/P	Geerdink, 2012; Kootker *et al.*, in prep.-a
Gelderland	Lent	Iron Age	x	x	A/P	Geerdink, 2012; Kootker *et al.*, in prep.-a
Gelderland	Kerkdriel	Iron Age		x	G	Kootker and Davies 2015
Gelderland	Meteren	Iron Age		x	A/P	Geerdink, 2012; Kootker *et al.*, in prep.-a
Gelderland	Nijmegen	Medieval		x	G	Kootker, 2015a
Gelderland	Oosterhout	Iron Age		x	A/P	Geerdink, 2012; Kootker *et al.*, in prep.-a
Gelderland	Ressen	Iron Age		x	A/P	Geerdink, 2012; Kootker *et al.*, in prep.-a
Groningen	Groningen	Medieval	x	x		n.p.
Limburg	Borgharen	Early Medieval	x	x	G	Kootker, 2014a
Limburg	Maastricht	Medieval	x	x	A	De Muynck, 2008; Van Tendeloo, in prep.
Limburg	Venlo	Medieval	x			n.p.
North Brabant	‘s-Hertogenbosch	Modern Era	x	x	G	Van Genabeek *et al.*, 2015
North Brabant	Eindhoven	Medieval	x		A	Sonders, 2009
North Brabant	Gilze Rijen	Modern Era		x		n.p.*
North Brabant	Kessel-Lith	Iron Age		x	G	Kootker and Davies 2015
North Holland	Alkmaar	Modern Era	x	x	A/P	Schats *et al.*, 2014; Kootker, 2015b; Van Hattum, 2015; Kootker *et al.*, in prep.-b
North Holland	Andijk	Bronze Age	x		A	Runia, 1987
North Holland	Blokhuizen	Early Medieval	x		A	Van Hattum, 2015
North Holland	Bovenkarspel	Bronze Age	x		A	Runia, 1987
North Holland	Castricum	Roman	x	x	G	Kootker and Altena, 2010
North Holland	Grootebroek	Bronze Age	x		A	Runia, 1987
North Holland	Haarlem	Medieval		x	G	Kootker, 2014b; Van Zalinge and Van der Linde, 2015
North Holland	Hoogkarspel	Bronze Age	x		A	Runia, 1987
North Holland	Middenbeemster	Medieval	x		P	Waters-Rist, in prep. (pers. Comm. A. Waters-Rist).
North Holland	Oosterleek	Medieval		x		n.p.
North Holland	Oostwoud	Bronze Age		x	A	Runia, 1987
North Holland	Uitgeest	Iron Age	x	x	A	Geerdink, 2012
North Holland	Velsen	Bronze Age	x		A	Runia, 1987

			Bioarchaeological research			
Province	Site	Period	Diet	Mobility	Reference	
North Holland	Zwaagdijk	Bronze Age	x		A	Runia, 1987
Overijssel	Mander	Bronze Age	x	x	G	Kootker and Panhuysen, 2014
Overijssel	Oldenzaal	Medieval	x	x		n.p.
Overijssel	Zwolle	Medieval		x	G	Clevis and Klomp, 2015
South Holland	Gouda	Medieval	x	x	G	Kootker, 2015c
South Holland	Hardinxveld-Giessendam	Late Mesolithic	x		P	Smits and van der Plicht, 2009
South Holland	Midden Delfland	Iron Age		x		Geerdink, 2012
South Holland	Oegstgeest	Early Medieval	x	x	G	Kootker and Altena, 2012; Kootker *et al.*, 2014
South Holland	Rijnsburg	Medieval	x		P	Lanting and Van der Plicht, 1995/6
South Holland	Rijswijk	Neolithic	x	x	G	Kootker, 2014c
South Holland	Rockanje	Iron Age	x	x	A	Geerdink, 2012
South Holland	Schipluiden	Neolithic	x	x	P	Smits and Van der Plicht, 2009; Smits *et al.*, 2010
South Holland	Valkenburg	Bronze Age/ Roman	x	x	A/P	Runia, 1987; Smits, 2006; De Muynck *et al.*, 2008; Geerdink, 2011
South Holland	Vlaardingen	Medieval	x	x	G	Van de Locht and Kars, 2008a; Van de Locht and Kars, 2008b
South Holland	Wassenaar	Bronze Age	x	x	G	Kootker *et al.*, 2014
Utrecht	Doorn	Medieval	x	x	G	Kootker, 2012
Utrecht	Wijk bij Duurstede	Early Medieval		x		n.p.
Zeeland	Domburg	Early Medieval	x	x		pers.comm Ten Harkel, see Van Dierendonck, 2015
Zeeland	Oostkapelle	Early Medieval	x	x		pers.comm Ten Harkel, see Van Dierendonck, 2015
Zeeland	Vlissingen	Medieval		x	G	Altena *et al.*, 2014

*Table 1. Overview of executed isotope research on archaeological human remains in The Netherlands in alphabetical order. Key: A – academic output; G – grey literature; P – peer reviewed paper or book chapter; n.p. – unpublished data; * – osteological data published in Van der Heijden, 2001.*

A. Varying preservation conditions (*e.g.*, soil pH, causing taphonomic loss of organic material).

B. Limited sample availability (*e.g.*, the repatriation and reburial of archaeological human remains).

C. Differences in economic pressure across the country. High economic pressure in a province instigates an increase in construction activities, and thus an increase in archaeological activities (excavations). Over the last 10 years, large construction and infrastructural activities in the provinces of South-Holland, Gelderland, North-Brabant and Limburg resulted in the highest ever number of archaeological excavations in these parts of

The Netherlands. Thus although the preservation conditions for organic materials are favourable in, for instance, the coastal provinces of Zeeland and Flevoland, the archaeological output is remarkably low due to the absence of ground-disturbing activities (www.erfgoedmonitor.nl).

D. Differences in excavation policy between provinces/archaeological regions. In 2011, most archaeological remains in the Dutch clay and peat districts were preserved *in situ*; at the location where they were found, and hence remained inaccessible for (bio)archaeological investigations. As a result, 89% of all archaeological sites discovered in the province of Flevoland remained buried, while in the loess region in Limburg 91% of the archaeological sites were preserved *ex situ* (Schute *et al.,* 2013). These differences in excavation policies result in difference in material availability across the The Netherlands.

The list presented in table 1 can be expanded if bioarchaeological research on archaeological animal remains or bone artefacts is taken into account (*e.g.* Van der Jagt *et al.*, 2012; Brusgaard, 2014; Esser *et al.*, 2014; Rijkelijkhuizen *et al.*, 2015). Moreover, the past few years isotope investigations have taken or will take place on Dutch heritage beyond the current borders of The Netherlands, such as in Cape Town, South Africa (Mbeki *et al.*, in prep.), Zeeuwse Uitkijk (Ytre Norskøya), an island of the Svalbard archipelago (Koon and Tuross, 2013), the Dutch Caribbean (Van Klinken 1991) and in Australia on Beacon Island where the VOC (Dutch East India Company) ship Batavia was shipwrecked on her maiden voyage in 1629 ("Shipwrecks of the roaring 40s" project – pers.comm. E. Smits, University of Amsterdam).

Conclusion

In brief, the abovementioned studies have proven that isotope geochemistry in Dutch archaeology can provide invaluable information with regards to palaeomobility studies of humans, animals and artefacts and palaeodietary investigations. To date, however, the vast majority of the available data has yet not been assembled, synthesised and published in (open access) peer-reviewed international journals or books. Clearly, isotope data has the potential of elucidating certain facets of our (pre) history that otherwise would have remained unexposed. Isotope geochemistry will be particularly powerful if results are integrated with archaeological, physical anthropological and aDNA data.

Isotope geochemistry will remain a strong tool in answering the research question "local or non-local" and will provide vital information about our history and the cultural and material changes that may have been introduced or catalysed by migration, trade and/or exchange of humans and artefacts respectively (*e.g.* palaeodiet, artefact typology, burial rite). The generation of regional isotopic databases is therefore essential; in particular for more quantitative interpretations of the data, as future bioarchaeological isotope research might shift from the "local or non-local" question to "where did they come from". This is certainly a more challenging question to answer, and also requires multiple lines of evidence (archaeological, historical and isotopic). To provide answers to this question, and

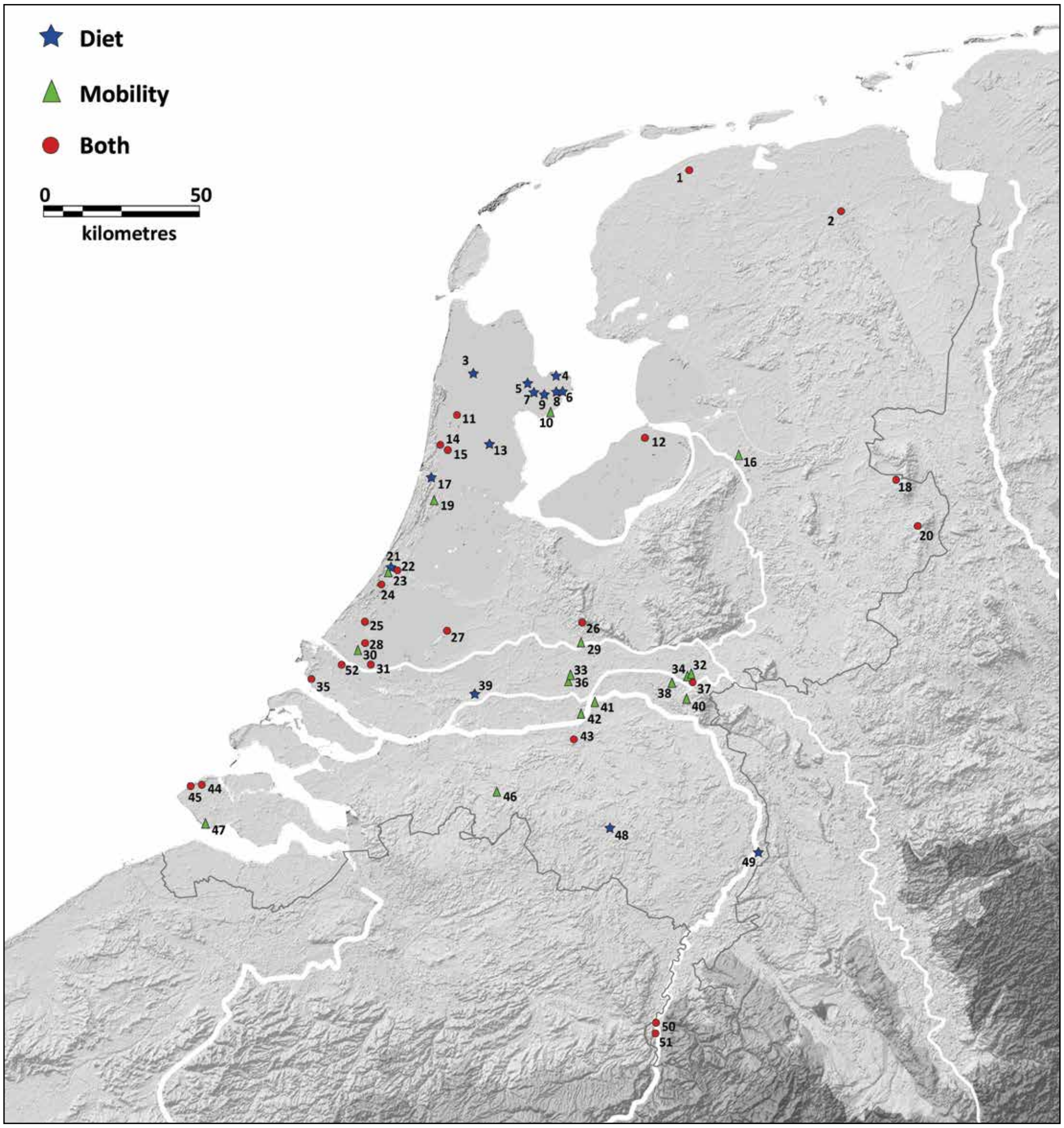

Figure 3. Geographical distribution of the archaeological sites in The Netherlands where stable and/or radiogenic isotopes have been applied to ancient human remains. Key: 1 – Hogebeintum; 2 – Groningen; 3 – Blokhuizen; 4 – Andijk; 5 – Oostwoud; 6 – Bovenkarspel; 7 – Zwaagdijk; 8 – Grootebroek; 9 – Hoogkarspel; 10 – Oosterleek; 11 – Alkmaar; 12 – Swifterbant; 13 – Middenbeemster; 14 – Castricum; 15 – Uitgeest; 16 – Zwolle; 17 – Velsen; 18 – Mander; 19 – Haarlem; 20 – Oldenzaal; 21 – Rijnsburg; 22 – Oegstgeest; 23 – Valkenburg; 24 – Wassenaar; 25 – Rijswijk; 26 – Doorn; 27 – Gouda; 28 – Schipluiden; 29 – Wijk bij Duurstede; 30 – Midden Delfland; 31 – Vlaardingen; 32 – Ressen; 33 – Geldermalsen; 34 – Oosterhout; 35 – Rockanje; 36 – Meteren; 37 – Lent; 38 – Beuningen; 39 – Hardinxveld-Giessendam; 40 – Nijmegen; 41 – Kessel-Lith; 42 – Kerkdriel; 43 – 's-Hertogenbosch; 44 – Oostkapelle; 45 – Domburg; 46 – Gilze Rijen; 47 – Vlissingen; 48 – Eindhoven; 49 – Venlo; 50 – Borgharen; 51 – Maastricht.

in line with a limited number of other countries in Europe and abroad, an initial strontium isotope distribution map of The Netherlands has been completed, which will be subject to future updates to increase its accuracy (e.a. Sjögren *et al.*, 2009; Evans *et al.*, 2010; Frei and Frei, 2011; Kootker *et al.,* 2016).

Researchers in The Netherlands are at the forefront of exciting methodological developments in isotope geochemistry designed for the application to forensic and archaeological science. Many of the on-going developments are allowing smaller samples to be analysed that results in either less sample destruction or the capability to analyse new sample types. The Netherlands appears to be entering exciting times for isotope archaeology both in an academic and commercial context.

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On the 'Quartzite Palaeolithic' of the Naarder Eng (Huizen, the Netherlands)

Relevance of a quartzite Neolithic axe find

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Abstract

This contribution reports on the recent find of a quartzite Neolithic polished axe from the Naarder Eng (Huizen, the Netherlands) and the implications of this find for the so-called 'Quartzite Palaeolithic' of the Naarder Eng (Walet & Boelsma 2000). The 'Quartzite Palaeolithic' refers to a site rich in quartzite artefacts discovered in 1998, just a few hundred meters from the findspot of the polished axe. From the technologically 'archaic' ("Clactonian") character of the artefacts, Walet and Boelsma argued that this site is Lower or Middle Palaeolithic in age. Koopman and Cruysheer (2012) opt for a late Middle Palaeolithic (MIS 3) age. Field observations reported here suggest that the site occurs on a localized outcrop of quartzite cobbles originally derived from the ice-pushed deposits at this locality. These quartzite cobbles are wind-shaped (ventifacts), indicating they were subsequently part of a Last Glacial Maximum (26.5-19 kyr BP) desert pavement. Some of the archaeological artefacts display remains of ventifact surfaces on their dorsal cortical parts, but they show no sign of wind abrasion on their ventral side and on flake scars. The site therefore more likely represents a lithic raw materials procurement site or open-air "quarrying" site that post-dates the Last Glacial Maximum, potentially significantly so. The find of the quartzite polished axe shows that this quartzite procurement site may well have been in use during the Neolithic, i.e. during the mid-Holocene.

Introduction

Two questions invariably pop up when simple stone tools are found. One is the question: "*is it real?*" (*i.e.* are they genuine artefacts, as opposed to, *e.g.*, 'geofacts'). If the answer to that question is affirmative, this is usually followed by the question:

"*how old are they?*". During his work at the *Rijksdienst voor Oudheidkundig Bodemonderzoek* (the Dutch National Archaeological Heritage Agency), Henk Kars got to deal with these questions as part of the notorious Vermaning affair and its aftermath (Kars 1989; De Vries 1997; Stapert 1986; Stapert *et al.,* 1998; Roebroeks *et al.,* 2004). Henk got involved because archaeometric, geological, geomorphological and other geoarchaeological methods and observations can and often do significantly contribute to finding the answers to these questions. Taphonomy, geomorphological and sedimentary history, the wider geological context and archaeometric arguments (*e.g.* the character of weathering) are often much more important in these issues than radiometric dates, which are too often taken too much at face value and are meaningless without an assessment of their context. Examples from my own research both before and during my post-doc at Henk's *Institute for Geo- and Bioarchaeology* (IGBA) are discussions on the age of *Homo erectus* fossils from Java (Langbroek and Roebroeks 2000; Langbroek 2004) and discussions on the age of bifacial stone tools found at Bose, southern China (Langbroek 2015). In this contribution, I present another, Dutch case of "*how old is it truly?*", a case which is literally "close to home" for Henk Kars. It concerns quartzite tools found on the Naarder Eng near Huizen in Het Gooi, in the center of the Netherlands, not far from Henk's place of residence.

Palaeolithic quartzite tools from the Naarder Eng, Huizen?

In February of 1998, amateur archaeologist Ben Walet discovered a surface site rich in quartzite artefacts on the Naarder Eng, an agrarian field complex on a Saalian age ice-pushed ridge near Huizen (Noord-Holland) in the center of the Netherlands. Over the course of a number of years, Walet and his fellow amateur Boelsma (Walet & Boelsma 2000) have collected hundreds of unambiguous but typologically agnostic quartzite artefacts at this site, most from an area a mere hundred meters in diameter.

The age of the site is open to debate, as Walet & Boelsma (2000) themselves acknowledged. Because of the archaic technological character of the artefacts, which is reminiscent of the Lower Palaeolithic "Clactonian" core reduction technique, they have argued that the site is of Middle or even Lower Palaeolithic age (Walet & Boelsma 2000). Among professional Palaeolithic archaeologists there is however a tendency to dismiss a Palaeolithic age for this site, but none of this has been published. As a result, the site still keeps lingering in the 'grey' literature. For example, Koopman & Cruysheer (2012) recently included it in an overview of the prehistory of Het Gooi assigning it a late Middle Palaeolithic (MIS 3) age.

I first got tangentially involved in this case 15 years ago near the end of my PhD at Leiden University. A crucial field find and some significant observations towards a solution were made in 2010 when I was a post-doc at the IGBA. These corroborated an already present suspicion. In this paper I present these observations, which evidence a significantly later date for the site.

Palaeolithic artefacts on or in glacial deposits in the Netherlands

Middle Palaeolithic artefacts and fossils of Middle Pleistocene mammals have been found in large quantities in coarse-grained river sediments of Early to Middle Saalian age in the ice-pushed ridges of the central Netherlands (Franssen & Wouters 1978; Stapert 1981; Stapert 1987; Niekus & Stapert 2005; Van Balen & Busschers 2010). These artefacts have been transported and re-deposited in a river system predating the Late Saale (MIS 6) maximum ice advance of the Drente glaciation at 150-170 Ka (Busschers *et al.*, 2008), although there is some disagreement about the distance and degree of secondary displacement of the artefacts as well as the age of the lithic industry (Offermans-Heykens 1998; Van Balen *et al.*, 2007; Van Balen & Busschers 2010). In any case, more or less rolled early Middle Palaeolithic artefacts can be found as a diffuse scatter widely distributed in ice-pushed fluvial deposits of the Urk Formation, as well as on the surface where these deposits outcrop. No convincing artefacts dating from the Lower Palaeolithic have been discovered in the ice-pushed ridges yet (Niekus & Stapert 2005).

From this perspective, a dense concentration of Lower or early Middle Palaeolithic artefacts on top of an ice-pushed ridge would be highly exceptional. Later Middle Palaeolithic artefact scatters deposited on the surface of the ice-pushed ridges after the retreat of the Saalian ice sheet (i.e. post-dating 160 Ka) as a result of Neandertal activity do exist but are rare in the central and northern part of the Netherlands. The majority of finds of this age concern isolated finds.

At present, one convincing rich Middle Palaeolithic surface scatter has been published from a similar geological context in the Netherlands: a spatially restricted find assemblage with several flint handaxes near Assen (Niekus *et al.*, 2011). Ongoing search activities on the Drenthe plateau suggest there are a few more (Niekus priv. com). Two other sites discovered earlier (Mander: Stapert 1982, Stapert *et al.*, 2013; and Hilversum-Corversbos: Offerman-Heykens *et al.*, 2010; Offermans-Heykens 1998) are disputable candidates, in the sense that it is questionable whether the artefacts found really constitute *in situ* concentrations rather than redeposited material or density variations in deep spatially continuous palimpsests of unrelated material (Roebroeks' "veil of stones": Roebroeks *et al.*, 1992). All the post-160 Ka sites mentioned contain artefacts with signs of heavy post-depositional weathering, like abrasion (including wind-gloss), frost-splitting and cryoturbation retouch.

For all these reasons, a relatively well-preserved dense Lower or Middle Palaeolithic surface scatter of artefacts that still shows the selective procurement and working of quartzite, like the Naarder Eng site, would be a unique and important discovery. In this contribution I revisit the site interpretation in light of recent field observations, a re-interpretation of the lithic assemblage and the recovery of an unambiguously Neolithic quartzite artefact near the site.

Site location, geological context and character of the Naarder Eng artefacts

Walet and Boelsma kindly took the author on a field visit to the site in 2002 and showed him the artefact assemblage collected over the previous years. Additional geological observations were done together with Jan Kolen and Ronald Frank during a second field visit to the site in April 2010.

The site is located in an agricultural field on the Naarder Eng (approximately 52.31° N, 5.23° E), situated on the northeast side of the Saale-age Laren-Huizen ice-pushed ridge (Figure 1). The ice-pushed deposits include fluviatile sediments of forerunners of the rivers Rhine and Meuse (Urk Formation) and possibly of rivers with an eastern origin (Sterksel Formation) (see Busschers *et al.*, (2008) for the wider context of these ice-pushed deposits and their ages). They are locally covered by glaciofluvial and moraine deposits (Drente Formation) and by Weichselian aeolian coversand deposits (Boxtel/Twente Formation).

The surface of the local landscape is very rich in erratic quartz, sandstone, quartzite and other erratic material (lydite, jasper, oolite) of southern origin – i.e. from the German Rhineland and Belgian-French Meuse area. The quartzite includes amongst others the coloured Taunus and grey Revinien varieties. During the field visit in 2010 we noted that while quartzites dominate the erratic spectrum found at the archaeological site, granites and other plutonic rocks, probably with a Scandinavian origin and glacially transported during the Drente glaciation (Zandstra 1988), dominate the erratic spectrum only a few hundred meters to the west and southwest. The quartzite deposits in the study area are hence spatially restricted.

The quartzite artefact assemblage recovered at the Naarder Eng by Walet & Boelsma (2000) consists of large numbers of mostly unmodified quartzite flakes. Several are partially or wholly cortical on the dorsal side (see example in figure 2, found by the author during the field visit in 2002) and there are just a few pieces with simple retouch (Walet & Boelsma 2000, their figs. 2 and 3; and personal observations by the author in 2002). Simple hard percussion techniques are employed at the site (Walet & Boelsma 2000) with generally broad, mostly non-prepared and sometimes cortical striking surfaces. The assemblage also contains 'tested' pieces, i.e. cobbles with one or a few flaking negatives which might indicate the on-site 'testing' of quartzite for quality assessment.

Although the artefact assemblage appears to be archaic from a technological point of view, and an assessment as 'Lower and/or Middle Palaeolithic' (Walet & Boelsma 2000) is therefore understandable, the quartzite assemblage contains no artefacts that are typologically unambiguously diagnostic for either the Lower or Middle Palaeolithic. This is important to note. While 'primitive' looking fractured rock is often readily assigned to the Lower Palaeolithic, it need not be: the first primary reduction stage in any lithic industry, irrespective of age, looks 'primitive'.

The artefacts are made of medium to coarse-grained grey to brown-grey, sometimes coloured quartzite and quartzitic sandstone with good flaking properties. Cortical flakes sometimes show remnants of wind-polished (ventifact)

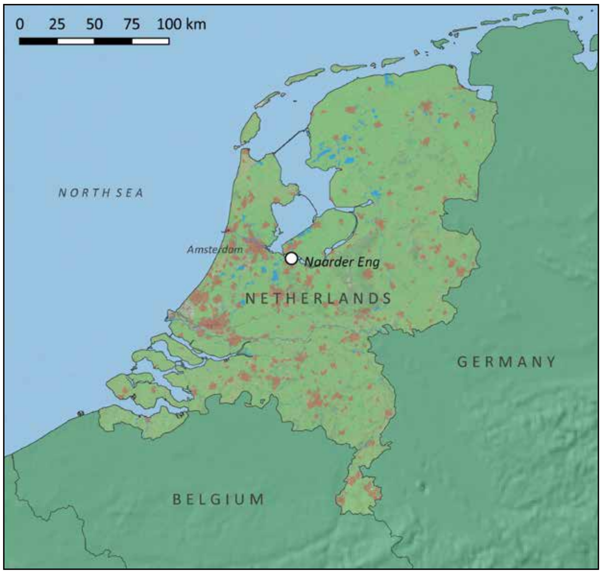

Figure 1a. Location of the Naarder Eng in the center of the Netherlands. MODIS image and SRTM elevation data courtesy of NASA.

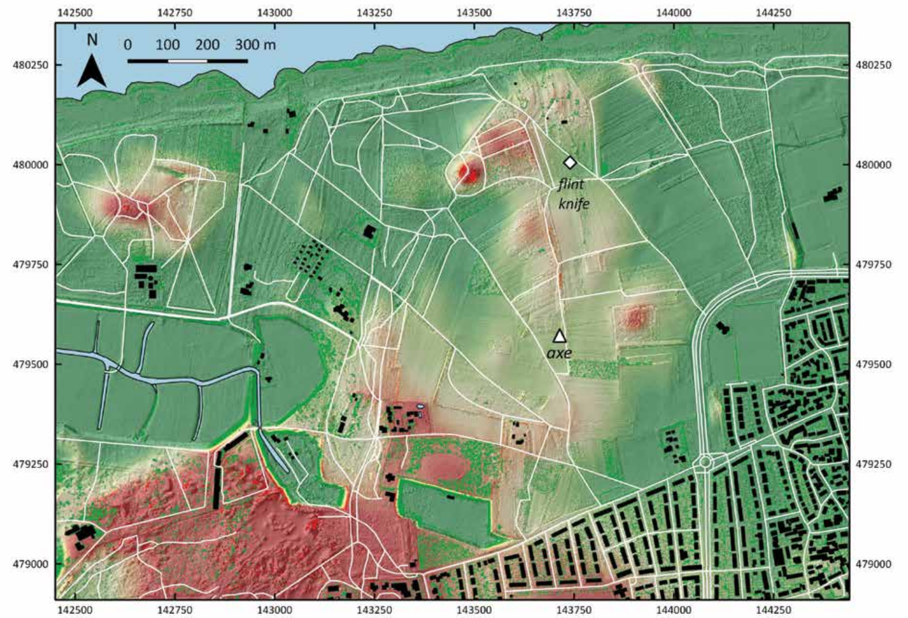

Figure 1b. Map of the area of interest, with the findspot of the Neolithic polished axe top and the late Neolithic flint knife indicated. The precise location of the quartzite site is not shown in order to protect the locality, but it is just east of the findspot of the flint knife. White lines are roads and footpaths. Buildings at lower right belong to the village of Huizen. The coordinate grid refers to the Dutch Topographic Grid (RD/Amersfoort) and is in meters. Elevation data are from the AHN, topographic data from TOPNL via PDOK.

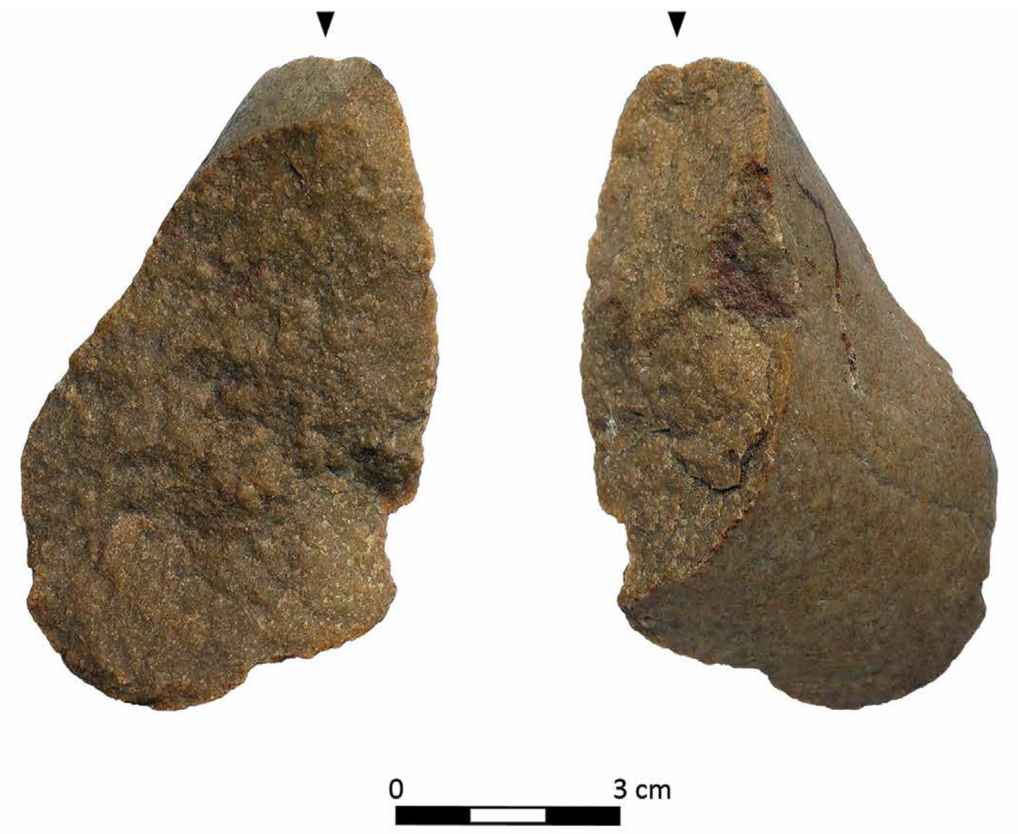

Figure 2. Typical quartzite cortical flake (left the ventral side, right the dorsal side with partial cortex), found at the Naarder Eng in 2002. Flaking platform is cortical. Photo: M. Langbroek.

surfaces on the dorsal side, indicating that they were produced from material that was picked up from a periglacial desert pavement. Large numbers of unmodified quartzite ventifacts are present at the site. The Laren-Huizen ice-pushed ridge has in fact long been known for the large numbers of ventifacts that can be found there (see *e.g.* Van der Lijn 1963, photo 83 and page 195).

The significance of ventifacts

Desert pavements with ventifacts formed through aeolian denudation of the finer fraction of the ice-pushed fluviatile sediments, creating a planation surface littered with large numbers of wind-polished and wind-facetted stones. The polishing and facetting into ventifacts is the result of the high particle load and strong winds during this denudation process. The formation of the desert pavements and these ventifacts is usually considered to date to the Last Glacial Maximum (LGM) (Schaftenaar 1976; Pannekoek & Van Straaten 1984), i.e. approximately 26,500 to 19,000 years ago, when strong arctic storms ravaged the subarctic tundra landscape. Ventifacts therefore significantly postdate the end of the Middle Palaeolithic (~40,000 years ago). This makes a Middle Palaeolithic or older date for the Naarder Eng artefacts unlikely. It is also unlikely that the quartzite artefacts date from an earlier period (i.e. from well before the LGM) but were incorporated in the desert pavement during the LGM as part of a lag deposit formation. In that case, the artefacts should have acquired the same natural (aeolic) surface modifications as the ventifacts, not only on the cortical sides but on all surfaces. Ventral sides and flaking scars on the Naarder Eng artefacts however show no signs of wind-induced abrasion (*e.g.* figure 2). For these reasons we should seriously consider a (much) younger age for the Naarder Eng quartzite assemblage.

A lithic procurement site?

That the site occurs right at a spatially restricted, rich natural exposure of quartzite cobbles with good flaking properties seems to be significant. It could point to a so-called "lithic raw materials procurement site" (i.e. an open-air quarry). When raw materials are tested and decorticated at such a site and then taken away for further reduction elsewhere, *e.g.* to be made into tools, the materials left at the procurement site -irrespective of age and technological tradition- form a 'primitive' looking assemblage of discarded tested pieces, primary stage debitage with significant numbers of cortical flakes and perhaps a few expedient tools (Binford & O'Connell 1984; Kolen *et al.*, 1999). This fits the general character of the Naarder Eng quartzite assemblage and its geospatial context. This kind of spatial separation of core or roughout production at the quarry site and next transport and actual further reduction elsewhere has been documented in several ethnographic situations, *e.g.* by Binford & O'Connell (1984) in Australia and Pétrequin & Pétrequin (1990) in New Guinea.

At our present knowledge, there is only one convincing Middle Palaeolithic lithic raw material procurement site in the Netherlands, Sint Geertruid-Henkeput (Kolen *et al.*, 1999), which is located at the southernmost tip of the country in the karst and loess landscape of Southern Limburg. Furthermore, there is only one Middle Palaeolithic quarrying site in North-western Europe showing a specialization in the procurement and working of quartzite: Reutersruh near Ziegenhain, Germany (Luttropp & Bosinski 1971).

A quartzite Neolithic axe find and its implications

During a visit to the Naarder Eng with Jan Kolen and Ronald Frank in April 2010 aimed at collecting ventifacts, the top of a broken quartzite Neolithic polished axe was found (Figure 3). As far as I know this polished axe is the only typologically unambiguous quartzite artefact found at the Naarder Eng. The axe was found at RD coordinates 143710/479570 (52.3040° N, 5.2215° E), within a few hundred meters of the "Palaeolithic" quartzite site (Figure 1).

The axe top measures 6.1 cm long with a maximum width of 5.45 cm and a maximum thickness of 2.9 cm. The width is 4.85 cm at the start of the cutting edge. It is oval in cross-section but with a flat facet at the sides. In the typology of Brandt (1967) it is either a *Fels-Ovalbeile* variety 1 or 2 type B, or a *Fels-Rechteckbeile* group B form 1, placing it typo-chronologically in the Middle Neolithic (i.e. mid-Holocene). It is made of a medium grained brown-grey quartzite. A hinged, long, "lip"-like flaking negative on one side (upper left of figure 3) is typical for a shock-

Figure 3. The Middle Neolithic (mid-Holocene) quartzite polished axe top from the Naarder Eng, found in 2010. Photo: M. Langbroek.

induced break during use. Additional flaking negatives distributed around the edge of the break surface in a regular fashion suggest preparation after this break, perhaps in an attempt to re-haft the remaining top of the axe in an expedient repair effort. Such repairs, while not common, are known from elsewhere in the archaeological record (Karsten Wentink priv. com.) and have for example been published from early Neolithic LBK contexts (Bakels 1987).

The axe find unambiguously shows that quartzite artefacts were used in the immediate area during the Neolithic. A broken, expediently repaired quartzite axe discarded near a quartzite outcrop yielding fresh materials for producing a new one brings up the hypothesis that the nearby quartzite outcrop might have been used as a raw materials procurement site during the Neolithic.

Figure 4. Late Neolithic/early bronze Age flint knife found near the site in 2015. Photo: M. Langbroek.

A worn late Neolithic or early Bronze age flint knife (Figure 4) was found ~150 meters west of the Naarder Eng quartzite site by Jan Kolen in June of 2015, again attesting to (late) Neolithic visits to the site. Walet & Boelsma's (2000) observation that quartz was also worked on the site is interesting, especially in light of the fact that quartz was frequently used as a tempering component in ceramics during the Neolithic and Bronze Age.

Summary and conclusions

In summary, the following is noted:

1. The Naarder Eng site spatially coincides with a spatially restricted outcrop of abundant quartzite erratics with good flaking properties.
2. Raw materials at this outcrop were worked intentionally by people in the (prehistoric) past. This included raw materials testing and the first stage of primary reduction (decortication) and flaking, which explains the apparent "archaic" artefact spectrum of the Naarder Eng assemblage.

Points (1) and (2) combined suggest a raw materials procurement site. Regarding the age of this site, I note that:

3. Ventifacts are among the quartzite erratics used as raw materials. Ventifacts are believed to date to the Last Glacial Maximum, 26,500 to 19,000 years ago, well after the end of the Middle Palaeolithic (~40,000 years ago). The flaked parts of the artefacts do not exhibit the same natural surface modifications as the ventifacts, indicating they are not older material reworked into this horizon by the LGM denudation process. This indicates a date younger than the LGM, excluding a Middle or Lower Paleolithic age.

4. Although technologically archaic in character, the Naarder Eng quartzite assemblage contains no artefacts of an unambiguous Lower or Middle Palaeolithic typology, which supports conclusion (3).
5. A typologically unambiguous Neolithic quartzite artefact (the top of a quartzite polished axe) was found within a few hundred meters of the site, suggesting that the procurement site could have been in use during the Neolithic. Other Neolithic lithic artefacts were found in the vicinity of the site. The reported presence of worked quartz at the site is interesting as quartz was used as tempering in Neolithic and Bronze Age pottery.
6. Lithic raw materials procurement could in principle have taken place at the site from the Late Glacial Maximum onwards, that is from the Late Upper Palaeolithic through the Mesolithic and Neolithic up to historic times. Point (5) suggests it was certainly in use during the Neolithic.

From these observations, I favour an interpretation as a "later prehistoric", probably Holocene raw materials procurement site for the so-called 'Quartzite Paleolithic' site on the Naarder Eng, with a strong suspicion that the site dates to the Neolithic. That does not diminish the importance of this site, which is unique in the Netherlands with its richness in quartzite artefacts. The site therefore deserves renewed research in order to clarify its geological context and archaeological implications.

Acknowledgements

I thank Ben Walet and Auke Boelsma for showing me the site and artefact assemblage in 2002 and for the exchange of ideas during the weeks afterwards. Discussions with Prof. Jan Kolen (Leiden) and Drs Ronald Frank (Hellevoetsluis), who accompanied me during a field visit, are gratefully acknowledged, as are much earlier discussions with Dr Alexander Verpoorte and Prof. Wil Roebroeks (Leiden) in 2002. Sjoerd Kluiving (VU Amsterdam) and an anonymous referee provided helpful comments on the manuscript. Last but not least I warmly thank Henk Kars for the opportunity to join the IGBA as a post-doc in 2008-2012. Part of this research was done while the author was an NWO-Veni postdoc at the former Institute of Geo- and Bioarchaeology, faculty of Earth and Life Sciences, VU University Amsterdam.

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Flooded, flattened and rebuilt archaeological sites

The case of strategic inundations during the Eighty Year's War and how the archaeology developed after reclamation of the landscape

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Introduction

The Dutch resistance against the Spanish army transformed vast coastal areas of the south-west Netherlands into flooded landscapes as part of a military strategy. Over 50,000 hectares of the late medieval landscape remained flooded for more than half a century, while some land would never be reclaimed again. In this flooded area both physical and anthropogenic processes soon began to have an impact on the former medieval landscape. This paper investigates the causes, implementation, extent and consequences that the strategic flooding had for the historical landscape and its archaeological remains, both during and long after the event. Questions remain as to what sort of archaeology may still be present in these formerly flood areas, its location and present condition? Although the focus of this paper is on the flooding events (AD 1568-1648), a comparison is made with other flood events in an attempt to clarify the whereabouts of the archaeological remains.

Background, issues and research method

In the early AD 1580s the majority of the seventeen Dutch provinces united in the Estates-General took the lead in the rebellion of the Low Countries against King Philip II of Spain. After several failures by three former governors appointed by King Philip to suppress the rebellion he again commissioned a new governor. This was the Duke of Parma who demonstrated his authority as new governor of the Low Countries in terms of strategy and politics resulting in the recapture of lost territory. In 1584 he besieged the Flemish towns of Bruges and Ghent and closed in on Antwerp. The Dutch, led by William of Orange and based at Middelburg in

Zeeland, desperately tried to drive off the Spanish from the southern bank of the Western Scheldt aiming to liberate the three towns. They did so by the strategic flooding of polders – previously undertaken in 1573 and 1574 around Alkmaar and Leiden – but now on the southern bank of the Western Scheldt. Experts in dike building and members of water boards were summoned to Middelburg to advise on the best places to breach dikes and sluices.

The experts advised making breaches at Saeftinghe (Weele sluice), Campen (north of Zaamslag) and Nieuw-Othene (now Othene near Terneuzen), which were destroyed in the course of 1584 (Figure 1). As a result, large areas were flooded in Saeftinghe as far south as Hulst and north of Axel and around Sluice. Also the north-western polders of Beveren (near Antwerp) were flooded as far as the east west running higher ground. However, the Dutch did not achieve their ultimate goal of protecting these towns; in that same year, Bruges and Ghent were subdued by the Spanish and in the following year the Dutch also lost Antwerp. The Spanish also held on to Axel until 1586, after which, a new set of inundations forced them to abandon the place. After a twelve-year truce (AD 1609-1621) hostilities resumed with new large-scale flooding in the area of Sluice and Oostburg (Figure 2).

Most of these flooded lands remained under water for over half a century and in some cases longer. The majority was only reclaimed gradually, again after the peace treaty of Munster was concluded in 1648 ending the Eighty Years' War. However, some areas such as Saeftinghe are still under the influence of the tides (De Kraker and Bauwens, 2000).

Historical geography is by far the most important research discipline used for investigating flooded landscapes (Wikaart *et al,*. 2009). Historical correspondence between stakeholders in the flooded area, for instance monasteries, chapters, feudal lords, water boards and towns, inform us about why, where and when dike breaches were made. Dike records, manorial records and historical maps provide additional information about dikes breached, the type of land flooded and the extent of flooding. The same documentary evidence provides information about what happened to the flooded area afterwards. Oral histories, which question farmers about anomalies in their land in terms of debris, archaeological remains and specific old infrastructure, such as old dikes and winding sand roads, field patterns, moated sites, also provides vital information about past settlements and buried infrastructure. Geological and palaeogeographical maps provide information about sediment erosion and deposition within the buried landscape (Van den Biggelaar *et al.*, 2014). Aerial photography can augment knowledge by identifying anomalies in soils, appearing as crop marks in mainly the summer months.. Further information can be obtained by the analysis of Digital Elevation Models and by archaeological surveying and trial trenching (Trimpe Burger, 1967; De Kraker, 2004; De Kraker and Aalbersberg, 2005; Gardiner and Hartwell, 2006).

The landscape of the research area

The present Western Scheldt is an estuary, which is, 4.8 km wide at its mouth (Breskens-Flushing) and becomes funnel-like inland; it has a tidal amplitude of 4.5 to 5.0 m on average and 5.0 to 6.0 m at spring tide. Given this tidal range, dikes to the east were built higher. The soil composition of the area predominantlycomprises

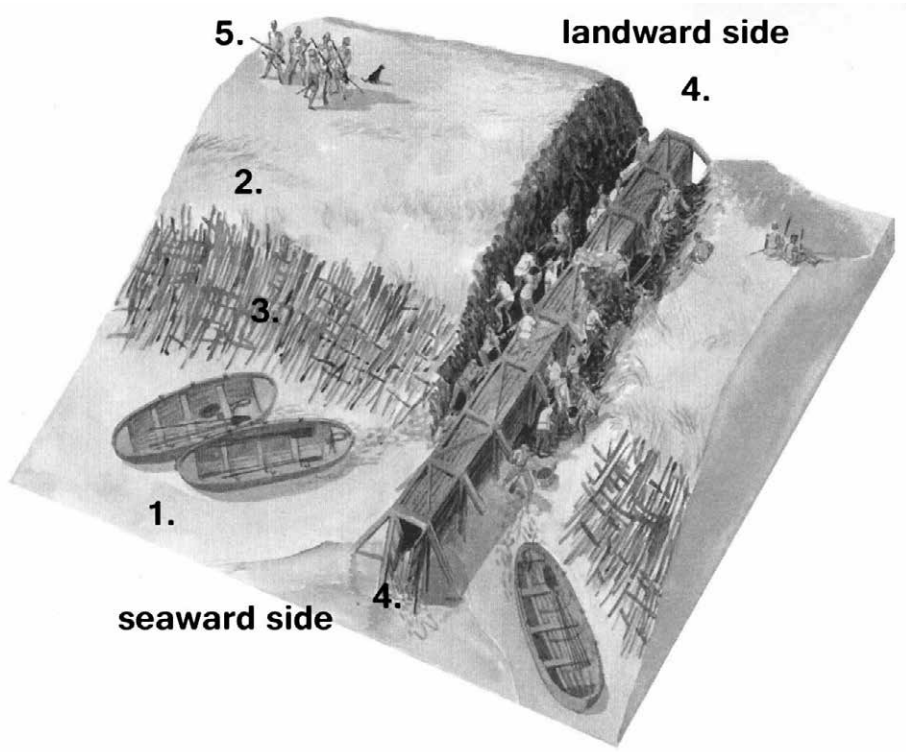

Figure 1. Cross-section of a breached dike. 1) Seaward side of the dike, 2) Dike with clay sods, 3) Extra protection of straw mats or wicker 4) Workers destroying a sluice and widening the gap, 5) Soldiers protecting the workers (model Saeftinghe Center).

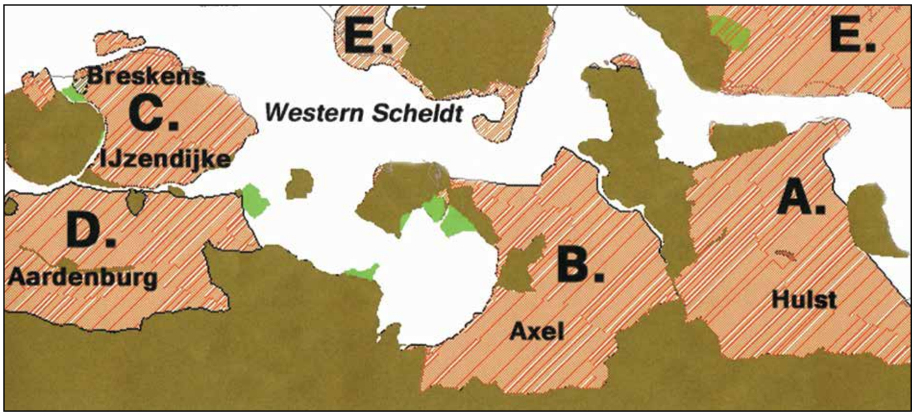

Figure 2. Extent of the strategic flooding in northern Flanders, now Zeeuws-Vlaanderen, between 1584 and 1621.

clays overlying peats, though clay is also found in recent deep tidal channels. Peatbogs in the south of the area lay higher and reached a height of 2 to 4 m. Close to the estuary, clay was deposited on top of peat, reaching an altitude of up to 1 m above average sea level. Between AD 1100 and 1500, most of the peat exposed at the surface had been cut for fuel and making salt, which resulted in a drop of 2 to

Figure 3. Example of a present clay landscape which did not erode during the strategic inundation. The position of soil layers is: on top post strategic inundation clay layer, below medieval clay layer, below (black) peat layer with remains of trees. (photograph by author, 2005).

4 m in surface elevation. In contrast, the peat lying underneath the clay remained mostly intact, but because of drainage it compacted, and therefore the surface level in these peat-clay areas also dropped (De Kraker, 2007; Soens, 2013)(Figure 3).

Most of the areas which were flooded were used for farming. The clay areas in particular were used for arable crops because of their high nutrient content. South of the clay area the peatbogs were completely cut, for fuel, but also for salt making (Leenders, 2007; De Kraker, 2007). Before the period of dike building the peatbogs had been flooded regularly or had come into contact with saline waters via the groundwater table. Northern Flanders in particular developed into an area of salt making, around towns such as Biervliet, Axel, Hulst, Oostburg and Sluice. In the course of the 15th century the declining number of local peatbogs resulted in a drastic reduction in salt making.

Flooding and consequences for the landscape

Although flooding at most locations occurred in the summer of 1584 and in July 1586, waters did not run as high then as they do during winter springtides and therefore, repairs could have easily been undertaken. But this did not happen because of the imminent danger of soldiers and war ships patrolling along the Western Scheldt. Therefore, no labourers could be hired and no building materials could be bought in to undertake the repairs. Meanwhile, each incoming and outgoing tide made breaches wider and deeper. Whilst the area was mostly inhabited by farmers they abandoned their farms and witnessed their harvests being destroyed by the rising waters. Fleeing over the higher inland dikes with their families and livestock, most returned at low tide to gather their valuables from barns and houses, until all

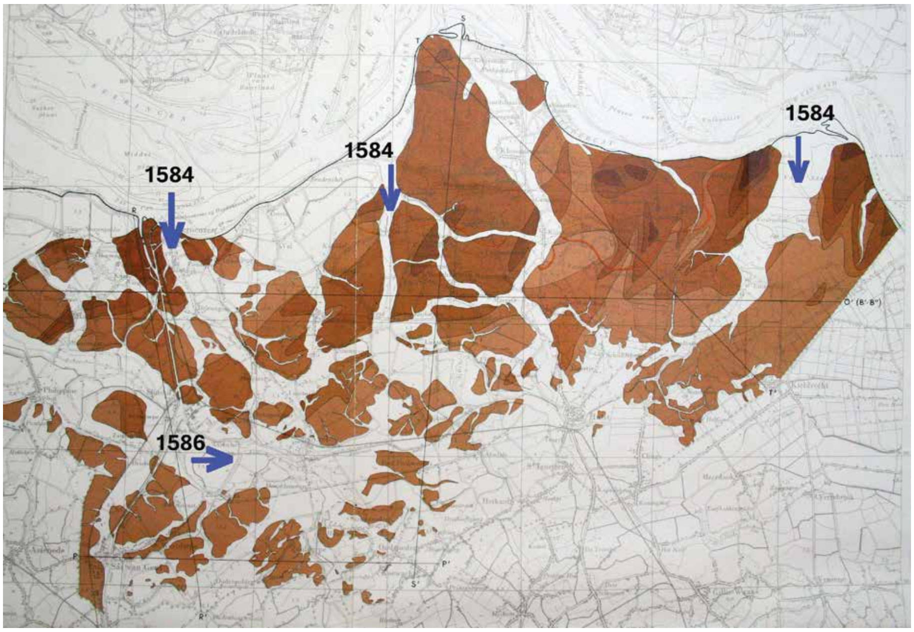

Figure 4. Presence of peat layer with freshly deposited clay above. Arrows indicate places of dike breaches with strong erosion has occurred and newly formed tidal channels developed (after Van Rummelen, 1977).

were emptied. Buildings remained standing in the flood waters, including entire villages with churches, towers and in some places even castles. Tall trees also stood in the flooded landscape and as a consequence, gradually dying.

The daily incoming and outgoing tides had a profound impact on the landscape (Figure 4). At the dike breaches completely new tidal channels were formed. One such new tidal channel was the Saeftingher Gat, another the Hellegat and a third the Otheense Kreek, while the breach west of Axel formed the Axelse Kreek. Within a decade these new tidal channels formed new shipping routes. In 1595 the town of Hulst decided to make both the Saeftingher Gat and the Hellegat safe for navigation by installing beacons.[a] It took twice as long before the new tidal channel south of Axel could be fully used for navigation. This new west-east running route was made safe for navigation as of 1615 by the installation of 104 beacons.[b]

The Saeftingher Gat at its deepest point eroded the underlying geological sediments to a depth of -15 m NOD (Van Rummelen, 1977) and was 2.5 km wide at the place of the initial breach. The breach with a width of more than 3 km forming the Axelse Kreek near Axel incised into the underlying geological sediments to a depth of -19 m NOD (Van Rummelen, 1977). Whereever water reached, it searched for the lowest lying places in the landscape – the existing ditches and drainage canals to the many small sluices in secondary dikes and sea walls. Vast low lying areas were the former peatbogs where long-term peat cutting had been undertaken. Most of these areas were located east and south of Hulst and south of Axel.

A number of high springtides and strong gales occurring during the following years pushed the incoming tides further inland, threatening the towns of Hulst and Axel. Between 1588 and 1613 high waters pushed twice into the town of

Hulst, which at an early stage decided to fully close-off its gate to the eastern side of the town. Erosion also affected some small settlements in the flooded area. The commander at Axel was concerned about water threatening the flooded ruins of the village of Beoostenblije through a newly formed small tidal channel.[c]

As well as erosion, deposition also occurred in the flooded landscape. As the breaches made as a consequence of military decision-making are well documented, they can be dated and precisely located on geological maps, and in turn the stratigraphy of the peat layers can be determined. Everywhere where remnants of those peat layers are still present in the subsoil the process of new clay deposition on top of them must have protected them. So the waters coming through the breaches made in 1584-1586 and 1621 must in some places have allowed quiescence and hence clay deposition to occur. In some places it took several decades before enough new clay had been deposited to make it profitable enough to re-embank an area. In other places, it took centuries before the larger tidal channels could fill up again. The present geological map combined with the digital elevation model clearly distinguishes all recently infilled tidal channels made during the Eighty Year's War lying 0.5 to 1.0 m higher than the lands which were re-embanked soon after flooding and 1.0 to 1.50 m higher than areas which were not flooded at all. Still remnants of the inundations are visible in the present landscape such as the Vlaamsche Kreek (breach 1584), Otheense Kreek (breach 1584) and the Axelse Kreek (breach 1586).

Flooding and the archaeology

When sea water enters an embanked area, it flows towards and along the lowest lying trajectories. Such trajectories include ditches, small canals, but also the extant creeks dating from the period prior to embankment. Because the polder area discussed here was one big mosaic of polders, each still having its own dike, water also started to batter against the secondary dikes penetrating the hinterland through freshly made gaps or along lower routes where roads connect polders or where there were culverts or small sluices. Before looking into the question of what happened to the archaeology in the flooded areas, we should outline what kind of archaeology might be expected there.

The most important settlements in the flooded area were villages. Most villages were small and looked more like hamlets. Their size ranged from fifteen to thirty houses, while the bigger villages might contain over fifty houses. Records of the number of hearths per parish from 1467 are misleading, because they also include all hearths outside the settlements, such as from all the surrounding farms. Most houses were built of wood, a few of stone, both nearly always having thatched roofs. Churches were brick buildings with slate roofs, while the floor tiles and window sections could be made of carved stone. Some churches were built of stone quarried at Tournai (Belgium). Churches also had glass windows, sometimes one or two with small sections of stained glass. Most churches had a bell tower. Around the church was the cemetery, which was fenced off with a brick wall and gate. Some villages had chapels (Zaamslag, Beoostenblije). Most villages had one or two windmills standing on higher ground. Village streets were usually simply made of sand with only the biggest ones comprising paved sections, and these were mostly near the church (SAG, K&Pl. no 2647).

Outside the settlements, many farms were spread out, mostly alongside roads. Farms consisted of a house, a barn and some small buildings, such as ovens and stables. The bigger farms were surrounded by moats, with orchards in the farmyard and small fenced-off pastures. Around the farmyard there were usually rows of trees. Generally, farm buildings were made of wood, with stone houses only occurring on the biggest moated sites.

In the flooded area some huge stone or brick buildings also existed. Around Axel and Zaamslag there were four castles, one monastery, one hospital and some moated sites, one of which was once exploited by the Knights Templar. Most of the castles developed as a motte castle of which the tower was replaced by stone or brick buildings with two or more stone towers. A bridge and gate building gave access to the moated sites on which usually several other buildings stood, such as stables (for both horses and other livestock), a falcon house, ovens, an ice cellar and sometimes even a chapel (Axel). If a castle yard was big enough, some included orchards, vineyards and pasture.

However, all that people could carry away from the flooded area was gone within a year or even sooner. So what happened to the remaining archaeology? A further systematic stripping of the area started, usually quite organized and in the area under discussion this was orchestrated by the Estates of Zeeland. On 13 February 1587 Commander Marinus Kempe was given an order to collect all useful building material from the flooded area, in particular from the churches of Saeftinghe and Zaamslag, the buildings of the Boudelo Abbey and the buildings of the Knights Templar at Zaamslag. The material had to be carried to locations controlled by Zeeland and used to build fortresses and protestant churches.[d] At Axel, the local commander wished to take down the church building of the flooded village of Beoostenblije for the building of a new fortress. On 6th August 1588 the Estates of Zeeland ordered the church of Axel and its town hall to be demolished and all the materials re-used elsewhere. The church bells and its clock had to be disassembled with great care and taken to Zeeland.[e] Some castles were changed into earthen fortresses, others were completely demolished. Even big tombstones were salvaged and taken.

This period of salvage activity represents the legalized and systematic demolition of a cultural landscape and its archaeology. A lot of the building materials were re-used elsewhere in buildings. In places where flooded lands were re-embanked quickly, much material was re-used in the construction of new farms. On those new farms, the foundations of wooden barns were medieval brick and the new farmhouses also contained a lot of medieval building materials. Large stones such as tombstones could be re-used as foundations in buildings too, but also in sluices which had to have solid foundations (Figure 5). What was left behind were the remains of many wooden poles still sticking deep into the ground; some could be very small and still show the fenced-off space of some pasture or orchard. Examples of these remains can still be found in the mudflats of the Western Scheldt (Rilland-Bath). Roads and ditches, including these of moated sites, can still be detected as crop marks in the landscape, only visible under favourable conditions. Of the demolished (stripped) settlements the basal layers of the brick foundations are still

Figure 5. Trial trench at Poonhaven in 1980. This excavation was carried out to find the church of the flooded village of Aendijcke (1584). The thick and wide walls were stripped down to the broken brick material stuck in mortar at 1.70 m below the surface level of the fields (photograph by the author).

Figure 6. Aerial Photograph of the same location of former Aendijcke with crop marks of the site of the church (photograph by author, 11 July 2011).

there along with the graves in the former churchyard. Pits of waste material and wells can still be found. Some intensively inhabited sites still show an abundance of pottery sherds and scattered brick remains. There could still be culverts present at locations where small canals run underneath roads and dikes.

Results and discussion

The combined effort of research disciplines such as history, historical geography, physical geography, archaeology and aerial photography has led to the reconstruction of the late medieval landscape, its settlements and its main infrastructure (Figure 6). The dating of tidal channels and distinction between areas of erosion and deposition have helped to identify places that are archaeologically important. Using the documentary sources, such as perambulatory registers in which all plots in a polder along with their size, ownership, user and neighbouring plots are recorded, has helped to show how the land was used and where farms were located with specific information about some large, single farms (moated sites). Tax registers have proved to be useful in reconstructing the settlements in terms of their size, structure and morphology.

Concerning the archaeological remains in the flooded area, the following can be said. In places where new tidal channels have caused significant erosion, nearly all archaeological remains have been lost. In places with an underlying peat layer and thick new clay deposits overtop, archaeological remains are still present. Flood events occurring during storm surges usually have devastating effects. Because huge waves enter polder areas very fast, buildings collapse and walls fall down. In areas where strategic flooding occurred, floodwaters usually entered into the polder areas gradually, and were therefore less destructive to buildings initially. But as the floodwaters were active for many decades, a systematic stripping of all building materials took place. Of wooden structures, only bottom pole remains were left behind and of brick structures, only the bottom part of the foundations were left behind consisting of debris in mortar supported by wood structures, sometimes reaching onto the Pleistocene sands. Buildings remaining untouched in the flooded area were exceptions to the rule. Such buildings were towers of castles or churches, which functioned as beacons or light houses in the area. The tower of the Zaamslag castle survived until as late as the 1690s. The church tower of the flooded village of Namen (1715) collapsed a few decades later; most of its building materials such as bricks were re-used to re-enforce the coastal defence at Walsoorden.

What happened to the stripped building material? Most of it was taken elsewhere to be reused again in the building of earthen bastions: Axel, Terneuzen and Flushing. Some leftovers were reused when the area was re-embanked. Of two castles, one was demolished at Zevenbergen in the 1740s and a second was demolished at Liesvelt shortly afterwards; most of the material was shipped to Walsoorden to be reused for re-enforcing the seawalls (De Kraker and Bauwens, 2000). These examples show that not only post-Roman buildings were built of re-used materials, but re-use of building material seems to be a re-occurring feature of landscape history.

Conclusion and outlook

Research on flooded landscapes as one type of disaster landscapes has shown interdisciplinary research to be vital to success. In flooded landscapes settlements and other structures change or simply vanish. Disappearance occurs at places of strong erosion, in particular where water enters a polder area. A much slower change occurs where gradual decay of remains sets in and where a systematic demolition during the first decade is followed by slow fine-grained deposition, eventually leading to burial by new (clay) sediments. In the case of the flooded areas of northern Flanders on the southern bank of the Western Scheldt, there was a well-organized stripping of all useful building material to be re-used for the benefit of Zeeland. Furthermore, roads, ditches and dikes were either covered, infilled, or strongly eroded. In some places culverts and remains of small sluices must still be present below the freshly deposited clay layers. Looking at the present landscape, most flooded remains not threatened are deeply buried and 'naturally' preserved. Threatened remains occur near towns, at places of road building and through the erosion of mudflats in the Western Scheldt. Future research should therefore focus on locating old sites and mapping them by using selective types of geoprospection such as ground penetrating radar, enabling us to evaluate threatened locations.

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Endnotes

[a] Gemeentearchief Hulst, town account. 1595/96, fol. 49vo-50vo.

[b] Gemeentearchief Hulst, town account. 1615/16, fol. 51ro.

[c] Zeeuws Archief Staten van Zeeland, 1208-I, letter 11 August 1593 written from Axel by Jan Piron to Gecommitteerde Raden of Zeeland.

[d] Zeeland Archives, Estates of Zeeland, no 1625, fol. 44verso, minute of 13 February 1587.

[e] Zeeland Archives, Estates of Zeeland, no 1625, fol. 255ro-vo; fol., 260vo (11 August 1588).

Many shades of brown

The condition and colour of Dutch archaeological textiles from dryland sandy soils, bogs, and the sea

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Abstract

Archaeological textiles excavated from Dutch soils usually have a brown appearance. Three sets of woollen textile finds varying both in age and burial context were analysed to study their original character. Bog finds from the Bronze Age (2000-800 BC) and late Iron Age (250-12 BC) were compared to pieces of fabric from the sandy soil of a large Early Medieval cemetery at Rhenen and a piece of cloth from a 17th century shipwreck found in the sea near Texel. The colour of the fibres was studied by naked eye and Dynolite microscope. Subsequently, the colourants were investigated using ultra-high performance liquid chromatography coupled to a photodiode array detector (UHPLC-PDA). The condition of the fibres and the possible use of a mordant were analysed by scanning electron microscopy coupled to an energy dispersive X-ray detector (SEM-EDX). Many of the fibres were degraded, brittle and stained. Fibres from samples from Rhenen showed severe damage most probably by bacteria and/or fungi. The analysed bog finds from the Bronze Age and late Iron Age are most probably not dyed. Whilst several of the Rhenen samples are most probably not dyed, some of them contain yellow dyestuffs possibly from local plants and one piece of fabric could have been dyed red with madder. A piece of cloth attached to a lead seal from a shipwreck was dyed purple with a mixture of madder and indigo or woad. In general, it seems that the majority of the prehistoric Dutch archaeological textiles are not dyed. However, we know from an extensive study into Hallstatt textiles that at least three quarters of that material was coloured. Therefore, the degradation of dyed materials from a variety of depositional contexts within the Netherlands should be studied further, as well as the local plants used in dyeing.

Introduction

Within certain archaeological environments textiles tend to degrade relatively easily (Huisman *et al.*, 2009). In The Netherlands, finds of prehistoric textile seem to be rare and when they are found they have a brown or brown-grey appearance that barely distinguishes them from their surroundings. Textiles will, in most cases, become brownish in the soil due to acidic conditions combined with hydrolysis (Huisman *et al.*, 2009). Previous research on textiles from the prehistoric salt mine of Hallstatt with excellent burial conditions for both the preservation of the material and the colour, showed that from the Bronze Age onwards, fibres have been dyed using complex techniques, for example, vat and mordant dyeing (Hofmann-de Keijzer *et al.*, 2013). Relatively little is known of the colour of prehistoric archaeological textiles found in the Netherlands since only a few analyses of dyestuff are published (Schlabow 1974; Van Haaster *et al.*, 2002; Zimmermann 2007; Joosten & van Bommel 2012). Recently, three sets of woollen textile finds varying both in age and burial context were analysed to study their original appearance. This article collates the results of these analyses, which allows a consideration of the influence of the burial context on the present character and condition of the textiles.

(Pre)historic textiles from sandy soils, bogs, and the sea

The oldest Dutch samples date from the Late Bronze Age/Early Iron Age and comprise two balls of wool and fragments of textile from the bogs of Smilde, Roswinkelerveen (Figures 1 and 2) and Emmererfscheiderveen (Van de Sanden *et al.*, 1996; Vons-Comis 1996; Van Vilsteren 2006; Fig. 1). They were found in the high moor peat during peat-cutting in the Dutch province of Drenthe. The water-saturated acid peat environment preserved the textiles well. They have a light and dark brown appearance, but no signs of their original colour (Table 1). The brown colour is due to the effect of the acid from the bog on the textile (Huisman *et al.*, 2009). The yarn of the ball of wool from Smilde is Z-spun and the wool is relatively coarse (Table 1). The second ball of wool was discovered in the Bourtangermoor, near Roswinkel (Roswinkelerveen). It was long assumed to be associated with amber beads and fragments of a horn comb, woollen fabric (a belt), a leather strap and a Bronze palstave. However, the ball of wool was found 350 meters from the other finds and was radiocarbon dated to the Early Iron Age, while the textile fragment dates to the Middle Bronze Age. The woollen yarn of the ball is S-spun and the wool is relatively fine (Table 1). In the bog of Emmererfscheiderveen, a male bog body with several pieces of textile and fur were found. The body dates from the 2nd half of the Bronze Age (13th century BC) and is the oldest one found in the Netherlands (Van der Sanden 1996). One of the five pieces of woven and braided textile from a woollen undercloth was sampled. The yarns are S-twisted and the wool is relatively fine. The fibres have very little natural pigment and must have been light coloured. The fabric now has a brown hue (Vons-Comis 1996). Following excavation the finds were put on display in the Drents Museum, though it is only since 2010 that the conditions of the display environment have been controlled.

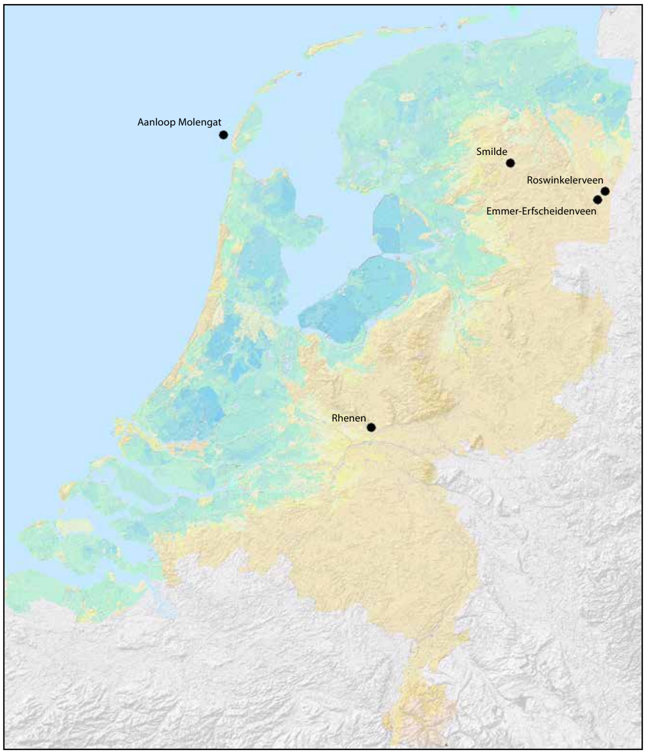

Figure 1. Map of the Netherlands with the locations where the textiles were excavated (M. Kosian, RCE).

Figure 2. Ball of wool from Roswinkelerveen (1924/X7-12, photo V. van Vilsteren).

Object	**Object code**	**Origin**	**Date**	**Colour**	**Soil**	**Thickness of Thread**	**Burial conditions**	**Excavation date**	**Storage**
Ball of wool	1907/XI 3	Smilde	Late Bronze Age	Lightbrown	High moore peat	20-40µm, 65, 80 and 100µm	Waterlogged/acid	1907	Climatised since 2010
Ball of wool	1924/X7-12	Roswinkelerveen (part of the Bourtangermoore)	Early Iron Age	Darkbrown	High moore peat	12-20µm	Waterlogged/acid	1924	idem
Plantmaterial from the bog	1924/X7-12 plant	Roswinkelerveen (part of the Bourtangermoore)		lightbrown	High moore peat		Waterlogged/acid		idem
Belt	1924.X.10	Roswinklerveen (350 m from the ball of wool)	Middle bronze Age	Lightbrown and dark brown	High moore peat		Waterlogged/acid	1924	idem
Fragment of textile	fragment C	Emmer-erfscheiderveen	Middle Bronze Age	Dark brown	High moore peat	12-20µm	Waterlogged/acid	1938	idem
Fibres	Rh218Bw	Cemetery	Early Medieval	darkbrown	Coarse sand		Oxygenated	1951	Climatised since 2005 at RH 50%, T18-20°C
Fabric	Rh775T	Cemetery	Early Medieval	black	Coarse sand		Oxygenated	1951	idem
Fabric	Rh666W	Cemetery	Early Medieval	black	Coarse sand		Oxygenated (partly) mineralised by Fe	1951	idem
Fabric	Rh669F	Cemetery	Early Medieval	Rusty brown	Coarse sand		Oxygenated	1951	idem
Fabric	Rh-828-Bw	Cemetery	Early Medieval	black	Coarse sand		Oxygenated	1951	idem
Fabric	Rh-844-W	Cemetery	Early Medieval	Black and darkbrown	Coarse sand		Oxygenated	1951	idem
Fabric	AM-1993-65-5	Gully Molengat near Texel	1630 AD	Brown and grey	marine		Oxygenated, (partly) mineralised by Pb	1984	Up to 1998 T: 15◦, RV 45. From 1998 onwards, not climatised

Table 1. Summary of samples which were analysed by UPLC and SEM-EDX. All samples consist of wool fibres.

Figure 3. Two pieces of Rhenen textile (photo M. Svenson).

The large early medieval (AD 375-750) cemetery of Rhenen (Province of Utrecht) excavated through (dryland) coversands on the west flank of an ice-pushed ridge surprisingly yielded several small pieces of textile (Brandenburgh *et al.*, 2012, Figs. 1 and 3). Part of the textile finds were mineralized, reflecting iron and copper corrosion associated with metal objects such as knives and clasps found close to the fabric. After excavation they were stored in cardboard boxes and kept in uncontrolled climatic conditions. From 2000 onwards they were moved to a storage room for organic material at the National Museum of Antiquities (RMO) to be kept under climatically controlled conditions (Temperature (T)=18-20°C, Relative Humidity (RH)=50%). In their present state, they have a rusty brown, dark brown or black appearance and show no sign of colour. Eight pieces from six different graves dating to the historic period (AD) were selected for analysis.

Finally, a small fragment of woollen cloth from a lead cloth seal from a shipwreck of AD 1630 in the gully Molengat near Texel was also analysed (Maarleveld & Overmeer, 2012, Fig. 1). The freight ship carried among other cargoes, bars of lead and iron, packs of cattle hides and woollen cloth. Part of the one hundred lead cloth seals that were found provides evidence that the woollen cloth originated from Leiden, Delft and Hondschoote. Eagle marks of the Leiden cloth point to different qualities of blue woad dye as a basis for black (one eagle), light violet (split eagle) or deep violet (double eagle). A stamp of a split eagle on two of the seals showed that this cloth must have been dyed with woad (Maarleveld & Overmeer, 2012, Fig. 32). However, the lead with the grey piece of textile did not have a stamp so its original colour is unknown and no primary colour is still visible. After excavation, the textile fragment was kept in a climatised storage room in Alphen aan den Rijn

(T= 15ºC, RH= 45%). In 1998 the finds were moved to the National storage building for Ship Archaeology in Lelystad, but they are not kept in a climatically controlled environment.

Analytical methods

Firstly, the colour of the fibres was studied macro- and microscopically using a Dynolite microscope at a magnification of 37 times. Fibres and chemical elements were analysed prior to dye analysis by scanning electron microscopy with energy-dispersive X-ray analysis (SEM-EDX, JSM5910LV). Analyses were performed with an accelerating voltage of 20 keV and in low vacuum (30 Pascal). SEM was also used to examine the contamination and condition of the fibres. On clean areas of the fibres, the presence of inorganic elements was investigated by EDX (Silicon Drift Detector with NSS software from ThermoFisher Scientific). In terms of elemental analysis, we focused on aluminium (Al), copper (Cu) and iron (Fe) because they could originate from mordent and/or from the soil, and copper and iron also have a colour-modifying effect on the textiles. However, although clean areas of the fibres were analysed, they could still be contaminated by elements from the soil. The samples were analysed using ultra high-performance liquid chromatography coupled with photo diode array detection (UHPLC-PDA), following the procedure published by Serrano *et al.* (2013). A detailed description of the methods used to analyse the fibres, elements and dyes is provided by Hofmann-de Keijzer *et al.* (2013), Serrano *et al.* (2013), Joosten & Van Bommel (2008) and Joosten *et al.* (2006).

Brittle, eaten and dyed?

The condition of the wool fibres was classified according to a system developed within the Hallstatt project (Hofmann-de Keijzer *et al.*, 2013)

Textile samples from bog environment

Five of the investigated samples came from a bog environment. The analytical results are presented in Table 2. The ball of wool from Smilde consists of fibres with thicknesses of around 10 and 50µm. The clean fibres are still flexible and the scales typical for wool are clearly visible. In addition to carbon (C), the fibres contained oxygen (O) and sulphur (S) from the wool, and traces of sodium (Na), magnesium (Mg), aluminium (Al), silicium (Si) and calcium (Ca). Plant material from the bog found next to the ball of wool also contained these elements together with chlorine (Cl) and potassium (K). Fibres from the textile fragments are degraded and stained. Those from the belt from Roswinkelerveen are not only degraded and stained, but also brittle and carry evidence of biological decay (Figure 4). They are heavily torn and cracked. It must be noted that the ball of wool from Roswinkel is hardly degraded. The fibres contain in addition to C, O and S typical for wool, traces of Na, Al, Si, Cl. Particles found on the fibres consist of the same elements.

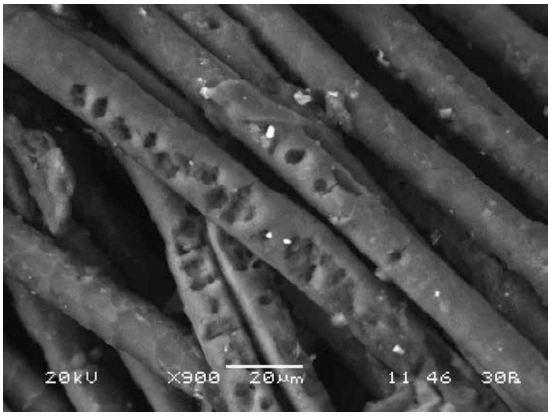

Figure 4. Backscattered electron (BE) image of fibres from the belt of Roswinkel (1924.X.10). Holes in the fibres are clearly visible.

Sample	Condition	Elements	Mordant	Dyestuff	Conclusion
1907/X1 3	Clean, hardly degraded but brittle fibres	Traces of Na, Al, Si and Ca	no	Fibre 1: Unknown yellow component	1: Not dyed or degraded
				Fibre 2: some unknown yellow components and some maclurin equivalents	2: possibly dyed yellow with unknown dye plant
1924/X7-12	Clean, hardly degraded but brittle fibres	Traces of Mg, Al, Si, Ca	no	Unknown yellow component	Not dyed or degraded
1924/X7-12 plant	NA	Traces of Na, Mg, Al, Si, S, Cl, K, Ca	no	Three yellow and some red components	Bog also contains dyestuff, one of them often occurs in textiles
1924.X.10	Degraded, brittle, stained fibres with holes	Traces of Na, Al, Si, Cl	no	Some unknown yellow components some maclurin equivalents	Probably dyed yellow with unknown dyeplant
fragment C	Degraded, brittle, strongly stained fibres	Traces of Na, Al, Si, Cl, Ca,	no	No components	Not dyed or degraded

Table 2. Summary of bog samples analytical results by SEM-EDX and UPLC.

Identification of dyes from bog samples proved to be a difficult task. In most samples unidentified yellow components were found and it is unclear if they originate from the archaeological environment or indicate the presence of a textile dye. It must be noted that bog itself is composed of plant remains, all plants contain natural colouring components which could have contaminated the textiles. In addition, it could be that dyes were degraded during their long preservation in the bog. In the sample taken from the plant remains (1924/X7-17-plant), several colouring components were found of which one was also recorded in the textile samples and is most likely an indication of this contamination. This was the only coloured component found in samples 1907/X13 and 1927/X7-12 (Figure 2) and it is believed that these textiles were either not dyed or that a possible dye had degraded to under the detection limit of the analytical equipment. However, the other yellow components in the textile samples were not found in the plant material from the bog and could therefore indicate the use of a still unknown dye. Also in these samples it must be recognized that the original composition of the dyes could have been different and is now degraded. In two samples, maclurin equivalents were found. These components are present in many plants and can therefore not be used as a specific marker.

Textile samples from the sandy soil environment

The samples found near Rhenen are not only from a different archaeological context, but also from another date. The results of the scientific analyses are presented in Table 3. Both fibres and (partly) mineralized fibres were analysed by SEM-EDX. The mineralized fibres have a rusty brown appearance. The fibres can be identified according to their impressions in corrosion material from metal objects. Most of them show scales typical of wool fibres. Some characteristics point to bast fibres as flax or hemp. The impression of the fibres consists of iron oxide, iron phosphate or a combination of both. The fibres that are not mineralised have a brown or black colour and are very brittle with many tears and cracks visible. The scales are degraded and the fibres are cracked and fibrillated and heavily stained with sand and clay particles and in one case with particles of silver chloride (Figure 5). The silver corrosion could originate from a metal thread or from a silver (inlayed) object. Most of the fibres contain holes or tunnels most probably caused by bacteria or fungi; in addition, many of the fibres are severely altered with a total loss of the cuticle (Figure 6, Wilson *et al.*, 2010). In addition to C, O and S typical for wool, the fibres contain major amounts of Si and Al and traces of phosphor (P), Cl, Ca, Fe and Cu. The high amount of Al is most probably not due to the presence of a mordant, but it may be connected to the microbes or fungi. Iron and copper originate from the soil and the objects in the grave. The presence of iron and copper could have stopped the biological decay of the fibres.

In a number of samples, no dyes were detected at all which means that these were either not coloured or that the dyes originally present have degraded below the detection limits of analytical equipment. In several other samples, unknown yellow and orange red components were found. Since their identity remains unclear, it is not possible to determine the specific plant species used. It could be that the original dyes have degraded and the components detected are degradation products. However, it could also be true that in the early Middle Ages local plants were used for textile dyeing which are unknown to modern researchers.. During the late Middle Ages, the number of plants used for dyeing became more and more restricted and focused on those plants which yield stronger colourants. Furthermore, some historical textiles survived since they embodied certain values and traditions; for exampletextiles and clothing of the upper class were made with expensive stable dyes. As a result, our knowledge about historical dyes does not reflect the reality, of daily life as it is mainly based on valuable textiles while textiles used by the common people did not survive the centuries and hence knowledge regarding them is lost. So it could be that the colourants found in the textiles from Rhenen which could not

Figure 5. BE image of a severely degraded fibre from Rhenen (Rh218 BW).

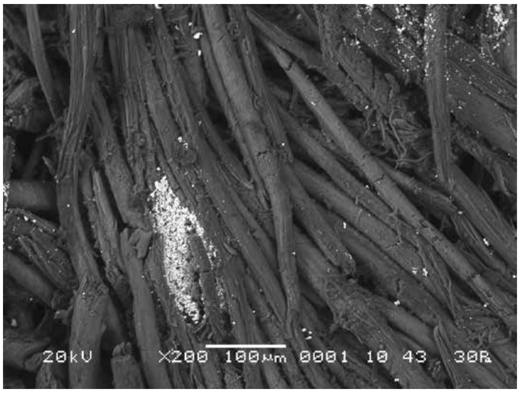

Figure 6. BE image of cracked and fibrillated fibres with holes from Rhenen (Rh775T). Particles of silver chloride are visible (light areas).

be connected to a known plant dye, actually originates from (local) dye plants used by common people. Further research should be focused on plants available locally which could be used for textile dyeing. In one sample (Rh775T), dyestuffs were identified. Purpurin is a red component extracted from the root of Rubiaceae species, like bedstraw species (*Gallium* species) and wild madder (*Rubia peregrina* L.). In addition, the red component indirubin was detected, which is a minor product in indigoid species such as indigo (*Indigofera tinctoria* L.) or woad (*Isatis tinctoria* L.). Based on chemical analysis, it is not possible to discriminate between the two species, however, based on the dating and origin of the textiles sample, woad is most likely. As mentioned before, indirubin is a minor component, the main component of indigo species is the blue component indigotin which was not found at all. Although it cannot be excluded that indigotin was degraded, it is much more likely that the dyeing with woad, which is a complicated process, did not result in a blue colour but in a more reddish one from indirubin. Previous research has indicated that under certain conditions, the ratio between indigotin and indirubin can completely change (Hartl *et al.*, 2015). Whether or not this indicates an unsuccessful dyeing process or that this was deliberately done remains unclear.

Sample	Condition	Elements	Mordant	Dyestuff	Conclusion
Rh218Bw	Degraded and stained fibres with holes	A minor amount of Cu and traces of Al, Si, P, Ca and Fe	?	Unknown or degraded yellow components	Dyed yellow with unknown dyeplant
Rh775T	Strongly degraded, brittle fibres with holes. Ag particles present	Major amounts of Al, S and Ag. Traces of Si, P, Cl, Ca, Fe and Cu	?	Purperine and an unknown red dyestuff	Wild madder and possibly woad
				Indirubin and an unknown yellow component	
Rh666W	Degraded, brittle and stained fibres with holes	Minor amounts of Ca and Cu. Traces of Mg, Al, Si, P, Cl, K, and Fe	?	Yellow dyestuff	Dyed yellow with unknown dyeplant
Rh669F	Mineralized fibres by iron(hydr)oxide	Major amounts of O, P and Fe and traces of Al, Si, Cl, Ca and Cu	?	Unknown or degraded orange-yellow component	Dyed orange yellow with unknown dyeplant
Rh-828-Bw1	Degraded and strongly stained fibres with holes	Major amounts of Al and minor amounts of Si and Cu	?	Unknown yellow dyestuff and an unknown orange-red dyestuff	Dyed orange red with unknown dyeplant
Rh-828-Bw2	Degraded and stained fibres with holes	A major amount of Al and traces of Si, P, Cl, K, Ca, Fe and Cu	?	No dyestuff detected	Not dyed or degraded
Rh-828-BW3	Degraded and stained fibres with holes	High amount of Al, a minor amount of Si and P and traces of Mg, S, Cl, Ca, Fe and Cu	?	No dyestuff detected	Not dyed or degraded
Rh-844-W	Strongly stained fibres with holes	A major amount of Al, and traces of Si, P, Ca, Fe and Cu	?	No dyestuff detected	Not dyed or degraded

Table 3. Summary of analytical results of Rhenen by SEM-EDX and UPLC.

Sample	Condition	Elements	Mordant	Dyestuff	Conclusion
AM-1993-65-5	Degraded and stained fibres	A major amount of Pb and traces of Al and Fe	Al?	Mixture of alizarine and purpurine. Indigotin	Dyed brown or purple (depending on the mordant used) with a mixture of madder and indigo
				Unknown orange-red component	

Table 4. Summary of analytical results of the sample from the shipwreck by SEM-EDX and UPLC.

One textile sample from the marine environment

The sample originates from another time period, the 17th century. The results of the scientific analyses are presented in Table 4.

The fibres of textile fragment from the shipwreck were covered with particles of lead oxide and/or sulphide. The fibres contain in addition to C, O and S typical for wool, traces of Al and Fe. The scales of the fibres are degraded and heavily stained. The sample contained a mixture of alizarin and purpurin pointing to the use of madder (*Rubia tinctorum* L.). In addition, the blue component indigotin originating from true indigo (*Indigofera tinctoria* L.) or woad (*Isatis tinctoria* L.) was identified and an unknown orange-red dyestuff was also found, though the latter could be a degradation product. The textile was dyed with a mixture of madder and indigo or woad and had most probably a purple or brown (primary) colour depending on the mordant that was used. EDX analyses of a fibre indicate that the mordant could have been aluminium or iron.

The colour and condition of the fibre reflects the biography of the textile

The current condition of the fibres is the sum of their ages, the uses of the fabric, the burial conditions and post excavation storage and curation. The study of the Hallstatt textiles showed that conservation and appropriate storage of these finds is vital to maintain their condition at the time of discovery (Morelli, 2005; Joosten *et al.*, 2006). After excavation, the investigated archaeological textiles were kept most of the time under uncontrolled climatic conditions.

The fibres of unused balls of wool are in relatively good condition compared to that of the belt and the textile fragment which shows tears and cracks. The differences in condition between the samples from the bog could be the result of their use in prehistoric times. However, degradation could also be caused by handling the fabric after excavation. The holes in the fibres of the belt from Roswinkelerveen may (possibly) be due to biological activity since they resemble those found in many of the fibres from Rhenen. However, no traces of iron and copper that can stop biological decay were found. The process of decay must have stopped due to changes in the soil burial environment.

The Rhenen material was most probably conserved by the presence of the chemical elements Fe and Cu, which also (partly) mineralized the fibres. The biological decay, seen as holes in the fibres, started most probably soon after burial and stopped due to the presence of iron and copper ions. The fibres are also very degraded and brittle. After excavation they were dried and stored in cardboard boxes in uncontrolled climatic conditions. Most probably, this is why they became brittle. The sand particles on and between the fibres are not reactive but sharp and can cause cracks and tears when the fabric is handled. It must be noted that on the fibres of the piece of fabric that was most probably dyed, red particles of silver chloride were found. This is an indication of the (near) presence of silver metal objects or metal thread. The piece of cloth from the shipwreck was protected from degradation by the lead oxide crust. The brittleness was most probably caused by the drying process after excavation.

The three different sets of material show that age is not the only factor that determines the condition of the fibres, since most the Bronze Age material is in a better condition than the early medieval textiles. If the fabric survives burial in an aggressive environment of biological decay, oxidation and seawater (though wool is said to be less vulnerable to decay in basic conditions under the influence of saltwater, Huisman *et al.*, 2009, 88), post excavation treatment like drying and the storage conditions defines the condition of the textile like brittleness and flexibility.

The situation for the dyes is even more complicated. It is clear that the older the textile, the more difficult it is to identify the dye source. We cannot make a strong connection between the archaeological context and the stability of the dye since it remains unclear if dyes were degraded or that textiles were simply not dyed. In addition, the use of dyes could have changed over the centuries and in particular less is known about the dyes used by common people. Before trends can be established about the stability of dyes from different archaeological origins, many more samples need to be analysed and the degradation patterns should be studied in more detail. It must be kept in mind that although the Dutch archaeological textile remains all look brown when excavated most probably many of them were dyed. Why can this be assumed? In prehistoric salt mines of Hallstatt in Austria dyed textiles survived thanks to the preservative properties of salt and the result of analyses was that three quarters of the textile finds were dyed (Hofmann-de Keijzer *et al.*, 2013). The prehistoric Dutch samples under investigation all originated from a special context, bogs and graves. Possibly, the colour of the fabric was not representative for that of the clothes that were worn daily. Therefore, samples from different contexts should be found and analysed.

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Carbon and nitrogen isotopic variation in bone collagen within the human skeleton

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Abstract

Objectives To study the variation in $\delta^{13}C$ and $\delta^{15}N$ in collagen from a single human femur, and between different bones of the same skeleton, in order to estimate the range of isotopic variation in archaeological isotope studies. *Materials and Methods* Multiple sampling of a single femur, and measurement of 15 different skeletal elements for nine individuals (eight archaeological and one modern). We have also measured the rib-femur spacing on a total of 24 individuals. We plot standardized isotopic scores for the multiple analyses from the same skeleton to make comparison easier between individuals. *Results* Measurements from cross-sections at various positions along the mid-shaft from a single femur gives a range of 0.30‰ in $\delta^{13}C$ and 0.26‰ in $\delta^{15}N$. There is measurable variation between different bones of the same skeleton, ranging between 0.17‰ and 1.10‰ for $\delta^{13}C$ and 0.24‰ to 1.17‰ for $\delta^{15}N$ for the skeletal elements most often sampled for archaeological work.

Discussion There is sufficient variation within a single femur to suggest that the choice of sampling position is important, with implications for the use of a subdivided femur as an international standard for isotopic measurements. Within a single skeleton there is generally a positive correlation between the $\delta^{13}C$ and $\delta^{15}N$ values, but one individual shows a negative correlation. We suggest that measuring a wider range of skeletal elements on the same individual, and plotting them as standardized isotopic scores, potentially gives considerably more insight into individual life histories than rib-femur spacing.

Introduction

Both archaeological and forensic science now make extensive use of isotopic measurements on bone collagen to make inferences about dietary sources, nutrition and mobility. In particular, because of the need to estimate the proportion of marine protein in the diet (for radiocarbon dating as well as for dietary purposes), there is an increasing tendency towards the application of models such as IsoSource (Phillips & Gregg, 2003) and later variants to predict dietary inputs based on measured values in bone collagen compared to the values determined in the different possible food sources. If there is more variation in the bone collagen measurements within a single bone, or between different elements of the same skeleton, than is commonly percieved, then the outputs of such models may be misleading. Moreover, given the increase in the number of isotopic studies on bone, and the creation of large databases of isotopic values, there is now considerable concern over the comparability of measurements from different labs. This has resulted in the recent publication of an interlaboratory comparison, based on multiple measurements of the same human femur (Pestle *et al.*, 2014). In order to randomize intra-bone variablility (Pestle *et al.*, 2014: 3), this femur was cut into 112 0.75g pieces, and each lab was sent a random selection of five pieces. We suggest below that this might not be an adequate precaution against intra-bone variability.

Apart from some early work by DeNiro and Schoeninger (1983), who measured collagen from seven bones each from three different rabbits raised on a monotonous diet, and also two bones each from 15 mink raised on a monotonous diet, there are very few isotopic studies (animal or human) which have taken multiple bone samples from the same individual. DeNiro and Schoeninger (1983: 202) concluded that there are 'only small variations in the δ^{13}C and δ^{15}N values of different bones of an individual'. They stated that the uncertainties in measurements of δ^{13}C and δ^{15}N from human bone collagen from a single bone 'will lie within about 1‰ of the isotopic ratios that would be obtained from the analysis of a larger sample of bones either from the individual or from other individuals of the same population who ate the same diet" (DeNiro & Schoeninger, 1983: 202). We note, of course, that these data were produced by off-line combustion and cryogenic separation of CO^2 and N^2. More recently, Olsen *et al.* (2014) have reported multiple collagen isotopic measurements on human skeltons. They reported pairs of measurements on a rib from each of six individuals, single measurements from rib, 2nd metacarpal and fibula from each of six individuals , and related ribs and vertebrae pairs from a further eight individuals. Within duplicates of the same rib, they reported maximum differences in δ^{13}C and δ^{15}N of 0.18‰ and 0.55‰ respectively (calculated from their supplementary data table, taking the most extreme values). For rib – 2nd metacarpal, the maximum differences are 0.27‰ (δ^{13}C) and 0.70‰ (δ^{15}N). For rib – fibula, they are 0.31‰ and 0.68‰ respectively. For related rib and veterbrae, the maximum differences are 0.40‰ and 0.83‰. In all cases, the intra- and inter-skeletal values vary by less than the 1‰ value suggested above by DeNiro and Schoeninger (1983), but they are still sufficiently large to perhaps place an important limit on the resolution of archaeological dietary reconstructions and comparisons.

The aim of this paper is to further examine the variation in stable carbon and nitrogen isotope values in a single skeletal element (in our case, a femur), and also in a larger number of different skeletal elements from the same person. The intention is to assess the variabity to be expected in a single bone, and in a single individual, so that realistic estimates can be made about what levels of isotopic differences are significant within and between humans. In part we worked with modern human tissue, which avoids problems of post-mortem diagenesis (Collins *et al.*, 2002; Hedges *et al.*, 2002), but also imposes ethical constraints on what can be known about the individual. However, over the period of this project it was only possible to completely sample one modern cadaver, so we also caried out multiple sampling on nine complete human skeletons from the excavations carried out by Oxford Archaeology at Swinton Unitarian Free Church, Salford, Manchester, UK. The burials dated from 1863 to 1963, with archaeological recovery restricted to pre-1900. Given the relatively short period of burial, we felt that these skeletons offered us the best chance of carrying out extensive sampling on relatively undaltered bone material, allowing us to compare these data with modern.

Materials and Methods

Modern samples

Modern samples were taken at the anatomy suite of the Department of Physiology, Anatomy and Genetics, University of Oxford. A 79-year old male with identification number "HO86, male" had given prior consent for his remains to be used for scientific research after death. The body was frozen as soon as possible after death and stored at -17° C. The cadaver was defrosted for two days before samples were taken. A scalpel was used to make incisions to expose the bone, after which a slice of the bone was cut using different types of handsaws. All samples were frozen again immediately after sampling, and approximately one month later transported to the containment laboratory in the Research Laboratory for Archaeology and the History of Art, University of Oxford for preparation. After defleshing, no observable pathologies were present. As many as possible of the larger bones from the left side of the body were sampled within the time available, and five rib samples from each side. The L- and R-specimens represent the left and right ribs respectively, with the numbers indicating which rib was sampled. The skeletal elements analyzed are listed in Table 1.

The samples were defrosted before defleshing. As much as possible of the residual tissue attached to the bone was carefully cut off before starting the defatting process. For defatting, the specimens were soaked in a solution of 2:1 $MeOH:CHCl^3$ (2:1 methanol: chloroform), after which they were placed in an ultrasonic bath for 30 minutes, and left overnight. The next day the samples were removed from the solution with tweezers and were soaked again in a fresh solution, followed by ultrasonicating and leaving overnight. The whole process took one to two weeks, depending on the size of the specimen and the amount of tissue left attached to it. Once no fat was left in the solution, the specimens were rinsed three times with 50 ml deionized water, again ultrasonicating for 30 minutes each time.

B 2	Fibula (left,mid-shaft)
B 3	Tibia (left, mid-shaft)
B 4	Femur (left, mid-shaft)
B 5	Ilium (left)
B 6	Vertebra L4 (left half)
B 8	Clavicle (left, medial)
B 9	Clavicle (right, medial)
B 10	Radius (left, mid-shaft)
B 11	Ulna (left, mid-shaft)
B 12	Humerus (left, mid-shaft)
B 13	Scapula (left)
B 15	Frontal (left)
B 16	Occipital (left)
Ribs:	
R R1	R L1
R R2	R L2
R R3	R L3
R R9	R L8
R R12	R L12

Table 1. Samples taken from cadaver HO86.

The bone fragments were roughly crushed (1-5 mm particle size) in a percussion mortar (repeatedly if necessary) before starting demineralization. For those bones that had a component of cancellous bone, these parts were avoided by removing the cortical component using a small circular saw attached to an electric hand drill at the lowest speed, in order to avoid generating heat. For the ribs, however, this was not possible, because the size of the specimens was small, so the cancellous bone on the interior part of the ribs was not removed (this differs from the work recently reported by Olsen *et al.* (2014), who were able to separate cortical from trabecular bone in their rib samples). All bone samples were superficially cleaned using an air abrasive system with 5 μm aluminium oxide powder before crushing. The weighed crushed bone was placed in a test tube and 10 ml cold 0.5 M HCl was added and left in the refrigerator for 48 hours, covered with tin foil. During this time all the tubes were shaken once or twice daily. The acid was changed every two days, and this procedure was repeated three times. Afterwards all samples were rinsed three times using distilled water.

The resulting collagen pellet was then gelatinized by heating in about 10 ml pH 3.0 water at 75 ^{0}C for 48 hours. Every tube was covered with a plastic lid to prevent the sample from drying out. The supernatant liquor was then filtered using Eezee^{TM} filters and decanted in pre-weighed Nalgene^{TM} tubes with a temporary Parafilm^{TM} cover. This solution was frozen overnight. The next day the Parafilm^{TM} covers were perforated and then tubes were frozen in a liquid nitrogen bath before lyophilisation. After 72 hours, the tubes were taken out of the freeze dryer. After removal of the Parafilm^{TM} cover, the tubes were weighed so that the collagen yields could be calculated.

Figure 1. Sampling points of Femur B.

A further sample of a modern left femur (Femur B) was also provided by the Department of Physiology, Anatomy and Genetics, which was used to test the variability of the isotopic values obtained from sampling in multiple locations. It was an unprovenanced femur originally used as part of the teaching collection. It was degreased before sampling using the method described above. Samples were obtained by drilling from the locations described and shown in Figure 1, and were demineralized and lyophilized as described above. A second modern femur from the same source (Femur A) was also sampled for this purpose, but the 22 collagen samples taken from it were subsequently found to have an average C/N molar ratio of 5.35 (range 3.75 to 12.5), which, if found archaeologically, would cause it to be rejected on the criteria of failing the test for acceptable collagen (C/N ratio between 2.9 and 3.4 (van Klinken, 1999)). It was therefore not considered further in this analysis, but the observation was made that it was much less dense than Femur B, and was considered to be potentially osteoporotic.

Archaeological samples

All the archaeological samples for this project are from an excavation at the burial ground of Swinton Unitarian Free Church in Salford (Manchester) carried out by Oxford Archaeology (Rowland and Loe, forthcoming). This was a commercial excavation undertaken in advance of redevelopment. A small brick chapel was built on the site in 1858, with the land around the chapel being established as a burial ground in 1863. The chapel was damaged by a storm in 1984, and was subsequently demolished. Some 330 burials spanning a hundred-year period from 1863 to 1963 were recorded, with the archaeological team only dealing with burials pre-dating 1900. Oxford Archaeology recovered and recorded 116 individuals from the site, including 17 additional 19th-century burials discovered during the course of the project not included in the main burial record. All the skeletons were stored and sampled at the Oxford Archaeology South offices in Oxford.

Table 2 lists the skeletal components that were sampled from eight skeletons as part of this study, although it was not always possible to sample the exact same set of bones in all cases. In addition to these eight skeletons which were multiply sampled we also took paired rib-femur samples from a further 15 skeletons. Table 3

1.	Frontal
2.	Occipital
3.	Mandibular ramus
4.	Scapula
5.	Humerus (mid shaft)
6.	Radius (mid shaft)
7.	Rib (upper)
8.	Rib (lower)
9.	Ilium
10.	Vertebra (lumbar)
11.	Femur (mid shaft)
12.	Femur (popliteal surface)
13.	Femur (greater trochanter)
14.	Tibia (mid shaft)
15.	Fibula (mid shaft)

Table 2. Samples taken from Swinton skeletons.

gives the osteological data for all the skeletons sampled from Swinton. In all cases, samples were removed either by drilling or snapping pieces off with clippers. In the laboratory, the solid bone samples were cleaned using an air abrasive system, followed by crushing. In accordance with our normal practice for archaeological bone, samples were not defatted prior to demineralization. Weighed bone fragments or powders were demineralized in 10 mL of cold 0.5M HCl, as described above, followed by gelatinization and lyophilisation, and finally weighing the resulting collagen. This is the standard procedure for preparing 'collagen' from archaeological bone. It does not remove noncollagenous proteins explicitly (present as perhaps 10% of the organic component in fresh bone), but work such as that of Tuross *et al.* (1988) has suggested that, because most NCPs are soluble relative to collagen, the mineral dissolution procedure is sufficient to isolate collagen.

Mass Spectrometry

Approximately 1-2 mg of collagen from each sample was weighed into tin capsules. In general triplicate samples were made by taking three separate aliquots from each collagen preparation, but in some cases (particularly for Femur B) only duplicate analyses were carried out. This is usually because insufficient sample has been taken for three aliquots, or because the collagen yield is low. The samples were analyzed on two SerCon 20/22 Isotope Ratio Mass Spectrometers in the Research Laboratory for Archaeology and the History of Art running in continuous flow mode with a helium carrier gas at a flow rate of 80 ml per minute, coupled to a SerCon GSL elemental analyzer. Isotopic values as well as elemental abundances were calibrated against an in-house alanine standard which itself is routinely measured against international standards whose values are traceable back to the PDB and AIR international standards for carbon and nitrogen respectively. The in-house standard was prepared from a 500 g sample of B-Alanine from the MERCK Corporation, Darmstadt, Germany. It was crushed, screened through a 125 µm sieve, and homogenised, and is routinely sent for external stable isotopic assay as part of the Oxford Radiocarbon Accelerator Unit's ISO9001 accreditation. Full details are given in Brock *et al.* (2010).

Skeleton No.	% Complete	Age category (years)	Sex	Summary of dental and skeletal pathology
SK 1002_83	76-100	Prime adult (26-35)	?F	AMTL; Periodontitis; Caries; DEH; Calculus
SK 1007_63	76-100	Prime adult (26-35)	F	AMTL; Caries; DEH Cribra orbitalia; Maxillary sinusitis; Osteophytosis; lumbarisation of SV1.
SK 1016_33	76-100	Adolescent (13-17)	M	Caries; calculus; DEH
SK 1016_53	76-100	Prime adult (26-35)	M	AMTL; Periapical cavity; Caries; Attrition Osteophytosis; Schmorl's nodes; Spondylosis deformans; Spinal OA; Periostitis; Peri-mortem trauma
SK 1020_33	51-75	Adolescent (13-17)	?F	Periapical cavity; Caries; Calculus Schmorl's nodes
SK 1020_33	51-75	Adolescent (13-17)	?F	
SK 1020_43	76-100	Prime adult (26-35)	?M	AMTL; Periodontitis; Periapical cavity; Caries; DEH; Calculus Osteophytosis; Schmorl's nodes; Spondylolysis – LV5 (bilateral); Spondylolisthesis; Healed cranial trauma.
SK 1021_53	76-100	Mature adult (45+)	??M	AMTL; DEH; Pipe notch, R max M3 peg tooth Cribra orbitalia; Osteoarthritis; Osteophytosis; Schmorl's nodes; Healed fractures; Periostitis.
SK 1021_73	76-100	Prime adult (26-35)	?M	Periapical cavity; Periodontitis; Caries; Calculus Cribra orbitalia; Osteophytosis; Schmorl's nodes; Lumbarisation; Periostitis.
SK 1023_43	76-100	Middle adult (36-45)	?F	AMTL; Periapical cavity; Attrition; Caries; Calculus. Osteophytosis; Periostitis; Rotator cuff disease; Joint capsule cyst – R Clavicle.
SK 1028_23	51-75	Adult unspec (>18)	?M	AMTL, Caries, DEH, Calculus Cribra orbitalia; Osteophytosis.
SK 1029_103	76-100	Prime adult (26-35)	?F	AMTL; Periapical cavity; Periodontitis Schmorl's nodes; osteophytosis; Sacralisation , Cribra femoralis; Osteochondritis non-dissecans.
SK 1029_23	76-100	Mature adult (45+)	M	AMTL; Periapical cavity; Periodontitis; Caries; DEH; Calculus Cribra orbitalia; Osteoarthritis; Osteophytosis; Schmorl's nodes; Healed fracture; Periostitis.
SK 1029_43	76-100	Middle adult (36-45)	?M	AMTL; Periapical cavity; DEH Osteophytosis; Schmorl's nodes; Persiostitis; Osteochondritis dissecans.
SK 1029_93	76-100	Prime adult (26-35)	?F	AMTL; Periapical cavity; Caries; Calculus; DEH; Dental prothesis Periostitis.
SK 1032_23	76-100	Prime adult (26-35)	F	AMTL; Periapical cavity; Caries; Calculus;DEH;Periodontitis; Attrition; Pronounced overbite Osteophytosis; Periostitis.
SK 1037_23	51-75	Adult unspec (>18)	?F	AMTL Osteoarthritis; Osteophytosis; Cribra orbitalia (bilateral); Spondylosis deformans; Button osteoma (probable).
SK 1038_23	76-100	Middle adult (36-45)	?F	AMTL; DEH; Caries; Calculus; Periapical cavity Osteoarthritis; Osteophytosis; Schmorl's nodes; Periostitis.
SK 1038_43	76-100	Prime adult (26-35)	?M	AMTL; Caries; Calculus Cribra orbitalia; Schmorl's nodes; Periostitis; Congenital/developmental – styolid process of L MC3 fused to capitate rather than MC3 base; Healed fractures; myositis ossificans traumatica; Perimortem trauma.
SK 1041_43	76-100	Middle adult (36-45)	?M	AMTL; Periapical cavity; Caries; Calculus; Attrition Osteophytosis; Osteoarthritis; Schmorl's nodes; Periostitis;Healed fracture; ??residual rickets.
SK 1041_43	76-100	Middle adult (36-45)	?M	
SK 1043_43	76-100	Middle adult (36-45)	M	AMTL; DEH; Caries; Calculus; Periapical cavity Osteophytosis; Schmorl's nodes; Osteoarthritis; healed fracture; ossified cartilage.
SK 1049_33	76-100	Middle adult (36-45)	F	AMTL; DEH; Caries;

Table 3. Details of Swinton skeletons. Key: AMTL – antemortem tooth loss; DEH – dental enamel hypoplasia; F – female; ?F – probable female; ??F – possible female; M – male; ?M – probable male; ??M – possible male.

Results

Measurements on standards

The data reported here were collected over a period of two years by three different analysts on two different mass spectrometers. The samples were run in a total of 21 different batches. Clearly, ensuring data consistency over this length of time is of the utmost importance. As noted above, a laboratory alanine sample is included several times within each batch, some of which are used to correct for drift, and others as independent secondary standards. In addition we also include a smaller number of replicates of USGS40 as a secondary standard. However, as we are primarily interested in the amount of variation within the data set rather than the absolute values we have not carried out a secondary multi point calibration against these standards. Instead we prefer to use these data as independent indicators of quality, and to reject any data (or if necessary the entire run) if the values on the alanine do not come within aceptable limits. In practice, this is not done on individual values. The independent alanine samples are regularly spaced throughout the batch of 40-50 samples, and if a sequence of them are seen to drift from the expected values (see below) by more than ± ~0.3‰ in either isotope then either the entire run, or all of the samples below where the instability is detected, is dropped.

In total we accepted data from 161 values of the alanine standard. Figure 2 shows the distribution of $\delta^{13}C$ and $\delta^{15}N$ values on the independent measurements on the alanine secondary standards. The average values (mean ± 1 sd) for the alanine across all the batches (n = 161) were:

$\delta^{13}C = -26.90 \pm 0.07‰$
$\delta^{15}N = -1.64 \pm 0.13‰$

The expected values for the alanine internal standard are -26.9‰ for $\delta^{13}C$ and -1.63‰ for $\delta^{15}N$. We also had data from USGS40 (L-glutamic acid) across all batches (n=40). The data are also plotted in Figure 2, and the average values (mean ± 1 sd) were:

$\delta^{13}C = -26.10 \pm 0.05‰$
$\delta^{15}N = -4.83 \pm 0.13‰$

The expected values for USGS40 are -26.389‰ (±0.042) for $\delta^{13}C$ and -4.5‰ (±0.1) for $\delta^{15}N$. Both sets of values compare well with the expected values and with several recent isotopic studies carried out in this laboratory (*e.g.*, Pollard *et al.*, 2011, 2012; Roberts *et al.*, 2012; Bonafini *et al.*, 2013).

Femur B

Femur B was multiply sampled (anterior, posterior, medial and lateral) on the femoral shaft at each of four cross-sectional points shown in Figure 1, and also at a number of other specific points. Each measurement was made in duplicate, and Table 4 shows the average results for each pair of measurements. Figure 3a shows the total variation in all the measurements taken on the same femur (the points represent the average value for each pair of measurements). The total range of the

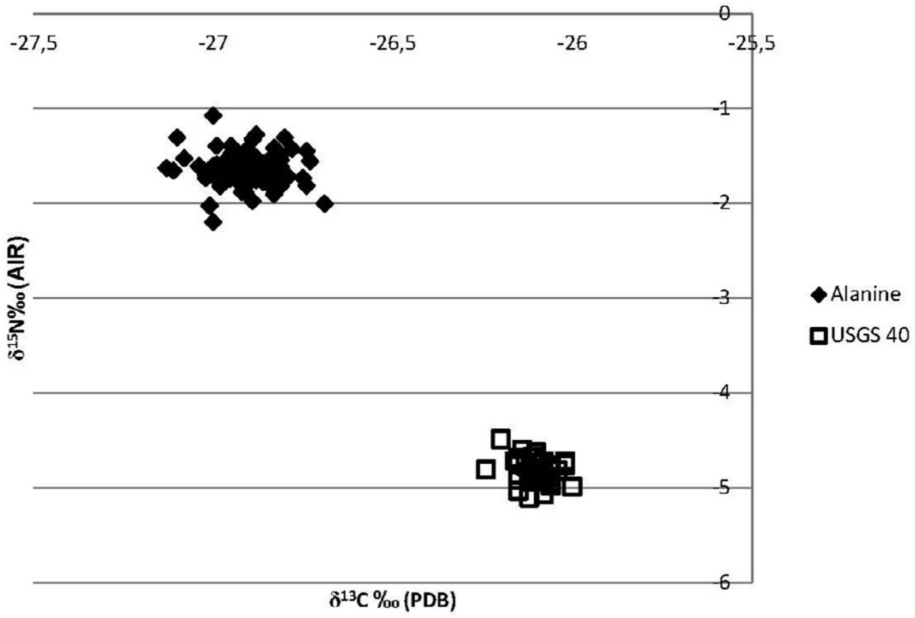

Figure 2. Measurements made on alanine and USGS 40 standards across all batches.

measurements are 1.24‰ for $\delta^{13}C$ and 0.69‰ for $\delta^{15}N$. It is noteworthy that the two most extreme samples in Figure 3a are the femoral neck ($\delta^{13}C$ = -12.79‰, $\delta^{15}N$ = 8.92‰) and the femoral head ($\delta^{13}C$ = -11.55‰, $\delta^{15}N$ = 9.61‰). This observed range is therefore likely to be an overestimate of the maximum variation encountered when sampling archaeological human femora for routine isotopic analysis, since some samples are taken from points (such as the femoral head, femoral neck and greater trochanter in the proximal femur and the left and right epicondyles in the distal) which would not normally be sampled if the femoral shaft is available. It is perhaps more realistic to focus only on the four cross sections taken at different points along the femoral shaft, as shown in Figure 3b. It is noticeable here that the lower cross section (CS1, taken about 6 cm above the epicondyles) is different from the other three in both range and average values. CS1 has a total range of 0.66‰ and 0.14‰ respectively in $\delta^{13}C$ and $\delta^{15}N$, whereas CS2 is 0.18‰ and 0.22‰, CS3 is 0.3‰ and 0.26‰, and CS4 is 0.18‰ and 0.08‰. CS1 has average values for $\delta^{13}C$ of -12.27‰ and $\delta^{15}N$ of 9.26‰, whereas CS2-4 are -11.81‰, -11.93‰ and -11.8‰ for $\delta^{13}C$ and 9.27‰, 9.24‰ and 9.21‰ for $\delta^{15}N$ respectively.

Thus, in this specific case, isotopic differences within a single femur are measureable. (Although we have not reported the data from Femur A for the reasons given above, we note that this too showed very large isotopic variations: -20.2 to -25.2‰ for $\delta^{13}C$, and 11.0 to 12.1‰ for $\delta^{15}N$). For the components which tend to have extreme isotopic values, such as femoral head and neck, trochanter and epicondyles, these differences may somehow be related to the process of fusion. Within the shaft of the femur itself there may be isotopic variations due to the location of muscle attachment, if we consider that greater forces are focussed on these areas and the bone may respond by remodelling faster. This might introduce

Name	**%C**	**%N**	**C/N**	**δ13C‰ (PDB)**	**stdev δ13C**	**δ15N‰ (AIR)**	**stdev δ15N**
CS1 Anterior	31.3	11.3	3.25	-12.39	<0.01	9.17	0.05
CS1 L_Lateral	33.5	12.0	3.26	-12.59	0.01	9.25	0.06
CS1 Posterior	29.4	10.5	3.27	-12.15	0.01	9.30	0.07
CS1 R_Lateral	37.9	13.7	3.24	-11.93	0.01	9.31	0.08
CS2 Anterior	33.4	12.0	3.27	-11.92	0.01	9.27	0.06
CS2 L_Lateral	32.3	11.7	3.22	-11.74	0.02	9.14	<0.01
CS2 Posterior	33.8	12.2	3.24	-11.74	0.01	9.32	0.08
CS2 R_Lateral	37.1	13.4	3.23	-11.84	0.04	9.36	0.09
CS3 Anterior	36.5	12.9	3.32	-12.04	0.13	9.23	0.08
CS3 L_Lateral	37.0	13.4	3.23	-11.75	0.03	9.39	0.04
CS3 Posterior	34.9	12.4	3.28	-11.87	0.03	9.19	0.11
CS3 R_Lateral	26.6	9.30	3.34	-12.05	0.05	9.13	0.16
CS4 Anterior	30.3	10.7	3.30	-11.74	0.01	9.17	0.18
CS4 L_Lateral	35.1	12.4	3.30	-11.85	0.01	9.24	0.16
CS4 Posterior	33.7	11.9	3.32	-11.89	0.01	9.19	0.15
CS4 R_Lateral	31.7	11.2	3.3	-11.71	0.04	9.25	0.06
Ant_Surface	33.8	12.3	3.21	-11.94	0.02	9.40	0.01
Fem_Head	42.5	15.5	3.20	-11.55	0.01	9.61	0.13
Fem_Neck	14.5	4.70	3.63	-12.79	0.02	8.92	0.20
G_Trochanter	42.8	15.2	3.29	-11.77	<0.01	9.45	0.01
L_Epicondyle	38.0	13.8	3.23	-11.86	0.04	9.48	0.04
Pos_Surface	38.9	14.2	3.21	-11.83	0.08	9.49	0.06
R_Epicondyle	40.1	14.6	3.21	-11.80	0.09	9.57	0.02

Table 4. Data on femur B (average of duplicate measurements).

an isotopic difference if the individual has dietary or physiological differences over the time period reflected by the earlier and later formation of bone. Similarly, we postulated that there might be isotopic differences between lateral-medial and anterior-posterior bone in the femoral shaft as a result of the biomechanical stress of walking, but in this particular case we have seen no systematic variation due to orientation within the cross section.

Multiple analysis of single human skeletons

The average results for each of the multiple analyses of nine archaeological specimens and the one modern cadaver are given in Table 5. All samples were analyzed in triplicate, unless otherwise noted. Table 5 shows the values from (as far as possible) the same 15 skeletal elements in eight archaeological samples and one modern cadaver. The archaeological samples were evenly divided between males (or probable males) and females (or probable females). The estimated ages

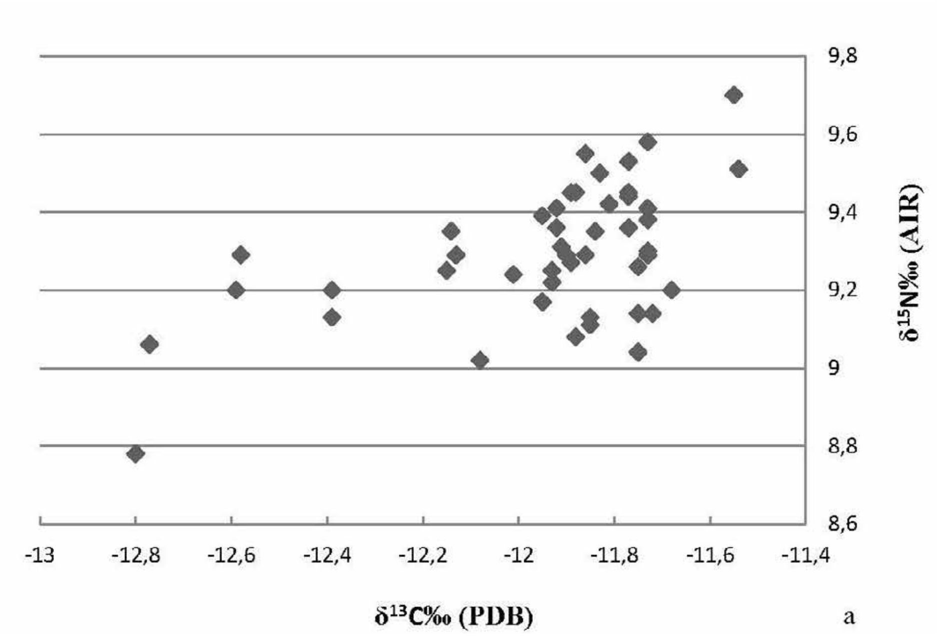

Figure 3a. Isotopic data obtained on all samples from Femur B (average of duplicate measurements).

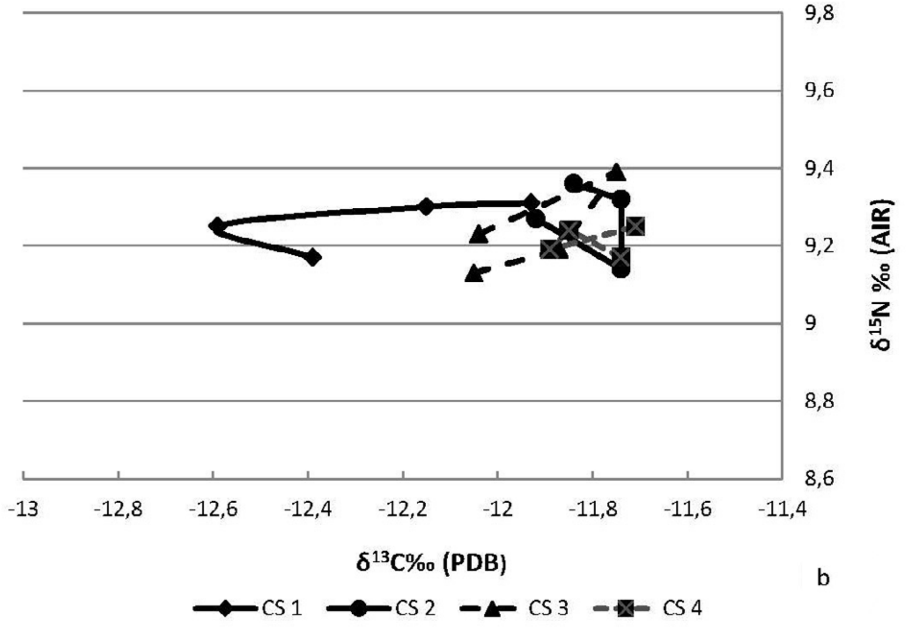

Figure 3b. Isotopic data obtained from four cross sections on Femur B (average of duplicate measurements).

ranged from SK 1020_33, an adolescent (probable) female aged 13-17 years, to three middle-aged adults aged between 36 and 45 years. The modern cadaver was considerably older (male, aged 79 years).

The summary presented in Table 6 shows that the total range of $\delta^{13}C$ in these individuals varies from a minimum of 0.50‰ to a maximum of 1.65‰, and, for $\delta^{15}N$, from 0.66‰ to 1.65‰. This range of variation is, of course, dependent on

Name	%collagen	%C	%N	C/N	δ13C‰ (PDB)	stdev δ13C	δ15N‰ (AIR)	stdev δ15N
HO86:								
Frontal (left)	17.9	42.6	15.6	3.19	-18.78	0.07	11.40	0.09
Occipital (left)	19.6	44.5	16.2	3.20	-18.46	0.05	11.56	0.19
Scapula (left)	24.5	43.2	15.7	3.21	-19.55	0.04	11.00	0.07
Ilium (left)	22.2	45.7	16.3	3.27	-19.95	0.09	10.72	0.07
Vertebra (L4 left half)	18.5	43.8	15.7	3.25	-19.63	0.09	10.89	0.11
Femur (left, mid-shaft)	30.6	43.2	15.7	3.21	-19.11	0.45	10.80	0.62
Humerus (left, mid-shaft)	20.0	45.0	16.6	3.16	-18.66	0.30	10.92	0.88
Radius (left, mid-shaft)	18.6	43.5	15.9	3.19	-18.61	0.16	11.41	0.11
Tibia (left, mid-shaft)	19.2	45.1	16.5	3.19	-18.71	0.10	11.08	0.06
Fibula (left, mid-shaft)	20.1	43.7	16.0	3.19	-18.63	0.04	11.23	0.08
Clavicle (left, medial)*	21.4	39.2	14.4	3.18	-18.78	0.09	11.45	0.19
Clavicle (right, medial)	40.1	43.4	16.1	3.14	-18.55	0.04	11.71	0.16
Ulna (left, mid-shaft)	20.6	42.5	15.6	3.18	-18.55	0.06	11.16	0.25
Ribs								
R L1	24.1	42.4	15.3	3.23	-19.57	0.03	10.99	0.14
R L2	22.3	45.0	15.9	3.30	-19.79	0.10	11.21	0.03
R L3**	29.8	42.1	15.0	3.27	-19.36	0.08	11.45	0.08
R L8	28.5	43.0	15.4	3.26	-19.71	0.09	11.04	0.21
R L12	17.7	44.3	15.3	3.38	-19.64	0.14	11.55	0.37
R R1	24.1	42.6	15.2	3.27	-19.63	0.12	10.90	0.18
R R2	21.0	42.9	15.3	3.27	-19.31	0.01	11.40	0.01
R R3	26.9	41.5	14.9	3.25	-19.45	0.16	11.29	0.19
R R9	20.3	43.8	15.6	3.28	-19.51	0.03	11.58	0.07
R R12	20.8	44.8	16.3	3.21	-19.33	0.32	11.21	0.35
Archaeological skeletons								
SK 1021_73 Frontal	53.6	43.2	15.8	3.20	-19.18	0.02	11.58	0.03
SK 1021_73 Occipital	34.3	43.6	15.3	3.33	-19.32	0.05	11.73	<0.01
SK 1021_73 Mandibular ramus	15.0	44.4	16.1	3.22	-18.97	0.01	11.67	0.04
SK 1021_73 Scapula	28.0	45.4	16.4	3.24	-18.85	0.02	11.80	0.05
SK 1021_73 Ilium	30.6	41.7	15.0	3.24	-18.96	0.06	11.56	0.06
SK 1021_73 Vertebra (lumbar)	29.8	42.0	15.2	3.22	-19.18	0.10	11.80	0.08
SK 1021_73 Rib (lower)	22.2	43.9	15.8	3.24	-18.85	0.02	11.96	0.03
SK 1021_73 Rib (upper)	18.1	43.3	15.6	3.24	-19.05	0.04	11.73	0.05
SK 1021_73 Femur (popliteal surface)	22.3	43.1	15.5	3.25	-19.43	0.04	11.31	0.07
SK 1021_73 Femur (mid shaft)	27.4	42.9	15.4	3.26	-19.30	0.05	11.25	0.02
SK 1021_73 Femur (greater trochanter)	26.9	43.3	15.7	3.23	-19.04	0.03	11.69	0.11
SK 1021_73 Humerus (mid shaft)	41.2	44.4	16.0	3.23	-19.31	0.04	11.20	0.02
SK 1021_73 Radius (mid shaft)	23.6	42.4	15.1	3.27	-19.49	0.03	11.26	0.05
SK 1021_73 Tibia (mid shaft)	25.6	41.5	14.8	3.27	-19.54	0.21	11.23	0.10
SK 1021_73 Fibula (mid shaft)	10.3	41.3	14.1	3.41	-19.55	0.02	11.75	0.02
SK 1023_43 Frontal	21.6	44.1	16.1	3.21	-19.81	0.03	11.55	0.05
SK 1023_43 Occipital	29.3	44.5	16.1	3.23	-19.87	0.04	11.26	0.03
SK 1023_43 Mandibular ramus	21.3	43.5	15.6	3.25	-19.94	0.07	11.66	0.02
SK 1023_43 Scapula	16.7	44.1	15.5	3.32	-19.55	0.01	11.82	0.02
SK 1023_43 Ilium	58.8	42.7	15.3	3.26	-19.40	0.02	11.86	0.05

Name	%collagen	%C	%N	C/N	δ13C‰ (PDB)	stdev δ13C	δ15N‰ (AIR)	stdev δ15N
SK 1023_43 Vertebra (lumbar)	19.4	42.3	14.8	3.33	-19.51	0.02	11.93	0.05
SK 1023_43 Rib (lower)	9.7	41.4	14.2	3.39	-19.82	0.04	11.90	0.03
SK 1023_43 Rib (upper)	19.0	42.1	14.8	3.31	-19.59	0.06	11.84	0.04
SK 1023_43 Femur (popliteal surface)	24.5	44.9	16.4	3.20	-19.81	0.03	11.42	0.05
SK 1023_43 Femur (mid shaft)	37.4	42.8	15.5	3.23	-19.80	0.04	11.28	0.05
SK 1023_43 Femur (greater trochanter)	14.8	44.7	15.3	3.41	-19.74	0.04	11.83	0.07
SK 1023_43 Humerus (mid shaft)	21.3	42.5	15.3	3.24	-19.77	0.04	11.31	0.09
SK 1023_43 Radius (mid shaft)	31.5	40.1	14.4	3.26	-19.93	0.06	11.19	0.03
SK 1023_43 Tibia (mid shaft)	21.3	42.9	15.5	3.23	-19.89	0.03	11.19	0.05
SK 1023_43 Fibula (mid shaft)	18.4	44.5	15.7	3.30	-19.81	0.03	11.56	0.07
SK 1029_43 Frontal	5.88	41.8	15.0	3.25	-20.31	0.04	11.84	0.05
SK 1029_43 Occipital	28.3	38.6	13.9	3.26	-20.30	0.1	11.77	0.05
SK 1029_43 Mandibular ramus	36.3	42.8	15.4	3.24	-20.29	<0.01	11.70	0.04
SK 1029_43 Scapula	21.2	45.2	16.4	3.21	-19.20	0.07	12.25	0.06
SK 1029_43 Ilium	22.9	47.3	17.1	3.23	-19.03	0.05	12.42	0.03
SK 1029_43 Vertebra (lumbar)	35.5	47.4	16.9	3.27	-19.18	0.02	12.65	0.01
SK 1029_43 Rib (lower)	27.1	45.8	16.3	3.27	-19.27	0.04	12.49	0.11
SK 1029_43 Rib (upper)	20.9	48.0	17.2	3.26	-19.42	0.04	12.38	0.02
SK 1029_43 Femur (popliteal surface)	37.4	47.2	16.9	3.25	-20.36	0.10	11.45	0.02
SK 1029_43 Femur (mid shaft)	16.7	47.5	16.6	3.35	-19.77	0.06	12.13	0.02
SK 1029_43 Femur (greater trochanter)	11.4	45.5	15.7	3.38	-19.29	0.02	12.60	0.02
SK 1029_43 Humerus (mid shaft)	23.8	43.7	15.6	3.26	-20.16	0.03	11.59	0.03
SK 1029_43 Radius (mid shaft)	12.4	46.6	16.4	3.31	-20.11	0.11	11.99	0.08
SK 1029_43 Tibia (mid shaft)	31.4	43.7	15.7	3.25	-20.36	0.10	11.32	0.03
SK 1029_43 Fibula (mid shaft)	19.1	42.8	15.4	3.25	-20.26	0.01	11.40	0.02
SK 1007_63 Frontal	16.1	41.8	15.1	3.24	-18.64	0.02	12.67	0.06
SK 1007_63 Occipital	7.2	42.6	15.3	3.24	-18.67	0.02	12.86	0.02
SK 1007_63 Mandible	14.8	43.1	15.8	3.19	-18.30	0.04	13.03	0.02
SK 1007_63 Scapula L	9.9	41.7	15.0	3.25	-18.40	0.01	12.92	0.06
SK 1007_63 Ilium R	15.5	41.3	15.0	3.22	-18.74	0.01	12.58	0.09
SK 1007_63 Vertebra, lumbar	5.6	42.5	15.5	3.21	-18.41	0.01	13.17	0.04
SK 1007_63 Vertebra, upper	29.5	37.1	13.7	3.16	-18.77	0.02	12.58	0.04
SK 1007_63 Rib, lower*	17.7	40.5	14.8	3.20	-18.57	0.04	12.68	0.02
SK 1007_63 Rib, upper	32.9	32.5	11.7	3.24	-18.78	0.02	12.32	0.03
SK 1007_63 Femur, popliteal L	14.3	39.7	14.2	3.27	-19.07	0.04	12.04	0.04
SK 1007_63 Femur, midshaft L	19.3	41.9	15.4	3.18	-19.39	0.02	11.89	0.03

*Table 5 (part1). Data on cadaver HO86 and nine Swinton skeletons and (average of triplicate measurements unless otherwise noted). Key: * n = 2; ** n = 4.*

Name	%collagen	%C	%N	C/N	δ13C‰ (PDB)	stdev δ13C	δ15N‰ (AIR)	stdev δ15N
SK 1007_63 Femur, trochanter L	7.2	39.0	14.4	3.16	-18.46	0.02	12.94	0.03
SK 1007_63 Humerus, midshaft L*	35.0	40.7	14.7	3.22	-19.01	<0.01	12.13	0.01
SK 1007_63 Ulna, midshaft	32.3	30.8	10.8	3.32	-18.99	0.02	12.24	0.13
SK 1007_63 Tibia, midshaft L	12.4	44.2	16.1	3.20	-19.65	0.01	11.70	0.02
SK 1007_63 Fibula, midshaft L	43.4	31.9	11.4	3.28	-18.81	0.01	12.29	0.06
SK 1016_53 Frontal	23.2	41.5	15.1	3.21	-18.94	0.01	11.64	0.10
SK 1016_53 Occipital	12.4	42.8	15.7	3.17	-18.94	0.02	11.71	0.01
SK 1016_53 Mandible L	42.5	36.5	13.3	3.21	-18.69	0.02	11.32	0.11
SK 1016_53 Scapula L	11.1	40.6	14.5	3.27	-18.71	0.02	11.28	0.07
SK 1016_53 Ilium R	21.9	41.5	15.2	3.19	-18.73	0.03	11.44	0.04
SK 1016_53 Vertebra, lumbar	12.4	39.9	14.6	3.19	-18.84	0.01	11.55	0.07
SK 1016_53 Vertebra, upper	15.3	40.6	14.9	3.19	-18.75	0.04	11.39	0.05
SK 1016_53 Rib, lower L	71.5	34.1	12.3	3.25	-18.61	0.02	11.18	0.06
SK 1016_53 Rib, upper L	21.0	42.6	15.5	3.22	-18.98	0.05	11.42	0.03
SK 1016_53 Femur, popliteal R	38.9	37.8	13.8	3.20	-18.97	0.04	11.38	0.07
SK 1016_53 Femur, midshaft R	21.4	44.9	16.5	3.18	-18.92	0.01	11.63	0.07
SK 1016_53 Femur, trochanter R	9.2	42.0	15.3	3.20	-18.72	0.02	11.45	0.05
SK 1016_53 Humerus, midshaft R	36.6	40.4	14.7	3.19	-18.89	0.02	11.53	0.11
SK 1016_53 Radius, midshaft R	8.4	43.7	15.9	3.21	-19.10	0.10	11.84	0.11
SK 1016_53 Tibia, midshaft R	17.2	46.0	17.0	3.16	-19.11	0.04	11.56	0.05
SK 1016_53 Fibula, midshaft R	14.0	43.2	15.8	3.19	-18.95	0.04	11.40	0.06
SK 1020_33 Frontal	6.3	43.6	16.0	3.19	-19.25	0.02	11.71	0.06
SK 1020_33 Occipital	13.2	44.0	16.2	3.18	-19.29	0.02	11.45	0.03
SK 1020_33 Mandible L	13.6	41.9	15.3	3.20	-18.83	0.02	11.06	0.05
SK 1020_33 Scapula	9.3	41.8	15.1	3.24	-18.64	0.02	12.67	0.06
SK 1020_33 Ilium R	9.6	42.7	15.9	3.15	-18.88	0.02	11.39	0.12
SK 1020_33 Vertebra, lumbar	9.2	41.1	15.2	3.16	-18.91	0.03	11.36	0.08
SK 1020_33 Vertebra, upper	16.0	40.9	14.7	3.25	-19.12	0.02	11.50	0.04
SK 1020_33 Rib, lower	17.8	43.1	15.6	3.22	-19.15	0.02	11.50	0.06
SK 1020_33 Rib, upper	20.6	42.9	15.7	3.19	-19.12	0.02	11.26	0.09
SK 1020_33 Femur, popliteal L	16.1	42.1	15.5	3.16	-19.01	0.02	11.04	0.08
SK 1020_33 Femur, midshaft L	14.5	43.1	15.7	3.20	-19.18	<0.01	11.40	0.07
SK 1020_33 Femur, trochanter L	14.1	40.4	14.6	3.23	-18.82	0.02	11.02	0.04
SK 1020_33 Humerus, midshaft*	5.6	40.8	14.9	3.20	-19.17	0.01	11.43	0.04
SK 1020_33 Radius, midshaft	21.0	47.6	18.0	3.12	-19.13	0.07	11.39	0.08
SK 1020_33 Tibia, midshaft L	40.2	31.9	11.5	3.25	-19.29	0.02	11.28	0.06
SK 1020_33 Fibula, midshaft L	14.1	44.2	16.3	3.17	-19.23	0.04	11.32	0.10

Name	%collagen	%C	%N	C/N	δ13C‰ (PDB)	stdev δ13C	δ15N‰ (AIR)	stdev δ15N
SK 1029_103 Frontal	10.3	42.9	15.7	3.19	-20.06	0.02	11.35	0.07
SK 1029_103 Occipital*	10.8	42.4	15.3	3.23	-19.85	0.04	11.55	0.13
SK 1029_103 Mandible R	39.1	36.7	13.4	3.19	-19.57	0.01	11.60	0.05
SK 1029_103 Scapula R	34.9	33.6	12.3	3.21	-19.68	0.02	11.43	0.06
SK 1029_103 Ilium R	15.1	40.5	14.6	3.23	-19.06	0.01	11.68	0.04
SK 1029_103 Vertebra, lumbar	26.2	44.4	16.2	3.19	-19.60	0.04	11.68	0.03
SK 1029_103 Vertebra, upper	9.9	44.6	15.9	3.27	-19.76	0.01	11.56	0.07
SK 1029_103 Rib, lower L	55.7	32.2	11.3	3.32	-19.41	0.04	11.54	0.04
SK 1029_103 Rib, upper L	44.7	32.6	11.7	3.25	-19.67	0.01	11.51	0.09
SK 1029_103 Femur, popliteal L	12.7	45.6	16.7	3.18	-20.37	0.01	11.08	0.03
SK 1029_103 Femur, midshaft L	18.1	45.1	16.5	3.20	-20.08	0.02	10.83	0.13
SK 1029_103 Femur, trochanter L	20.8	44.4	16.3	3.18	-19.46	0.03	11.58	0.04
SK 1029_103 Humerus, midshaft L	8.4	45.6	17.0	3.14	-19.95	0.03	11.29	0.06
SK 1029_103 Radius, midshaft L	41.2	38.6	14.1	3.18	-20.15	0.03	10.88	0.04
SK 1029_103 Tibia, midshaft L	29.7	40.9	15.3	3.12	-20.09	0.02	11.14	0.06
SK 1029_103 Fibula, midshaft L	16.7	43.7	15.9	3.21	-20.07	0.02	11.13	0.04
SK 1041_43 Frontal	14.9	43.5	16.0	3.18	-19.09	0.03	12.16	0.07
SK 1041_43 Occipital	12.3	43.2	15.8	3.19	-19.45	0.03	11.82	0.07
SK 1041_43 Mandible R	7.1	42.4	15.4	3.22	-18.77	0.02	12.50	0.03
SK 1041_43 Scapula L	5.6	43.1	16.1	3.12	-18.93	0.01	12.28	0.08
SK 1041_43 Ilium R	11.1	44.4	16.4	3.15	-18.59	0.03	12.56	0.06
SK 1041_43 Vertebra, lumbar*	13.2	44.7	16.1	3.24	-18.42	<0.01	12.80	0.01
SK 1041_43 Vertebra, upper	8.8	43.4	15.9	3.20	-18.88	0.02	12.38	0.07
SK 1041_43 Rib, lower R	13.6	45.0	16.7	3.15	-19.06	0.03	12.42	0.06
SK 1041_43 Femur, midshaft R	16.0	42.7	15.9	3.13	-19.51	0.01	11.97	0.03
SK 1041_43 Femur, trochanter R	5.6	41.8	15.3	3.20	-18.01	0.02	12.72	0.04
SK 1041_43 Humerus, midshaft L	29.4	43.5	16.3	3.11	-19.13	0.02	12.11	0.02
SK 1041_43 Radius, midshaft L	14.0	45.1	16.7	3.15	-19.50	0.02	12.16	0.01
SK 1041_43 Tibia, midshaft R	35.6	44.1	16.2	3.17	-19.65	0.01	11.97	0.03
SK 1041_43 Fibula, midshaft R	16.1	44.8	16.7	3.13	-19.36	0.02	12.04	0.04

*Table 5 (part 2). Data on cadaver HO86 and nine Swinton skeletons and (average of triplicate measurements unless otherwise noted). Key: * n = 2; ** n = 4.*

the specific choice of skeletal elements measured, and is constrained by the relatively limited age range of the individuals studied here. It is not necessarily representative of the total variation that might be obtained during routine archaeological isotope analysis, since it includes bones (or parts of bones) which would not normally be sampled if ribs and femora were available. The columns labelled 'realistic range' in Table 6 are therefore the ranges obtained if the choice of skeletal element is limited to rib (upper and lower), femur (midshaft), humerus, radius, tibia and fibula, which are

Skeleton	Sex	Age	Range δ13C (‰ PDB)	Range δ15N (‰ AIR)	'Realistic' range δ13C (‰ PDB)	'Realistic' range δ15N (‰ AIR)	Regression equation	r2
SK 1021_73	M?	26-35	0.70	0.76	0.70	0.76	y = 0.6635x + 24.307	0.406
SK 1023_43	F?	36-45	0.54	0.74	0.34	0.71	y = 1.1795x + 34.969	0.467
SK 1029_43	M?	36-45	1.33	1.33	1.09	1.17	y = 0.7955x + 27.77	0.841
SK 1007_63	F	26-35	1.35	1.43	1.08	0.98	y = 1.1276x + 33.692	0.906
SK 1016_53	M	26-35	0.50	0.66	0.50	0.66	y = -0.8151 – 3.9	0.516
SK 1020_33*	F?	13-17	0.65	1.65			y = 0.5364 + 21.649	0.075
			0.47	0.69	0.17	0.24	y = -0.7082x - 2.1812	0.372
SK 1029_103	F?	26-35	1.31	0.85	0.74	0.24	y = 0.6656x + 24.545	0.666
SK 1041_43	M?	36-45	1.65	1.31	0.59	0.93	y = 0.5812x + 23.335	0.842
HO86	M	79	1.50	1.0	1.10	0.70	y = 0.2007x + 14.991	0.122

*Table 6. Summary of data on nine complete skeletons. Key: *These data have a negative correlation, apart from one value (scapula). The second row gives the values omitting this point. The 'realistic' range is for a smaller set of skeletal elements, more likely to be measured in archaeological isotopic studies.*

the most likely elements to be sampled. The observed ranges within a single skeleton are thus slightly reduced to 0.17 to 1.10‰ for δ^{13}C and 0.24 to 1.17‰ for δ^{15}N.

Qualitatively, simple plots of δ^{13}C against δ^{15}N for the 15 samples taken from each individual broadly show two different patterns, distinguished by the gradient of the correlation line. Table 6 gives the equation of the regression line and the value of r^2 for the full dataset within each skeleton. Figure 4a shows the scatterplot for SK 1007_63 (the individual with the strongest positive correlation between δ^{13}C and δ^{15}N), and Figure 4b shows the same for SK 1016_53, the only individual with an unequivocal negative correlation. (SK 1020_33 also shows a negative correlation, providing one point – the scapula – is omitted).

Discussion

Variation within a single skeleton

From the data shown above, there is no easily discernible pattern to the relationships between age, sex and observed isotopic patterning, beyond the fact that one or possibly two individuals (SK 1016_53 and SK 1020_33) show a negative relationship between δ^{13}C and δ^{15}N within their skeleton, in contrast to the variably strong positive correlations given by the other individuals. We suspect there might be a weak relationship between estimated age at death and the total range of δ^{13}C and δ^{15}N values within the skeleton, with younger individuals showing a lower measured range, but this suspicion would require a much larger study to verify.

In order to search for systematic patterns in the isotopic values from the collagen of different skeletal elements within the body, we have devised a procedure whereby the value of each bone is standardized to the mean for the measured δ^{13}C and δ^{15}N values within each skeleton, and expressed as the difference from the mean in standard deviation units (the equivalent of a standard score system). In most individuals, this

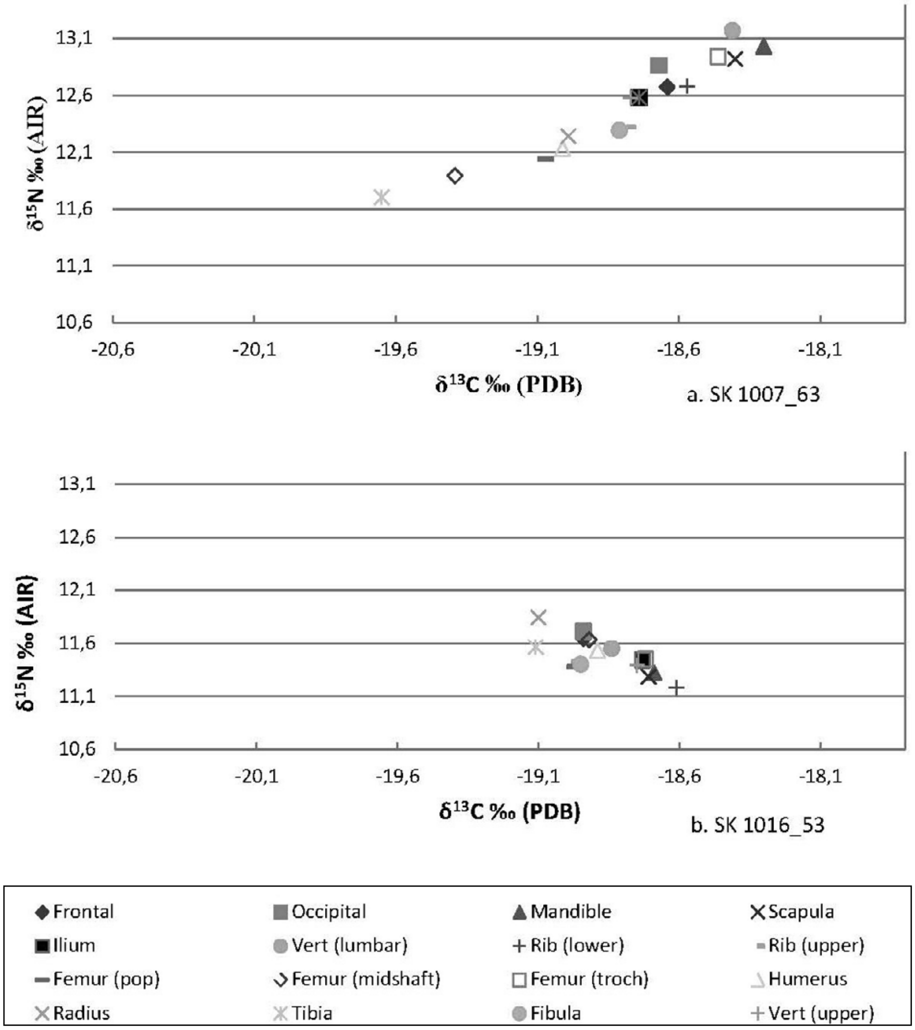

Figure 4. Isotopic plot of data from: a) SK 1007_63 (Female, age 26-35 years). b) SK1016_53 (Male, age 26-35 years).

shows a systematic pattern of variation between the skeletal elements. Generally, for δ^{13}C, the scapula, ilium, lumbar vertebra and greater trochanter all have positive values (i.e., the individual δ^{13}C values for these elements tend to be less negative than the skeletal average), and the mid-shaft femur, humerus, radius, tibia and mid-shaft fibula values are all negative (i.e., the δ^{13}C values are more negative), although there is significant variation in these patterns between individuals. Figure 5a shows the standardized values for δ^{13}C and δ^{15}N from individual SK 1020_33, in which the values of δ^{13}C and δ^{15}N move (approximately) together – higher standardized values in δ^{13}C correspond roughly to higher standardized values of δ^{15}N. This means that less negative values of δ^{13}C are associated with higher values of δ^{15}N, and *vice versa*, as would be predicted from the positive correlations observed above. In contrast, however, Figure 5b shows the same data for SK 1016_53, which is in general anti-correlated between δ^{13}C and δ^{15}N.

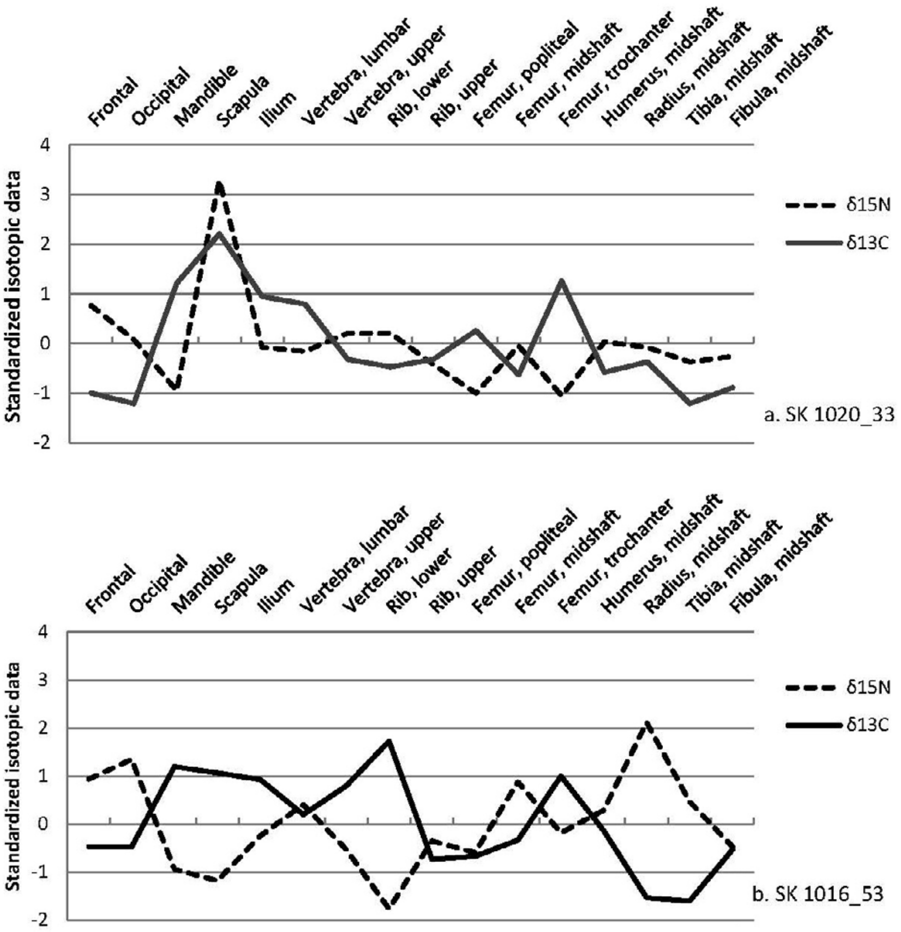

Figure 5. Standardized isotopic data: a) SK 1020_33 (?Female, age 13-17 years), b) SK 1016_53 (Male, age 26-35 years).

The possible significance of the similarities and differences between these patterns for specific individuals is discussed further below. Since, however, in our small sample of nine individuals, we observe a general pattern of flat and irregular bones being less negative in $\delta^{13}C$ than the skeletal average and the long bones being more negative, we suggest that this poses an interesting question for archaeologists. If this is a systematic pattern, to what degree are the isotopic values in a particular bone, or part of a bone, related to bone function and physiology as well as to diet? This deserves further investigation, particularly so if some individuals do not appear to conform to this pattern.

The utility of rib-femur spacing compared to 'whole skeleton' patterning

The difference between isotopic values from different parts of the same skeleton has sometimes been used in archaeology as a way of detecting changing diet over an individual's lifetime. Continual resorption and remodelling of bone leads to different rates of bone turnover within the skeleton, which, in turn, means that different elements of the skeleton give dietary information from different periods of time prior to death. Turnover rates in humans are not known precisely, but it is generally accepted that cortical bone replaces itself more slowly (approximately 25 years) than trabecular bone (approximately 3-4 years: Olsen *et al.*, 2014: 599; Hedges *et al.*, 2007). Thus, an individual who died aged more than 30 might be expected to show dietary differences as measured between rib and femur, if she or he had a radically different diet between earlier and later life, or if they spent their later years in a different ecological environment to that of their younger life.

In particular, Sealy *et al.* (1995) measured δ^{13}C and δ^{15}N in dentine, enamel, rib and femur or humerus from five individuals excavated in South Africa. One ('Vergelegen') was an African woman assumed to have been a slave, dating to the 18th century AD. She showed a marked shift in all ratios measured. Before early adulthood (in her 3rd molar dentine, 2nd incisor dentine and femur) she had δ^{13}C and δ^{15}N values from a C^4 biome, consistent with a tropical or sub-tropical inland area of southern Africa. At the end of her life (rib), she had elevated δ^{15}N values, consistent with a more marine diet following a move to the coast. In this example, strontium isotopes were also measured corroborating the evidence from the light stable isotopes, and confirming the utility in this case of measuring rib-femur spacing. Subsequently, such measurements have become relatively common in other isotopic mobility studies, and therefore the purpose of this discussion is to compare rib-femur spacing measurements with measurements of overall skeletal variability.

Figure 6 shows the variability in isotopic measurements made on collagen from five pairs of ribs from the same individual (cadaver HO86, male aged 79). The total observed range between these ten samples is 0.50‰ in δ^{13}C and 0.67‰ in δ^{15}N. Even left-right pairs can show up to 0.48‰ difference in δ^{13}C (R2 – L2) and 0.34‰ in δ^{15}N (R12 – L12). These results suggest that the choice of rib might have a significant effect when measuring rib-femur spacing. In most archaeological work, it is often not possible to be precise about which rib has actually been sampled, because in all but the most highly-articulated skeletons ribs are often not identified to location. It might also be the case that sampling rib without separating cortical from trabecular bone introduces a higher degree of variability.

During the course of this work we have had the opportunity to measure rib-femur pairs on a total of 24 individuals [HO86, the eight samples discussed above (arbitrarily taking the value for the upper rib in each case), and a further 15 individuals analysed from the site of Swinton (sample details given in Table 3 and isotopic data in Table 7)]. Figure 7 shows that the majority of the values for the rib-femur spacing (calculated as $\Delta = \delta^{rib} - \delta^{femur}$) are positive for both Δ^{13}C and Δ^{15}N (implying that for δ^{13}C femurs are more negative and for δ^{15}N femurs are more positive). The maximum range for Δ^{13}C is -0.52 to +1.40 ‰ and for Δ^{15}N = -0.48 to +0.91‰.

The majority of these samples come from a single site (Swinton), which on archaeological and historical evidence is likely to be socially homogeneous. If we assume that the Swinton population was broadly exposed to the same diet, and therefore experienced relatively similar dietary differences between early and later life, then it is interesting to ask if the differences between individuals shown

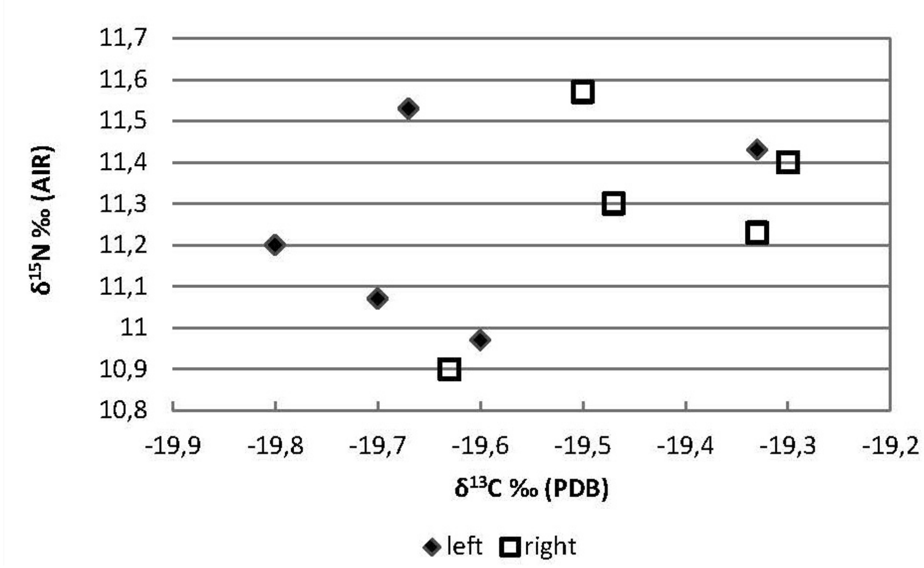

Figure 6. Isotopic values for multiple ribs from same individual (HO86, male, 79 years).

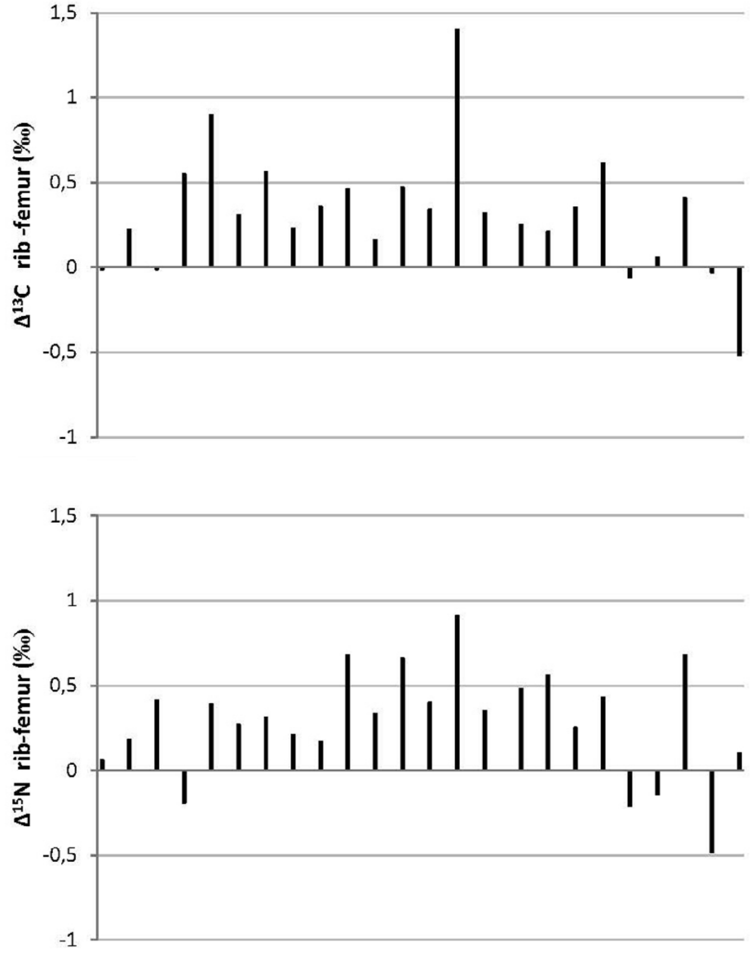

Figure 7. Rib-femur spacing for 24 individuals (upper figure $\Delta^{13}C$, lower $\Delta^{15}N$).

Rib-Femur Pairs	%collagen	%C	%N	C/N	δ13C‰ (PDB)	stdev δ13C	δ15N‰ (AIR)	stdev δ15N
SK 1002_83 rib	12.6	46.5	16.9	3.21	-20.13	0.09	11.31	0.04
SK 1002_83 femur	19.1	48.0	17.4	3.22	-20.12	0.03	11.25	0.06
SK 1016_33 rib	18.9	48.5	17.7	3.2	-18.54	0.03	11.50	0.06
SK 1016_33 femur	23.1	43.5	15.7	3.24	-18.76	0.06	11.32	0.05
SK 1020_33 rib	10.0	48.2	17.6	3.19	-19.13	0.03	11.50	0.03
SK 1020_33 femur	17.6	43.4	15.7	3.22	-19.12	0.06	11.09	0.07
SK 1020_43 rib	19.7	54.5	20.0	3.18	-19.50	0.04	12.05	0.02
SK 1020_43 femur	19.8	44.6	16.3	3.2	-20.05	0.06	12.24	0.06
SK 1021_53 rib	12.2	45.0	16.2	3.24	-18.73	0.04	11.77	0.02
SK 1021_53 femur	21.3	49.3	17.9	3.21	-19.63	0.10	11.38	0.09
SK 1028_23 rib	16.9	56.5	20.7	3.18	-18.60	0.06	11.83	0.08
SK 1028_23 femur	21.7	46.9	17.0	3.22	-18.91	0.04	11.56	0.04
SK 1029_23 rib	17.7	55.1	20.3	3.17	-19.17	0.06	11.14	0.01
SK 1029_23 femur	21.3	44.1	15.9	3.23	-19.73	0.04	10.83	0.06
SK 1029_93 rib	20.2	46.4	16.8	3.22	-19.65	0.01	11.27	0.03
SK 1029_93 femur	20.3	48.3	17.6	3.2	-19.88	0.05	11.06	0.01
SK 1032_23 rib	18.8	51.4	18.7	3.2	-19.41	0.05	12.3	0.04
SK 1032_23 femur	20.7	44.4	16.1	3.23	-19.77	0.03	12.13	0.05
SK 1037_23 rib	19.0	54.4	19.8	3.21	-19.20	0.03	12.03	0.02
SK 1037_23 femur	21.8	46.3	16.7	3.23	-19.66	0.05	11.35	0.04
SK 1038_23 rib	9.7	56.2	20.5	3.19	-18.46	0.06	12.58	0.09
SK 1038_23 femur	21.9	45.2	16.1	3.28	-18.62	0.26	12.25	0.13
SK 1038_43 rib	12.1	53.0	19.4	3.18	-18.50	0.09	12.98	0.07
SK 1038_43 femur	21.8	44.1	16.0	3.21	-18.97	0.01	12.32	0.11
SK 1041_43 rib	20.4	56.2	20.6	3.18	-19.2	0.04	12.12	0.09
SK 1041_43 femur	21.0	43.6	15.9	3.2	-19.54	0.04	11.72	0.03
SK 1043_43 rib	19.1	45.0	16.2	3.23	-18.57	0.18	12.77	0.06
SK 1043_43 femur	18.5	37.3	13.7	3.19	-19.97	0.06	11.86	0.10
SK 1049_33 rib	19.1	51.4	18.7	3.21	-18.68	0.04	12.92	0.03
SK 1049_33 femur	21.0	43.5	15.7	3.23	-19.00	0.06	12.57	0.02

Table 7. Rib-femur pairs (average of triplicate measurements).

in Figure 7 might be related to age, or are simply a reflection of physiological differences between individuals. Figure 8 plots Δ^{13}C and Δ^{15}N against approximate age at death, suggesting that there might be a positive relationship between both isotope spacings and age at death, at least for the archaeological samples. However, given what has been observed above for the isotopic variation within a single femur

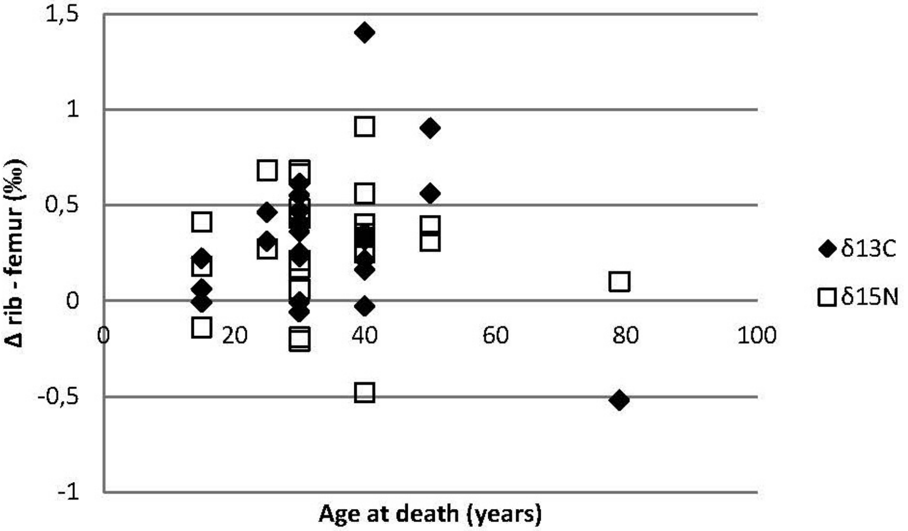

Figure 8. Age at death against rib-femur spacing.

(differences of up to 0.30‰ in $\delta^{13}C$ and 0.26‰ in $\delta^{15}N$) and between different ribs on the same individual (up to 0.5‰ in $\delta^{13}C$ and 0.67‰ in $\delta^{15}N$), it is clear that differences of less than 0.8‰ in $\delta^{13}C$ and ~1‰ in $\delta^{15}N$ *could* simply be due to the choice of sample. The same conclusion could also be arrived at by simply comparing the reported errors on each measurement. A cautious interpretation of Figure 7 would therefore be that only two samples (SK 1021_53 ($\Delta^{13}C$ = +0.9‰) and SK 1043_43 ($\Delta^{13}C$ = +1.4‰)) really show any evidence of a shift between rib and femur in $\delta^{13}C$, and none are significant in $\delta^{15}N$. This is at least plausible, since these two individuals are amongst the oldest in the dataset, apart from the modern sample HO86, which seems to behave quite differently (a negative shift in $\delta^{13}C$ of -0.51‰, and virtually none (+0.1‰) in $\delta^{15}N$).

Drawing together what has been observed on the distribution of isotopic values across the entire skeleton and comparing this to the discussion on rib-femur spacing, it might be pertinent to point out that larger datasets of up to 15 different measurements per skeleton show much clearer differences between individuals than do simple measurements of rib-femur spacings. For example, SK 1020_33 (Figure 5a) shows a 'normal' pattern of isotopic variation (at least when compared to the other data presented here), but has rib-femur spacing values of $\Delta^{13}C$ = +0.06‰ and $\Delta^{15}N$ = -0.15‰, whereas SK 1016_53 (Figure 5b), which shows a completely different pattern, has rib-femur spacing values of $\Delta^{13}C$ = -0.06‰ and $\Delta^{15}N$ = -0.21‰. Thus, although the 'whole skeleton' measurements are completely different, the rib-femur spacings for both individuals are quite similar, and so small that they would not otherwise attract attention. Does the difference in 'whole skeleton' patterning tell us something about individual biography that is not reflected in the rib-femur spacing? This at least suggests that further analysis of a larger number of skeletal elements per individual would be worthwhile, to determine what is 'normal', and why such differences occur.

Conclusions

When carrying out a large number of stable isotope measurements on bone collagen using continuous-flow mass spectrometry, it is important to ensure that the within-batch and batch-to-batch variations are kept within acceptable limits. Here we have used data from 21 different analytical batches, carried out by three different analysts on two different machines, over a period of two years. By carefully monitoring the values on our in-house alanine standard, we show that we can achieve a reproducibility of ± 0.07‰ (one sigma standard deviation) in the $\delta^{13}C$ values and ± 0.13‰ (one sigma) in $\delta^{15}N$. This is verified by using USGS40 as a second independent secondary standard.

When considering the reproducibility of measurements made on a single femur, we have found a total range of the measurements (i.e., the difference between the highest and lowest values recorded, taken as averages of pairs of measurements) of 1.24‰ for $\delta^{13}C$ and 0.69‰ for $\delta^{15}N$. This potentially overestimates the range that might be expected during normal archaeological isotope sampling, since it includes elements of the bone from which samples would not normally be taken. Restricting the calculation to cross-sections at various positions along the mid-shaft, we find a range of 0.30‰ in $\delta^{13}C$ and 0.26‰ in $\delta^{15}N$. There may be a systematic relationship between location on the femur and isotopic value, perhaps relating to muscle attachment and biomechanical stress affecting the local rate of bone turnover, but in this one sample we saw no systematic orientational variation around the cross-sections. We suggest that, if this level of variation within a single femur is verified by further analysis, then it might devalue the use of such a bone as an 'international standard' (Pestle *et al.*, 2014) unless significant efforts are made to homogenize the sample. We found similar levels of isotopic variation between the measurements on ten ribs of a single individual (HO 86: 0.50‰ in $\delta^{13}C$ and 0.67‰ in $\delta^{15}N$). This is greater than the maximum variation between pairs of measurements taken on equivalent ribs by Olsen *et al.* (2014) (0.18‰ in $\delta^{13}C$ and 0.55‰ in $\delta^{15}N$), which might indicate the importance of separating cortical from trabecular bone.

Within a single human skeleton, we found larger levels of variation (from a minimum of 0.50‰ to a maximum of 1.65‰ for $\delta^{13}C$, and, for $\delta^{15}N$, from 0.66‰ to 1.65‰). These ranges include skeletal elements that would not normally be sampled for isotopic studies, but even when these are removed (the 'realistic' dataset), the variation remains at between 0.17‰ and 1.10‰ for $\delta^{13}C$ and 0.24‰ to 1.17‰ for $\delta^{15}N$. These figures are comparable with those reported by Olsen *at al.* (2014) for a more limited range of components: they report maximum differences of 0.40‰ for $\delta^{13}C$ and 0.70‰ in $\delta^{15}N$ for differences between ribs and either 2nd metacarpal, fibula or vertebra in the same individual. On the data presented here, there is some evidence for systematic variation between isotopic values for different elements within the same skeleton, which might suggest a metabolic or physiological component to the variability, but there is also considerable evidence for intra-individual variation. This is most easily seen and compared by plotting the skeletal elements in a fixed order, after having first converted the $\delta^{13}C$ and $\delta^{15}N$ values for each element to standard scores by replacing them with the distance from the mean value for the skeleton in standard deviation units. These plots, for the limited number of skeletons reported here, appear to show a certain consistency (generally a positive correlation between the $\delta^{13}C$ and $\delta^{15}N$ values for all the components, and a positive correlation between $\delta^{13}C$ and $\delta^{15}N$ values for the same element), but some individuals appear to show a radically different pattern, for reasons which we cannot yet explain. We suggest, however, that comparison of these patterns across a skeleton is more likely to show variations in life history than simple observations of rib-femur spacing. In this context, we wish to raise the point that several factors are thought to influence the rates of bone remodelling, including hormonal effects, menopause, diet, and mechanical stress (Carter, 1987). The practice of comparing the isotopic values from skeletal components with relatively slow turnover (*e.g.*, femur) with those of faster turnover (*e.g.*, rib) and interpreting the difference as solely due to dietary differences between earlier and later life (*e.g.*, Roberts *et al.*, 2012) may therefore be an oversimplification.

Overall, we concur with DeNiro and Schoeninger's (largely-ignored) observation that the uncertainties in measurements of $\delta^{13}C$ and $\delta^{15}N$ from human bone collagen from a single bone are of the order of 1‰ (DeNiro and Schoeninger, 1983: 202). If the levels of variability demonstrated here prove to be typical, then differences of less than ~1‰ in both $\delta^{13}C$ and $\delta^{15}N$ are well within sampling error and natural variation. Consequently, we counsel caution when interpreting dietary differences between individuals based on smaller isotopic differences, and particularly when inputting such values into isotopic ecology models. Naturally, since this paper is based on a relatively few number of cases, it should be taken more as a call for more data to be collected rather than a definitive statement.

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Landscape and hominin habitation history of Flevoland (central Netherlands)[a]

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Abstract

In this paper we discuss the landscape development and evidence for hominin activity in Flevoland (central Netherlands). This discussion demonstrates that the area consists of a stacked stratigraphic sequence of different landscapes with (possible) traces of hominin activity dating back to the period 220-170 ka (MIS 7/early MIS 6). In this paper, four time periods are selected for discussion that cover the (1) Upper Middle to Late Saalian (220-170 ka), (2) Younger Dryas (12.9-11.7 ka), (3) mid-Holocene (6000-5400 BP) and (4) Late Holocene (1200-8 BP). During each of these four time periods the study area is characterised by a different environmental setting and specific evidence of hominin activity. Apart from the examination of these four different landscapes and their associated evidence, this paper suggests directions for future research for each of these periods of investigation.

Introduction

The subsurface of Flevoland contains a stacked sequence of stratigraphic environments that provide evidence of multiple past landscapes. In this paper, four of these landscapes representing different time periods are examined to provide snapshots of past environments (Figure 1), together with the evidence for the nature of discrete hominin activities within these respective landscapes. The four time periods selected for discussion are: (1) late Middle to Late Saalian (220-170 ka; early Middle Palaeolithic), (2) Younger Dryas (12.9-11.7 ka; late Final Palaeolithic), (3) mid-Holocene (6000-5400 BP; Early Neolithic) and (4) Late Holocene (1200-8 BP; Medieval and Modern history). Furthermore, for the oldest period of investigation (late Middle to Late Saalian, 220-170 ka), the study area has been enlarged to include the central Netherlands, in order to better understand, analyse and synthesize the landscape and remains of hominin activities of Flevoland.

The contrasting natural environments and associated geological processes examined for the subsurface of Flevoland are typical of those associated with the Late Quaternary development of the western and central Netherlands.

Although the four different investigated environments are variable and contrasting over time, there are physical similarities between these landscapes. For example, for the most recent period of investigation (1200-8 BP) the peat island Schokland was the focus of research as it was one of the few areas in Flevoland that was inhabited during that period. Peat areas may be part of a coastal landscape, as is the case in the investigated mid-Holocene coastal landscape in Flevoland (see figure 5 in Van den Biggelaar *et al.*, 2015). Although no archaeological remains dating to the mid-Holocene have yet been found in these peat areas this may be due to the lack of research in these areas; for example, investigations in northwest Germany indicated that Neolithic archaeological remains can be present in peat areas within wetland environments (*e.g.*, Swifterbant/Rössen site Hüde 1; Kampffmeyer, 1991). In addition, erosion of the peat area since the mid-Holocene may have destroyed preserved archaeological remains within those areas. At a national or continental scale, coastal and deltaic landscapes are similar in terms of reduced effects of seasonality and the wide variety of available food resources in contrast to most inland areas. The differences in the richness and abundance of natural resources between the inland and coastal areas in the Netherlands affected subsistence practices (*e.g.*, Louwe Kooijmans, 1993; Amkreutz, 2013 for the mid-Holocene). These similarities and differences can be used to better understand hominin-environment interactions at a macroscale. Floodplains and wider valley floors could contain a wide variety of resources in different ecotones. An inland floodplain landscape was present in Flevoland during the Younger Dryas (YD). At that time, Flevoland was part of the terrestrial higher ground in close proximity to the lowland North Sea area, thereby forming an important location to study YD hominin-environment interaction within a northwest European framework. A large diversity of natural sources was also present in Flevoland during the Late Saalian (~ 170 ka) when a deltaic river landscape existed in the area (Busschers *et al.*, 2008). This landscape had a high exploitation potential due to the availability of freshwater resources (*e.g.*, Rhine-Meuse river; see Busschers *et al.,* 2008) and the availability of rocks suitable for the production of artefacts (Van den Biggelaar *et al.*, 2016a).

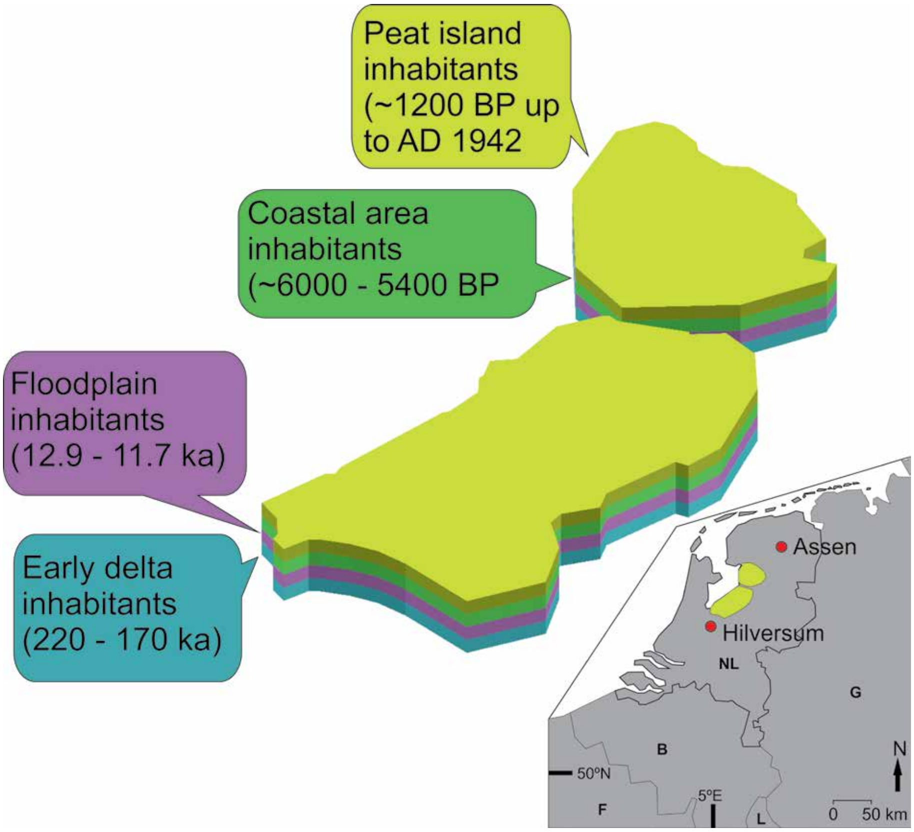

Figure 1. Map of Flevoland showing each of the four selected periods of investigation as a layer, together with the landscape setting and age of each layer. These layers are in chronological order. The inset shows the location of Flevoland within the Netherlands and the locations of Weichselian archaeological sites at Hilversum and Assen.

Late Middle to Late Saalian (220-170 ka, early Middle Palaeolithic)

The western part of the ice-pushed ridges in the central Netherlands contain deposits of the Late Saalian combined Rhine-Meuse fluvial system (~170 ka; Busschers *et al.,* 2008). This fluvial system continued northwards via Flevoland towards the North Sea Basin (Busschers *et al.*, 2008), implying that combined Rhine-Meuse deposits are also present in the buried part of the ice-pushed ridges located in southwest Flevoland. Given the occurrence of early Middle Palaeolithic (EMP) artefacts in the Saalian Rhine-Meuse deposits in the central Netherlands (*e.g.*, Stapert, 1981, 1987, 1991; Van Balen, 2006; Van Balen *et al.*, 2007), combined with the hypothesis that these deposits are possibly also present in the buried part of the ice-pushed ridges of the central Netherlands (southwest Flevoland), EMP artefacts could potentially be present in southwest Flevoland. This hypothesis is supported by the fact that the gravel size and cobble abundance of the pre-glacial Rhine-Meuse deposits in the buried part of these ridges are coarse enough for artefact manufacture (Van den Biggelaar *et al.*, 2016a).

Southwest Flevoland was possibly part of the most northwesternly region with rocks within superficial sediments coarse enough for artefact manufacture during the EMP at the eastern margin of the southern North Sea (i.e. western Netherlands and adjacent offshore area) (Van den Biggelaar *et al.*, 2016a). As the southern North Sea area possibly played a key role in EMP hominin-environment interaction in northwest Europe (Roebroeks, 2014), determining the role of the superficial rock resources in southwest Flevoland in the mobility pattern of EMP hominins in the area is critical to better understanding this relationship (Van den Biggelaar *et al.*, 2016a). This pattern is especially crucial during periods of climatic cooling (*e.g.* early MIS 6) when natural resources were more spatially segregated (Kelly, 1995). To determine the maximum distance between food sources that fitted the mobility pattern of EMP hominins during cool periods, areas lacking EMP remains should be investigated to determine the distance between food patches (Gamble, 1995). The distance between these patches can be used to determine the distance from Flevoland in a northwesterly direction where natural resources should be present in order to fit the mobility radius of EMP hominins.

The EMP artefacts recorded in the ice-pushed ridges in the central Netherlands have a probable age range of 220-170 ka (Van den Biggelaar *et al.*, 2016a), corresponding to MIS 7 and early MIS 6. Although no other evidence of EMP hominins dating to MIS 6 are known (north)west of the central Netherlands (Figure 2. For references see Appendix 1), this may reflect investigation bias and lack of recent research owing to the inaccessibility of these marine and deep subsurface areas. Within the southern North Sea area *in situ* archaeological remains have been found 11 km offshore of southeast England in the lower reaches of the palaeo-Yare fluvial system (Area 240; figure 2) (Tizzard *et al.*, 2014). The sediments in which these artefacts were found were likely to have been deposited within the shallow channels of a braidplain (Tizzard *et al.,* 2014), which is a similar environmental context as the EMP finds from the central Netherlands (see Busschers *et al.*, 2008). Although these artefacts described by Tizzard *et al.*, 2014) probably date to ~250-200 ka BP (MIS 8/7) future research is needed to determine whether within the southern North Sea area archaeological sites dating to MIS 6 are present. The presence of *in situ* archaeological remains in the area of the palaeo-Yare indicates the potential for (geo)archaeological research into EMP hominin activities. Furthermore, the good preservation of the submerged coarse-grained sediments in the cores of Area 240 (Tizzard *et al.*, 2014), allows gravel data from the artefact-bearing interval (unit 3B) to possibly be compared to determine the trend in downstream fining. This comparison may indicate the maximum downstream area within the lower reaches of the palaeo-Yare fluvial system where aggregate can be found that is coarse enough to produce artefacts. Just as for the area northwest of Flevoland, further downstream in the palaeo-Yare, in the region where rocks are not coarse enough for the production of artefacts, EMP hominins could still have undertaken activities by bringing with them rocks to be made into artefacts or ones pre-manufactured as tools.

East of the central Netherlands towards northern Germany, no EMP archaeological sites dating to MIS 6 have yet been found. As most parts of northern Europe were devoid of hominins during cold climatic conditions, like

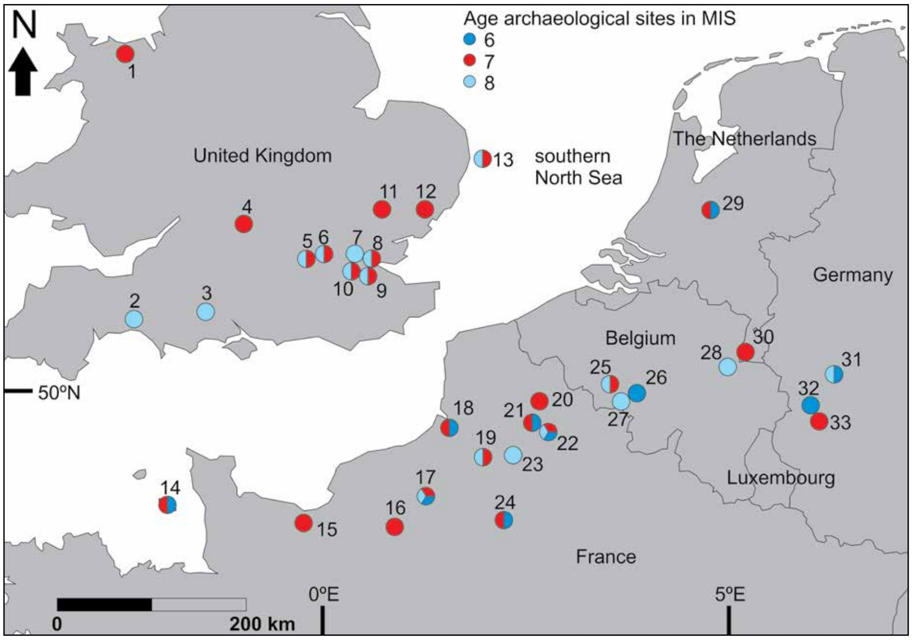

Figure 2. Overview of most likely age of early Middle Palaeolithic (MIS 8-6) archaeological sites in northwestern Europe. The locations of the archaeological sites are compiled from De Heinzelin and Haesaerts (1983), Buckingham et al. (1996), Conard and Prindiville (2000), Lamotte (2001), Scott and Ashton (2011), Van Baelen and Ryssaert (2011) and Tizzard et al. (2014). Data on the age is compiled for previous research (see Appendix 1 for references). Numbers refer to sites mentioned in Appendix 1 and are used for this research: (1) Pontnewydd; (2) Broom; (3) Harnham; (4) Dix's Pit, Stanton Harcourt; (5) West London (Yiewsley area); (6) Creffield Road; (7) Botany Pit, Purfleet; (8) Lion Pit Tramway Cutting, Thurrock; (9) Baker's Hole and the Ebbsfleet Channel; (10) Stoneham's Pit, Crayford; (11) Jordan's Pit, Brundon; (12) Stoke Bone Bed, Ipswich; (13) Area 240; (14) La Cotte de St. Brelade; (15) Ranville; (16) Tourville-la-Rivière; (17) Le Pucheuil; (18) Saint-Valéry-sur-Somme; (19) Salouel; (20) Biache – Saint – Vaast; (21) Oisiers à Bapaume; (22) Gentelles; (23) Gouzeaucourt; (24) Therdonne; (25) Rissori; (26) Carrière Hélin; (27) Mesvin IV; (28) Kesselt-Op de Schans; (29) Central Netherlands; (30) Maastricht-Belvédère; (31) Ariendorf 1 & 2; (32) Tönchesberg; (33) Schweinskopf-Karmelenberg.

MIS 6 (Hublin & Roebroeks, 2009), it is unlikely that during these conditions hominins were present east of the central Netherlands (*e.g.* northern Germany). Similarly, in the northern Netherlands, the environmental setting during MIS 6 was probably characterised by a polar desert (Zagwijn, 1973), bordered in the north by the Fennoscandian ice sheet (Busschers *et al.*, 2008), inhibiting hominin activity at that time.

Younger Dryas (12.9-11.7 ka, late final Palaeolithic)

During the Younger Dryas (YD) (12.9-11.7 ka; Steffensen *et al.*, 2008), sea level in the North Sea was approximately 50m lower than the present-day (see Bradley *et al.*, 2011), resulting in large parts of the North Sea area constituting dry land. At that time, cool climatic conditions prevailed in the Netherlands, combined with a vegetation type dominated by forest tundra (Hoek, 1997). During this period, the landscape was characterised by elevated aeolian (sand) dunes and ridges within the fluvial systems in southern Flevoland (Eem valley) and northern Flevoland (IJssel-Vecht valley) (*e.g.*, Wiggers, 1955; Menke *et al.*, 1998; Peeters, 2007; Van den Biggelaar *et al.*, in press;). No traces of hominin activities dating to the YD have so far been found in Flevoland. This absence of evidence most likely reflects the thick Holocene cover (up to ~8 m) overlying the YD landscape (i.e. Pleistocene land surface) (Van den Biggelaar *et al.*, 2016), making it difficult to locate YD archaeological remains. Across the rest of the Netherlands a similar situation occurs, with YD archaeological remains primarily recorded in areas that lack Holocene deposits (Van den Biggelaar *et al.*, 2016b). Although the model presented by Van den Biggelaar *et al.* (2016b) to predict the location of YD archaeological remains in southern Flevoland still needs to be tested, it provides a way to investigate other areas where YD archaeological remains have not yet been found (i.e. the western Netherlands and the North Sea area). To test this model two steps must be undertaken. Firstly, to determine the accuracy of the landscape classification generated by the concept of Topographic Position Index (TPI; Guisan *et al.*, 1999; Weiss, 2001), a coring campaign should be undertaken within southern Flevoland in an area that according to this classification has an elevated Pleistocene surface within the zone of highest probability of YD archaeological remains (see figure 5 in Van den Biggelaar *et al.*, 2016b). Based on economic and technological reasons, an elevated area should be selected in the south-eastern part of southern Flevoland where the Pleistocene surface is closest to the present-day ground surface (i.e. thinnest sequence of Holocene deposits; figure 5 in Van den Biggelaar and Kluiving, 2015). If such a coring campaign does not confirm the presence of an elevated Pleistocene surface at that location, the TPI-generated landscape classification should be adapted. However, if the coring data confirms the presence of an elevated area, then the second stage should involve trial trenching of the area to determine the presence or absence of YD remains. This procedure should be performed at several locations to improve the statistical significance of the outcome of the procedure.

Filling in the geographical gap in the distribution of YD archaeological remains in northwest Europe (see Van den Biggelaar *et al.*, 2016b), will be of major importance to advance hypotheses on the YD subsistence economy, settlement patterns and spatial organisation; currently, it is unknown what activities were performed during this period in the western Netherlands and the North Sea area. In particular, the latter area is of major importance because during the YD this location is the lowland part of the landscape and has a high potential for well-preserved archaeological remains on the seabed capable of providing high resolution research data (*e.g.*, Weerts *et al.*, 2012; Peeters & Momber, 2014).

Mid-Holocene (6000-5400 BP, Early Neolithic)

During the mid-Holocene (6000-5400 BP), the landscape of Flevoland was characterised by a wetland area with localized dryer ridges underlain by glacial tills and aeolian dunes (see Ente, 1971, 1976; Ente *et al.*, 1986; Hacquebord, 1976; Menke *et al.,* 1998; Peeters, 2007; Van den Biggelaar *et al.*, 2015). During this period habitation concentrated on the dryer glacial ridges and aeolian dunes within the wetland region that gradually expanded and transformed from a freshwater tidal area to a peat marshland (Van den Biggelaar *et al.*, 2015). Although archaeological remains that date within the range of 6000-5400 BP have primarily been found on higher ground within the Eem and IJssel-Vecht valleys, this is most likely because until now (geo)archaeological research in the area has focused on those elevated zones. Therefore, it is possible that the known mid-Holocene archaeological remains in Flevoland do not provide a representative overview of the archaeological record as such remains could also be present in the lower-lying zones within the valleys (*e.g.*, the peat areas). Although many of the lower-lying areas within the Eem and IJssel-Vecht valleys were inundated during the mid-Holocene around 6000 BP, large parts of these areas remained dry (see Van den Biggelaar *et al.,* 2015). Future research needs to be focused on these dry areas to determine whether traces of mid-Holocene activity is present.

Within the IJssel-Vecht fluvial system, various levees have been documented that date to the mid-Holocene (*e.g.*, Swifterbant area: Hacquebord, 1974, 1976), however, for the Eem fluvial system, very few levees are documented (see Woltinge, 2010 for an example of a levee in the Eem system). Like the levees in the IJssel-Vecht valley, the levees in the Eem have a high potential to preserve traces of crop cultivation, because of the high natural fertility. To determine the presence or absence of later prehistoric crop cultivation in the levee deposits of the Eem valley a two-step approach is needed. Firstly, the mid-Holocene levees of the Eem fluvial system should be mapped by a combination of coring campaigns and analysis of the surface elevation map of the area (AHN-3: www.ahn.nl). Secondly, the presence or absence of mid-Holocene archaeological remains should be determined on the mapped levees via a coring campaign. If no remains are found during coring, trial trenches should be opened to increase the investigated surface area and thereby also the chance of finding mid-Holocene archaeological remains. For any trench survey, levees should be selected that are closest to the current ground surface to limit financial costs and technical issues. When coring and/or trenching surveys indicate the presence of mid-Holocene archaeological remains on levees in the Eem valley, the sediments in which these remains are incorporated should be sampled for palaeobotanical analyses. It is expected that integrated palaeogeographical mapping and palaeobotanical sampling would yield significant results since archaeological and pollen remains are likely to be well-preserved in the clayey deposits of the levees. These remains are of major importance to improving our understanding of wetland cultivation practices.

Late Holocene (1200-8 BP, Medieval period and Modern history)

Around 1200 BP the peatland at Schokland (southern Noordoostpolder, northern Flevoland) was inundated and gradually transformed via a brackish environment (~900 BP), into an island in a fully marine environment (~400 BP) (see Van den Biggelaar *et al.*, 2014); today, it forms a landlocked island (created around 8 BP) (*e.g.*, Van der Heide & Wiggers, 1954). Reclamation of this peatland started possibly as early as 1150 BP (Hogestijn *et al.*, 1994). Due to this reclamation, the surface area of Schokland lowered, resulting in the increasing influence of the North Sea on the former island. As a response to this influence, embankments were constructed in the area since ~750 BP (Van der Heide & Wiggers, 1954; Hogestijn *et al.*, 1994). Until the evacuation of the former island in AD 1859 (Handelingen Staten-Generaal, 1857-1858, 1858-1859 in Geurts, 1991), the inhabitants of Schokland struggled against the impact of the Zuiderzee. Between 1200 and 8 BP clay was deposited on this island, which is located in the former Zuiderzee area (inlet of the North Sea in the centre of the Netherlands). The spatial thickness and distribution of this clay on Schokland is explained by a combination of the location of its embankments and proximity to the coastline (Van den Biggelaar *et al.*, 2014). However, Van den Biggelaar *et al.* (2014) indicated that both the North Sea and the River IJssel may also have affected the Late Holocene sedimentation pattern on the former island as they could have influenced the availability of sediment and the hydrological conditions in the Zuiderzee area at that time. The Late Holocene clay at Schokland contains calcareous foraminifera (*e.g.*, *Ammonia beccarii*, *Haynesina* sp. and *Elphidium* sp.) (Van den Biggelaar *et al.*, 2014), implying marginal marine conditions (Murray, 2006). The presence of these foraminifera indicates that the North Sea was possibly a source area for the Late Holocene clay on the former island. The River IJssel may also have contributed to clay deposition on Schokland during the Late Holocene as the delta of this river is located just east of the former island, indicated by the contemporary surface topography that gradually increases from the eastern side of Schokland to the east (Van Balen, 2008). However, to determine whether the IJssel fluvial system was a source for the Late Holocene clay at Schokland, sediment samples from the river are needed for geochemical (*e.g.* major element composition) and grain size analyses in combination with end-member modelling (un-mixing of grain-size distributions: Weltje, 1997; Weltje & Prins, 2003). Apart from exterior influences on the sedimentation pattern of Schokland, local compaction effects on the clay and peat could also have affected the Late Holocene sedimentation patterns of the clay (Van den Biggelaar *et al.*, 2014). Before the effect of compaction on deposition can be determined, the amount of compaction needs to be studied first. Although the surface downwarping rate at Schokland was investigated by Van den Biggelaar and Pieters (2012), this study focused only on the last 200 years, as surface elevation measurements of the former island are limited to this period. Further research is needed to determine whether this period may be extended by correlating the sedimentary remains of storm surges on Schokland with historical storm records that mention the elevations these surges reached. As the remains of storm surges within the subsurface deposits of the former island have been dated by OSL to ~ AD 1615 and between ~ AD 1745 ± 30 and AD 1785 ± 20) (Van den Biggelaar *et al.*, in prep.), historical sources need to be investigated to determine whether storm events during these periods affected Schokland.

The Zuiderzee already existed prior to AD 1615 (see Vos & De Vries, 2013), indicating that sedimentary remains of storm surges prior to AD 1615 may be present on Schokland. The lack of preservation of such remains could possibly be related to its distal position to the coastline and the high surface elevation of the central north part of Schokland compared to the remainder of the former island (compare figures 2B and 5 in Van den Biggelaar *et al.*, 2014). To determine the influence of both elevation and distance to the coastline on the deposition of the sandy laminae that are indicative of storm surges, such laminae at the lower more proximate parts of Schokland need to be dated by OSL. If these laminae yield similar OSL dates to the ones at core location 38, further research is required to determine what may have influenced the lack of preservation of sedimentary remains of storm surges at Schokland prior to 1600 AD.

Conclusions

In this paper we have illustrated the subsurface landscape of Flevoland as recorded in the stack of sedimentary deposits and demonstrated how different landscapes have the potential to record traces of hominin activity that could date back to the period 220-170 ka (MIS 7/early MIS 6). Flevoland was possibly part of the area that was inhabited by the early Middle Palaeolithic hominins of the central Netherlands prior to the Late Saalian glaciation (~150 ka). This region may have played an important role in the mobility pattern of EMP hominins in the North Sea basin as at that time it was possibly the most northwesternly region with rocks coarse enough to allow the manufacture of artefacts in the region that encompasses the western Netherlands and adjacent offshore area. In the western part of the southern North Sea (offshore of southeast England), the furthest downstream area where such lithics have yet been found, the archaeological potential is currently unknown. However, due to the presence of well-preserved Late Saalian sediments in the southern North Sea area, there is a high potential to determine the trend in downstream fining of these sediments by gravel analysis. These well-preserved sediments, combined with the presence of known *in situ* EMP archaeological remains in the southern North Sea, indicate the potential of the area for (geo) archaeological research into EMP hominin activity. Although such traces dating to MIS 6 are unknown northwest of the central Netherlands, research in the southern North Sea area is needed to determine whether archaeological remains dating to MIS 6 are present in the area.

Well-dated *in situ* YD archaeological remains have not yet been found in Flevoland, possibly due to the thick Holocene superficial sediment cover. The accuracy of the TPI-generated landscape classification for the YD landscape of Flevoland needs to be tested to determine whether it can be used for predictive modelling purposes of YD archaeological remains in buried landscapes (*e.g.* in the western Netherlands and the North Sea). If this classification is accurate, field validation checks are needed to determine whether YD archaeological remains are present within the zone that has the highest probability to contain such material.

During the period 6000-5400 BP, the Eem and IJssel-Vecht valleys transformed from a freshwater tidal area to a peat marshland. While within this area mid-Holocene archaeological remains are only known from the elevated parts of the landscape, future research is needed to determine whether such remains are also present in the lower-lying areas when these were still dry (*e.g.*, around 6000 BP).

Further research is also needed to locate mid-Holocene levees in the Eem valley and determine whether evidence of crop cultivation is present at those levees. Such traces may improve our understanding of wetland cultivation practices.

Between 1200 and 400 BP Schokland gradually transformed from a peatland into a fully marine environment. Although the sedimentation pattern of the Late Holocene clay that was deposited on the former island during the period 1200-8 BP was explained by a combination of embankments and its proximity to the coastline, future research is needed to determine whether the North Sea, the IJssel river and local compaction effects also contributed to the observed pattern. The period for which the amount of compaction can be determined may be extended beyond the last 200 years with the use of storm surge records.

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Endnotes

[a] This paper is the first part of the General Discussion chapter in the dissertation of Van den Biggelaar (2017).

Appendix 1

Most likely age of early Middle Palaeolithic sites in northwest Europe. Location of the sites was compiled from De Heinzelin and Haesaerts (1983), Buckingham *et al.* (1996), Conard and Prindiville (2000), Lamotte (2001), Scott and Ashton (2011), Van Baelen and Ryssaert (2011) and Tizzard *et al.* (2014).

Site no. (see Fig. 2)	Archaeological site (1)	Most likely age (MIS) (2)	Age in ka (3)	Type of dating (2 and 3)	References
United Kingdom					
1	Pontnewydd	late 7	200 ± 25 (TL)	Chrono- and biostratigraphy and TL	Green, 1984, 1988 (1), Aldhouse-Green, 1995; Schreve, 1997 (2), Huxtable, 1984 (3)
2	Broom	late 9/ early 8	324-282	OSL, sedimentary and chronostratigraphy	Salter, 1898; Green, 1988; Marshall, 2001 (1), Hosfield and Chambers, 2009 (2), Toms *et al.*, 2005 (3)
3	Harnham	late 8	265-250	Amino acid racemization and biostratigraphy	Melville and Freshney, 1982; Bates *et al.*, 2014 (1), Bates *et al.*, 2014 (2-3)
4	Dix's Pit, Stanton Harcourt	7		Biostratigraphy	Buckingham *et al.,* 1996; Buckingham, 2007 (1), Schreve, 1997 (2)
5	West London (Yiewsley area)	late 8/ 7		Chronostratigraphy	Brown, 1895a, b (1), Ashton *et al.*, 2003; Scott *et al.*, 2011 (2)
6	Creffield Road	late 8/ 7		Chronostratigraphy	Brown, 1886 (1), Ashton *et al.*, 2003; Scott *et al.*, 2011 (2)
7	Botany Pit, Purfleet	8		Chrono- and biostratigraphy	Wymer, 1968, 1985; Schreve *et al.*, 2002 (1), Bridgland, 1994; Schreve *et al.*, 2002; Bates *et al.*, 2014 (2)
8	Lion Pit Tramway Cutting, Thurrock	8/ 7		Chrono- and biostratigraphy and amino acid racemization	Dibley and Kennard, 1916; Warren, 1923a, b; Bridgland, 1985; Bridgland and Harding, 1995 (1), Bridgland, 1994; Schreve *et al.*, 2006 (2)
9	Baker's Hole and the Ebbsfleet Channel	late 8/ early 7		Chrono- and biostratigraphy	Spurrell, 1883, 1884; Abbott, 1911; Smith, 1911; Wenban-Smith, 1995 (1), Burchell, 1954; Bridgland, 1994; Schreve, 1997; Scott *et al.*, 2010 (2)
10	Stoneham's Pit, Crayford	late 8/ early 7		Chrono- and biostratigraphy and amino acid racemization	Spurrell, 1880a, b; Kennard, 1944 (1), Schreve, 1997; Schreve *et al.*, 2006 (2)
11	Jordan's Pit, Brundon	late 7	230 ± 30 and 174 ± 30	Uranium-Thorium (U-Th), chrono- and biostratigraphy	Moir and Hopwood, 1939; Wymer, 1985 (1), Schreve, 1997 (2), Szabo and Collins, 1975 (3)
12	Stoke Bone Bed, Ipswich	late 7		Chrono- and biostratigraphy	Layard, 1912, 1920; Wymer, 1985 (1), Schreve, 1997 (2)
13	Area 240	late 8/early 7	250-200	Stratigrapy and OSL	Wessex Archaeology, 2011; Tizzard *et al.*, 2014 (1), Wessex Archaeology, 2011; Tizzard *et al.*, 2014 (2-3)
France					
14	La Cotte de St. Brelade	late 7/ early 6	238 ± 35 (TL)	TL, biostratigraphy and pedogenesis	Nicolle and Sinel, 1910; Callow and Cornford, 1986; Pope *et al.*, 2012; Scott *et al.*, 2014 (1), Callow, 1986 (2), Huxtable, 1986; Scott, 1986; Van Vliet-Lanoë, 1986 (3)
15	Ranville	early 7	235-205	Biostratigraphy, U-Th and ESR	Cliquet *et al.*, 2008 (1), Auguste, 2008; Bahain *et al.*, 2008 (2-3)
16	Tourville-la-Rivière	7	226-183	ESR and U-series	Verron, 1979; Vallin, 1991; Guilbaud & Carpentier, 1995 (1), Faivre *et al.*, 2014 (2-3)
17	Le Pucheuil	late 8/ early 7, late 7/ early 6		Chronostratigraphy	Ropars *et al.*, 1996 (1-2)

Site no. (see Fig. 2)	Archaeological site (1)	Most likely age (MIS) (2)	Age in ka (3)	Type of dating (2 and 3)	References
18	Saint-Valéry-sur-Somme	late 7/ early 6 (?)		Chronostratigraphy	De Heinzelin and Haesaerts, 1983 (1-2)
19	Salouel	late 8/ early 7		Chronostratigraphy	Ameloot-Van der Heijden *et al.*, 1996 (1-2)
20	Biache – Saint – Vaast	late 7 (here: 200 ka)	175 ± 13 (TL) and 253 + 53/-37 (ESR)	Thermoluminescence (TL), Electron Spin Resonance (ESR) and biostratigraphy	Tuffreau and Sommé, 1988 (1), Sommé *et al.*, 1988; A. Tuffreau, pers. comm. from Rots, 2013 (2), Huxtable and Aitken, 1988; Yokoyama, 1989 (3)
21	Oisiers à Bapaume	late 7/ early 6	194 ± 21	Infrared Stimulated Luminescence (IRSL)	Tuffreau, 1972, 1976; Koehler, 2008 (1), Balescu and Tuffreau, 2004 (2-3)
22	Gentelles	late 9/ early 8, late 7/ early 6	300-250, 180	Chronostratigraphy	Tuffreau *et al.*, 2001 (1), Tuffreau *et al.*, 2008 (2-3)
23	Gouzeaucourt	possibly 8		Chronostratigraphy	Sommé, 1975; Tuffreau and Bouchet, 1985; Lamotte, 2001; Tuffreau *et al.* 2008 (1); Tuffreau and Bouchet, 1985 (2)
24	Therdonne	late 7/ early 6	178 ± 11	Chronostratigraphy, TL	Locht *et al.*, 2000; Hérisson, 2007 (1), Locht *et al.*, 2000 (2-3)
Belgium					
25	Rissori	8-7		Chronostratigraphy	Adam and Tuffreau, 1973 (1), Adam, 1991, 2002 (2)
26	Carrière Hélin	6		Chronostratigraphy	De Heinzelin, 1959; Cubuk, 1975; Michel, 1978; Cahen, 1984 (1), Haesaerts, 1978; Pirson *et al.*, 2009 (2)
27	Mesvin IV	8	300-250	Uranium-Thorium (U-Th), chrono- and biostratigraphy and palynology	Cahen *et al.*, 1984; Cahen & Michel, 1986 (1), Haesaerts, 1978; Cahen *et al.*, 1979, 1984; Cahen and Michel, 1986; Van Neer, 1986 (2-3)
28	Kesselt-Op de Schans	early 8	300	Chronostratigraphy	Van Baelen *et al.*, 2007, 2008 (1), Van Baelen *et al.*, 2007 (2-3)
The Netherlands					
29	Central Netherlands	late 7/ early 6 (here: 220-170)	168 ± 19 (OSL)	OSL, typochronology and chronostratigraphy	Stapert, 1981, 1987, 1991; Van Balen, 2006; Van Balen *et al.*, 2007 (1), for literature see discussion in chapter 3 (2), Busschers *et al.*, 2008 (3)
30	Maastricht-Belvédère	7	250 ± 20 (TL), 220 ± 40 (ESR)	Thermoluminescence (TL), Electron Spin Resonance (ESR) and chrono- and biostratigraphy	Van Kolfschoten and Roebroeks, 1985; Roebroeks, 1988 (1), Van Kolfschoten and Roebroeks, 1985; Vandenberghe *et al.*, 1987; Roebroeks, 1988; Van Kolfschoten *et al.*, 1993 (2), Roebroeks, 1988; Huxtable, 1993 (3)
Germany					
31	Ariendorf 1 & 2	8 and 6	>220 (most likely ~ 250) and 190-150	Chronostratigraphy/ Tephrochronology	Bosinski *et al.* 1983; Turner, 1986, 1997 (1), Van den Bogaard and Schminke, 1990; Turner, 1997; Richter, 2011 (2-3)
32	Tönchesberg	6	between 121 ± 11 and 129 ± 12 (TL)	TL and chrono- and biostratigraphy	Conard, 1988; Conard, 1992 (1), Conard, 1992 (2), Zöller *et al.* 1991 (3)
33	Schweinskopf-Karmelenberg	7	198	U-Th and chronostratigraphy	Bosinski *et al.*, 1986; Schäfer, 1990 (1), Schäfer, 1990 (2), pers. comm. from C. Tiemei in Schäfer, 1990 (3)

Reconstructing palaeolandscapes in the eastern Rhine-Meuse delta (The Netherlands)

Finding the starting point of the Linge channel?

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Abstract

The Linge is a water body in the central Netherlands, comprising a western part which is a natural branch of the Rhine delta, and an eastern part which is largely artificial. This latter part consists of a series of drainage channels dug to drain excess water from the Betuwe, the area between the Lower-Rhine and Waal river branches. These drainage channels have been constructed within the framework of medieval land reclamation. In some places residual gullies have been used to create these channels. The contemporary Linge starts near Doornenburg with an inlet sluice in the dike along the Pannerden Canal. However, this situation is not original, because the Pannerden Canal was dug in AD 1707, leading to the isolation of a piece of the Betuwe, which is also known as the Isle of Gelderland.

At the eastern side of the Isle of Gelderland the village of Herwen is located, originating in Roman times as a fortification and probably known as Carvium. Oral history suggests that during the mid-20th century the main local watercourse was called “Lingse Graaf”. This may correspond to a text from AD 1552, which states that the Linge started at Lobith, near the 16th century bifurcation of the Lower-Rhine and Waal. This paper illustrates how the natural water course and

drainage channels developed in the area from late medieval times until the present. This allows us to assess whether the Linge channel originated near Lobith or that we should reject this possibility.

Introduction

The Linge, situated in the central Netherlands, is a water body that has formed and evolved through two different mechanisms (Cohen *et al.,* 2012). The western part, from Tiel to Gorinchem, originated as a natural branch of the Rhine delta, and was used for transport since at least Roman times, evidenced by the discovery of a Roman vessel near Kapel-Avezaath, 5 km west of Tiel (Louwe Kooijmans, 1968; Berendsen, 1990; Brouwers *et al.*, 2013, 26). In contrast, the eastern part, from Doornenburg to Tiel, is largely artificial, consisting of channels constructed within the framework of medieval land reclamation, to drain the low-lying basins of the Betuwe, between the Lower-Rhine (Nederrijn) and Waal river branches (Figure 1).

Today the Linge begins east of Doornenburg, at an inlet sluice constructed in the 1950's in the dike along the Pannerden Canal ("Pannerdensch Kanaal") (Figure 2). This canal was dug in AD 1707 in order to improve the navigability of the Lower-Rhine river branch (Van de Ven, 2007, 59-66; 143-146). The new artificial channel replaced part of the natural river branch which has since been called Old Rhine. This river segment ceased to be used for transports and this area became a polder in the 20th century by the construction of new dikes at the upstream and downstream end.

It is conceivable that the construction of the Pannerden Canal has intersected with the earlier drainage system of this area and that the Linge could have started further eastward prior to canal building. The cut off part of the Betuwe east of the canal is since known as the Isle of Gelderland ("Gelders Eiland") also as the Three Village Polder ("Driedorpenpolder", named after the settlements of Pannerden, Herwen and Aerdt) and now drains northwards into the Old Rhine via a pumping station in its dike (Figure 2).

The course of the Linge is referred to in a historical petition of AD 1552 by inhabitants of the Lower Betuwe, which indicates that it had its starting point at Lobith, near the tollbooth, situated in the current center (Van Veen, 1916, 178). If correct, this suggests that the Linge originated near the medieval bifurcation of Lower-Rhine and Waal. However, it must be stressed that no other known historical documents mention the presence of the Linge east of Doornenburg / Pannerden.

A possible new insight into the historical development of the Linge is provided by an oral history report of Mr. Herman Peters, an inhabitant of the present village Herwen; his account suggests that around 1940 the watercourse south of Herwen was called the "Lingse Graaf". The term "graaf" is common in this region and refers to a dug waterway.

This new account by a living resident provided an opportunity to review the available evidence with respect to the the Lingse Graaf, its relationship to the Linge and to consult different sources of information in order to examine whether this possibility could be confirmed by additional analysis of historical and geomorphological data. In order to address these questions, the whole drainage system of the Three Village Polder has been scrutinized.

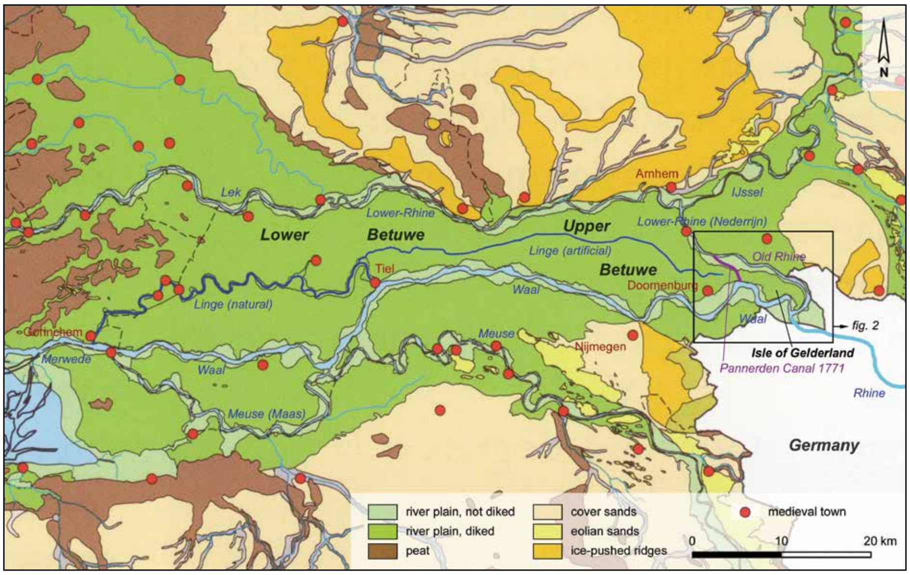


Figure 1. Course of the natural and artificial Linge within the Rhine-Meuse delta with the Pannerden Canal and the cut off part of the Betuwe. Map background represents the situation about 1500 AD (Vos et al., 2011).

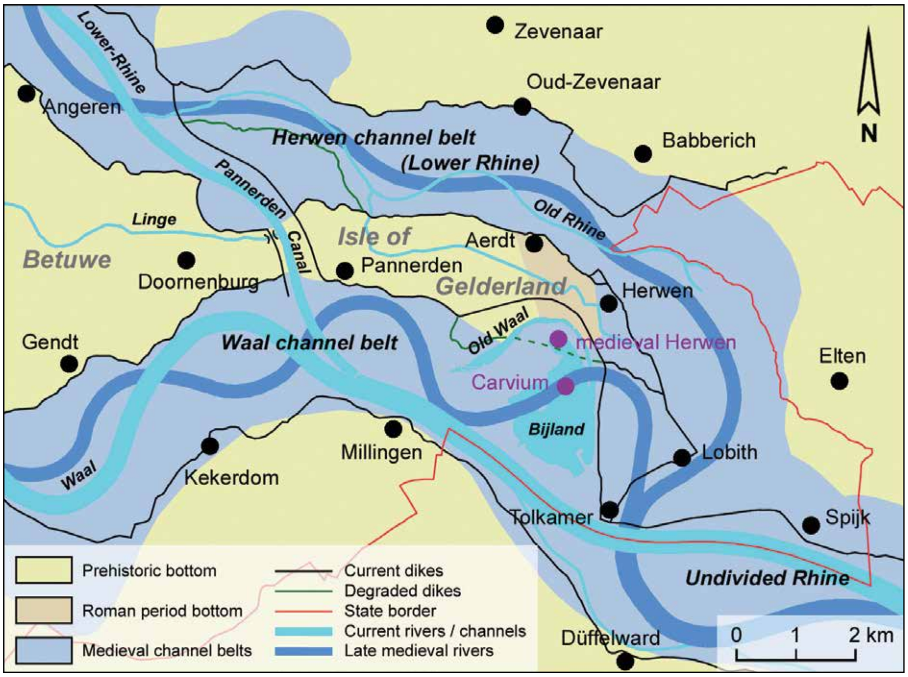


Figure 2. Situation of the Isle of Gelderland, the part of the Betuwe cut off by the construction of the Pannerden Canal. The late medieval bifurcation of the Rhine is situated southwest of Lobith. The current starting point of the artificial Linge at the inlet sluice built around 1950 from the Pannerden Canal, is situated east of Doornenburg. (Map after Verhagen et al., 2017, fig. 9).

Herwen probably developed as a Roman fortification (*castellum*) called Carvium (Verhagen, 2014). Remains of it were found in part of the Bijland (Figure 2) during the sand and gravel extractions in the 1930's to the 1950's. During the northward encroachment of the big Waal meander of the Bijland (Old Waal) in the 18th century the medieval village of Herwen was swallowed (Van Petersen, 1974, map 1; see fig. 2). After that a new village Herwen was founded in its current location and at some distance from the area eroded by the Waal a replacement river dike was constructed in AD 1771-1772 (Van de Ven, 2007, 100-101). As a result, a large area originally situated inside of the dike was now located outside of it.

Previously collected evidence

The western part of the Linge is a river branch of the Rhine-Meuse delta (Cohen *et al.*, 2012, channel belt no. 97), which splits from the Waal (channel belt no. 175) at Tiel and flows into the Upper-Merwede (channel belt no. 109) at Gorinchem (Figure 1). The sedimentation of the Linge channel started about 200 BC, while the channel was dammed at its upstream end at Tiel in AD 1307, just one or two centuries after its embankment.

The eastern part of the Linge, between Doornenburg and Tiel, is largely artificial, consisting of channels that have been constructed within the framework of medieval land reclamation, to drain the low-lying basin areas of the Betuwe. The flow of drainage water was facilitated by the partial use of ancient residual gullies as well as the digging of ditches through low basins and sometimes through stream ridges (Gouw & Erkens, 2007; Mentink & Van Os, 1985, 111-112; Vink, 1954).

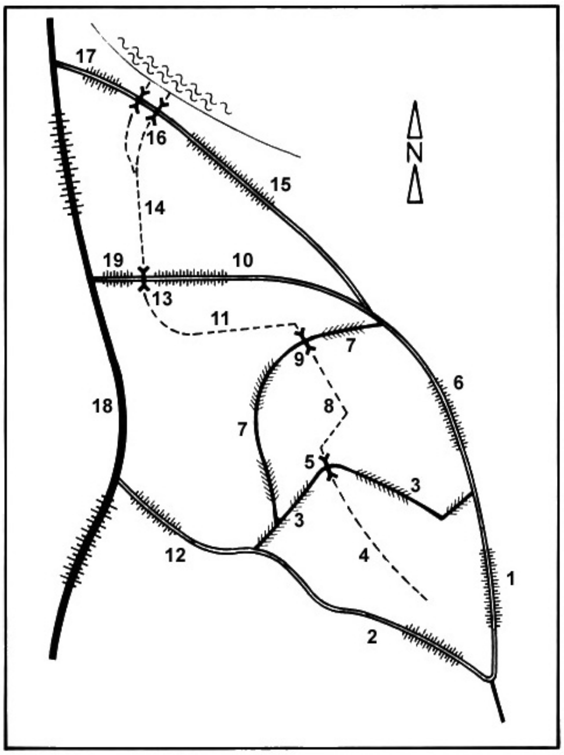
The development of the system of river dikes in the eastern delta of the Rhine started separately in each village with the construction of "zijdewendes", "achterwendes" and thereafter the "voorwendes" in a period of partial embankments (10th-13th century). This allowed every village to discharge its water into suitable areas near the river such as depressions and channels in the flood plain and the adjacent border areas between villages (De Koning *et al.*, 2009, 18-20).

From the 13th century onwards, there is a phase of ring dike construction, whereby the partial embankments of the villages were connected to each other. For example, the ring dike of the "Ambt Over-Betuwe", including the village polders Pannerden, Herwen and Aerdt. During this phase, each village was drained via a sluice at the lower part of its polder on the adjacent river.

For the Three Village Polder the digging of the Pannerden Canal in AD 1707 had a big impact on water management (Van de Ven, 2007, 59-66). It was preceded in AD 1701 by the construction of a retrenchment (wall with moat) between the Waal and Lower-Rhine to protect Holland against the French Army during the Spanish War of Succession. At this time the moat was not connected with the river Waal in order to maintain the embankment of the river. However, in AD 1707 the moat was widened and connected with the rivers allowing the first ships through the canal. Along the east side of the canal a new dike was built (Van de Ven, 2007, 60-62).

One might assume that the present drainage channel to the north into the Old Rhine (Figure 2) would have been constructed after the building of the Pannerden Canal, but historical records indicate that drainage into the Rhine already existed

Figure 3. *Schematic map of the situation of water management in the Polder area of Pannerden, Herwen and Aerdt in 1659. Doornenburg and the Betuwe are situated at the westside (left of nr. 18). Source: Van Petersen 1978.*



by AD 1659 (Figure 3, Van Petersen, 1978, 25). Fig. 3 illustrates that the water of the Three Village Polder was discharged by a sluice (13) in the Deukerdijk (19) into the Pannerdense Waard. The water was then discharged through two sluices (16) on the Lower-Rhine (now known as Old Rhine).

Although in more recent times it has been stated that the starting point of the Linge channel is to be found directly east of Doornenburg in the fields of "Honderd Morgen" (Mentink & Van Os, 1985, 110-114; Mulder, 2002, 23-25), the question remains as to what was the impact of the digging of the Pannerden Canal on the water management in this area. Was there before AD 1707 a continuous drainage system for both the Three Village Polder and (the rest of) the Betuwe and what was its planform morphology?

Results of new evidence

In order to investigate the ancient drainage system near Doornenburg and in the Three Village Polder we analysed data from historical maps and other documentary sources and created a Digital Elevation Model (DEM) by LIDAR of the region.

Local depressions and old river channels

The DEM map of the area of Pannerden and Doornenburg indicates that the Linge could have been truncated by the construction of the Pannerden Canal (Figure. 4, red arrows). North of Doornenburg the drainage channel of the Linge is situated

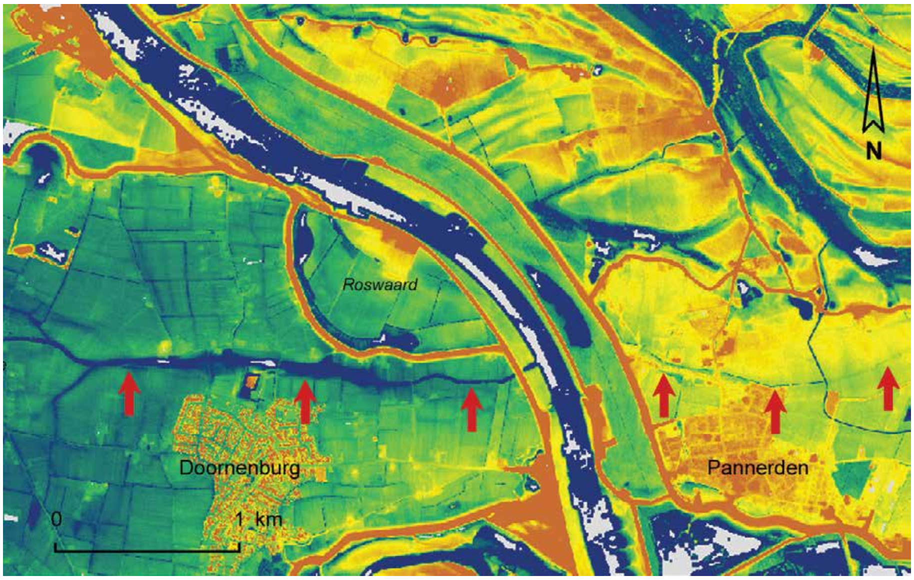


Figure 4. Digital Elevation Model image by LIDAR of the area around the Pannerden Canal. Source: www.ahn.geodan.nl/ahn, AHN1 (1998), accessed: June 2014, viewer set between 10.0 and 13.0 m above sea-level.

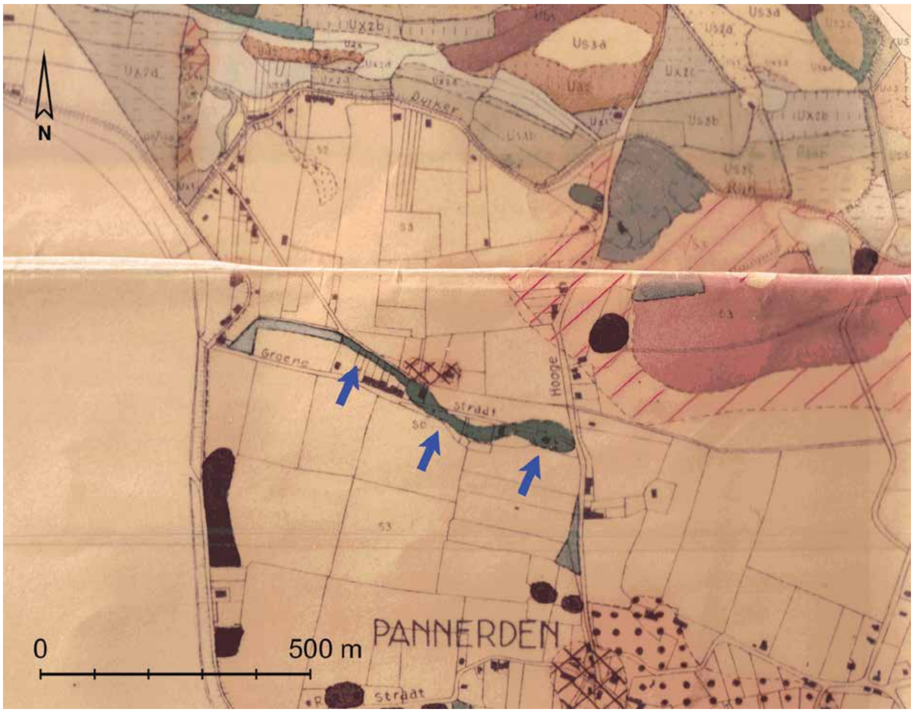


Figure 5. Residual gully northwest of Pannerden, detected by Stiboka. Source: Pons, 1952.

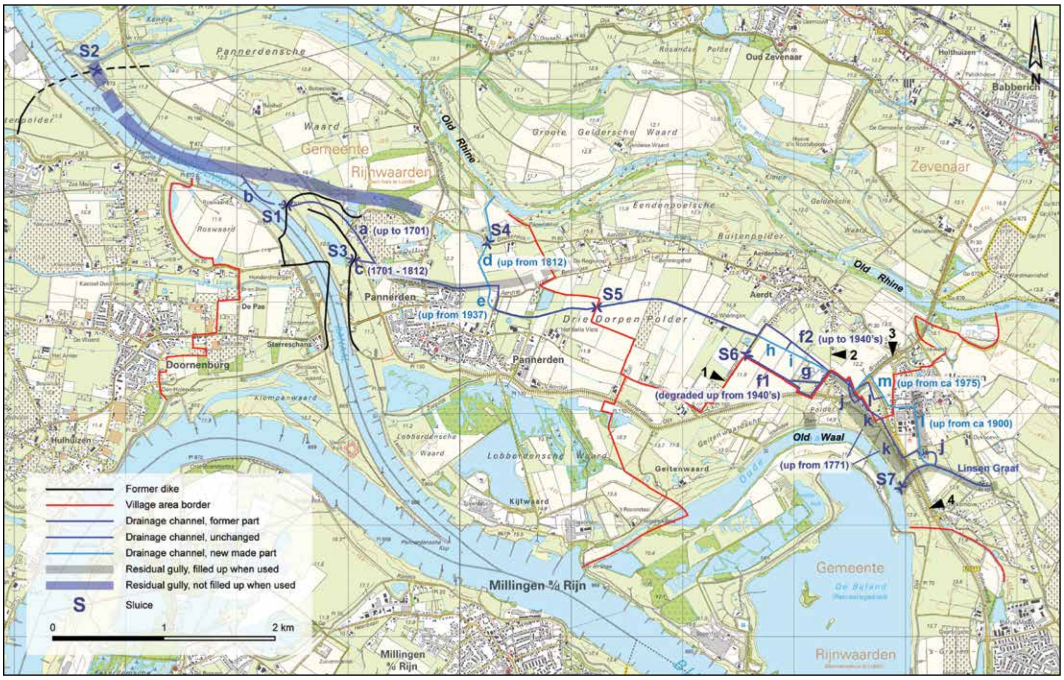


Figure 6. Current and former drainage channels in the Three Village Polder as derived from historical maps. Streets that are referred to in the text: 1 = Loostraat, 2 = Heuvelakkersestraat, 3 = Brugweg, 4 = Batavenweg. Other phenomena are referred to in the text. Map background: Topographical map 2009, scale 1:25,000, by the Dutch Topografische Dienst, map nr. 117.

in a 100 m wide residual gully. Further to the east the low area is still recognizable but is narrower, although it is still wider than the current watercourse and has been mapped as a residual gully (Figure 5, Pons, 1952).

North-east of Pannerden the current drainage channel crosses the low area noted on the DEM. Here the potential residual gully on the DEM seems to emanate from the east-north-east (Figure 4), but because it is quite narrow we cannot exclude that it concerns the subsided remains of a disused drainage channel. It is difficult to determine on the DEM whether the low areas on either side of the Pannerden Canal belong to a single gully system.

Old drainage channels in the Three Village Polder

On a map from AD 1705, the Linge is shown as starting near Doornenburg, while the area of Herwen, Aerdt and Pannerden is drained separately by a waterway to the north-west into the Lower-Rhine (map nr. 1). However, on a map from AD 1573 the drainage from the area of Herwen, Aerdt and Pannerden along Doornenburg continues via the Linge (map nr. 2). On the other hand, a map from AD 1633 shows the Linge channel starting in the area “Honderd Morgen” near Doornenburg (map nr. 3).

In order to reconstruct the drainage configuration before and after the digging of the Pannerden Canal, several historical maps of the region were analysed. This investigation allowed us to identify the known positions of former drainage channels, which are presented together with the contemporary water network in fig. 6. Age estimates for individual features are drawn from these historical maps and other documentary sources. The maps used for this analysis are summarized in the table of appendix 1.

In order to be able to reconstruct former trajectories of drainage channels accurately map nr. 4 ("Verpondingskaart", AD 1771-1800, part is represented in fig. 8) provides us with good baseline knowledge. First, palaeo-drainage channels located on this historical map are drawn on the current topographic map. Based on these historic channel positions, watercourses from even older maps could be correlated more easily, by comparing and identifying boundary positions that have changed little. In the following section, the ancient watercourses will be summarized per sub-area, but described only when directly relevant to this study.

Former drainage network near the Pannerden Canal

The channel from the area as presented on map nr. 5 (AD 1694, fig. 7) flows through a sluice in the Deukerdijk (Figure 6, S1 and d2), with (breakthrough) ponds at either side of the dike (Figure 6, a) and then within a fairly short distance (Figure 6, b) drains into an old Rhine gully. This river gully subsequently flows through a sluice (Figure 6, S2 and d1) into the former Lower-Rhine (now Old Rhine). Also notable is that the main Lower-Rhine dike of the Betuwe, named Luijendijk, is situated along the old Rhine meander of the Roswaard and with a sharp turn southward it is connected as a transversal dike ("Dwarsdijk") with the dike along the river Waal (Figure 6, d3; fig. 7 and 8).

A map from AD 1703 shows the situation after the construction of the retrenchment which began in AD 1701 (map nr. 6). The transversal dike has been used as a barrier and was extended with a newly raised earthen wall along the old gully to the Lower-Rhine. In front of this retrenchment wall a moat was built, partly formed from the old river gully. The moat was not connected to the Waal (Figure 6, d5). The drainage channel then flowed into the moat via the southern (short) conduit (Figure 6, c, *cf.* Figure 8) with no sluice at that point (because there is no embankment along the canal).

The map of AD 1707 shows the completed Pannerden Canal (map nr. 7). At some distance to the east side of the canal a new dike has been built (Figure 6, d4). The mouth of the drainage channel is now equipped with a sluice in the new dike (Figure 6, S3). On a map from AD 1756, the canal appears to have been widened as far as the new dike (map nr. 8). The sluice of the drainage channel is now called the Great Sluice ("Groote Sluijs").

Situation in the area between Pannerden and Aerdt / Herwen

From a point 1 km north-west of Pannerden a new drainage channel (Figure 6, d) with a sluice (S4) carries the water from the Three Village Polder into the Old Rhine up since 1812 (Van Petersen, 1978, 34). At the point where this channel was connected to the existing drainage system the kinks in the system were adapted in 1937 to improve water flow (map nr. 9). A new bend (Figure 6, e) was connected in the extension of the northern drainage channel. One kilometer east of this location a sluice is indicated at the point where the old border Aerdt-Pannerden crosses the

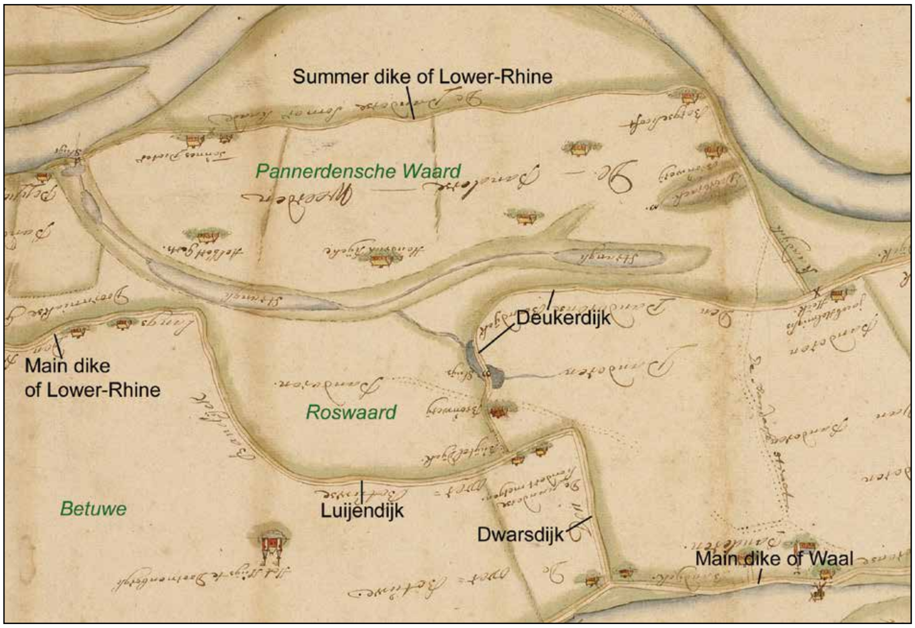


Figure 7. Part of the map from 1694 with the situation before the construction of the Pannerden Canal. Source: see appendix 1, map nr. 5.

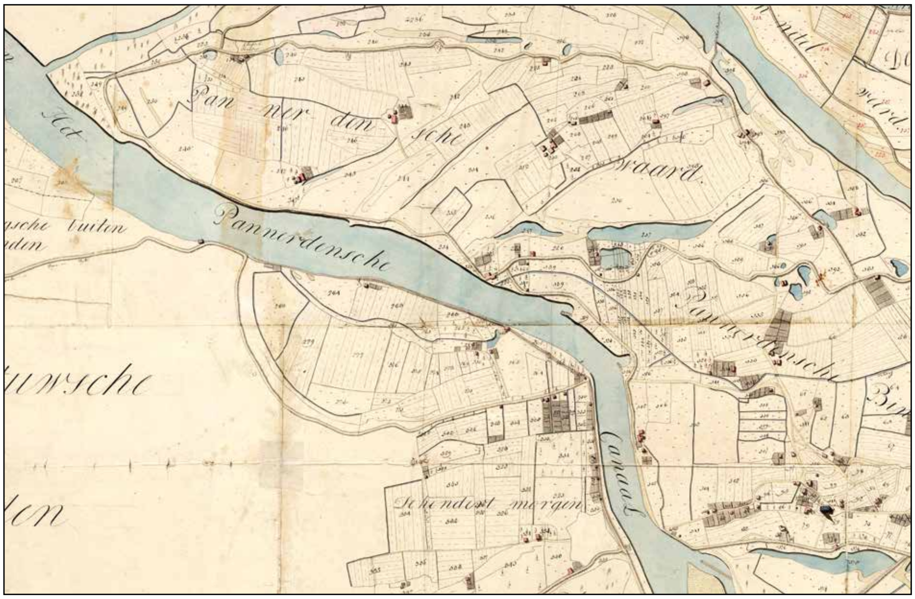


Figure 8. Part of the Verpondingskaart (of 1771-1800) with nearly the same area as shown in Figure 7. Source: see appendix 1, map nr. 4.

watercourse (Figure 6, S5). In AD 1866 this sluice is recorded as "Aerdtse Sluisje" (map nr. 10). Further east another sluice is indicated at the Loostraat (Figure 6, S6), though continuing in this direction no other sluices are shown on this map.

Old drainage channels near Herwen

In the 18th century the drainage channel south of Aerdt divided and flowed along the two long sides (Figure 6, f1 and f2) of a rectangle (map nrs. 4 and 11). The new dike north of the Old Waal was in AD 1771-1772 laid over the southern corner of this rectangle, after which it has been shortened with a new channel segment (Figure 6, g). The other adaptations of the watercourse within the rectangle (Figure 6, h and i) are recorded on the maps of 1937 and later. On a map from 1943 (map nr. 12) the upstream part of the watercourse south of Herwen bears the name "Linsen Graaf" (Figure 6). In AD 1770 there was an outlet with a sluice into the (Old) Waal (map nr. 14; fig. 6, S7).

The watercourse downstream from the Linsen Graaf is indicated on map nr. 4 and flows to the north-west directly along the new dike of AD 1771 and then moves along the former border between Herwen and Aerdt to the current Heuvelakkersestraat (Figure 6, j). Two channel segments are situated parallel to the inner foot line of the dike (Figure 6, k), which can be considered as new trajectories (shifted eastward) after the building of this dike, just like the new segment g. Before 1903, the route of flow has been moved further eastward from the dike of 1771 (map nr. 13, fig. 6, l). During the construction of the Brugweg and the Batavenweg in about 1975 the course was partly shifted again (Figure 6, m), without significant changes in the trajectory.

Discussion and conclusions

The Isle of Gelderland, the truncated part of the Betuwe, created by the digging of the Pannerden Canal, was and is drained by a system of artificial channels, partly made utilising residual gullies and partly new features dug through low-lying basins. The trajectory north of Pannerden is located in a residual gully of an unknown age (Figure 4). However, whether this residual gully is connected with the one near Doornenburg in which the Linge channel is situated, is unclear. This latter residual gully might be of prehistorical age, like many such features in the eastern part of the Betuwe (Mulder, Salverda en Van den Hurk 1979, 31-32).

Recent coring undertaken near Herwen has revealed four hitherto unknown residual gullies (Figure 9, Verhagen *et al.*, 2017). The sediments of three of these have been dated by AMS radiocarbon methods. The largest gully (Figure 9, B) was dated to between 90 BC and 55 AD, while gullies A and C are dated around the 5th century AD.

By combining this data with the course of the drainage channel near Herwen, we can conclude that the Linsen Graaf was constructed in residual gully D. The further route to the north-west was positioned along the eastern border of residual gully B. However, because the new dike of 1771 was also built upon or near the eastern border of gully B, it is difficult to identify this route in the field. On the other hand, the western border of this large gully can still be identified in the local relief of several plots (meadows) between the dike and the Old Waal. The large gully would have been a very prominent and recognizable feature in the landscape prior to the building of the new dike and would have formed an attractive option for determining the position of the drainage channel during the Middle Ages. This pre-existing feature also explains why the Heuvelakkersestraat at the junction with the

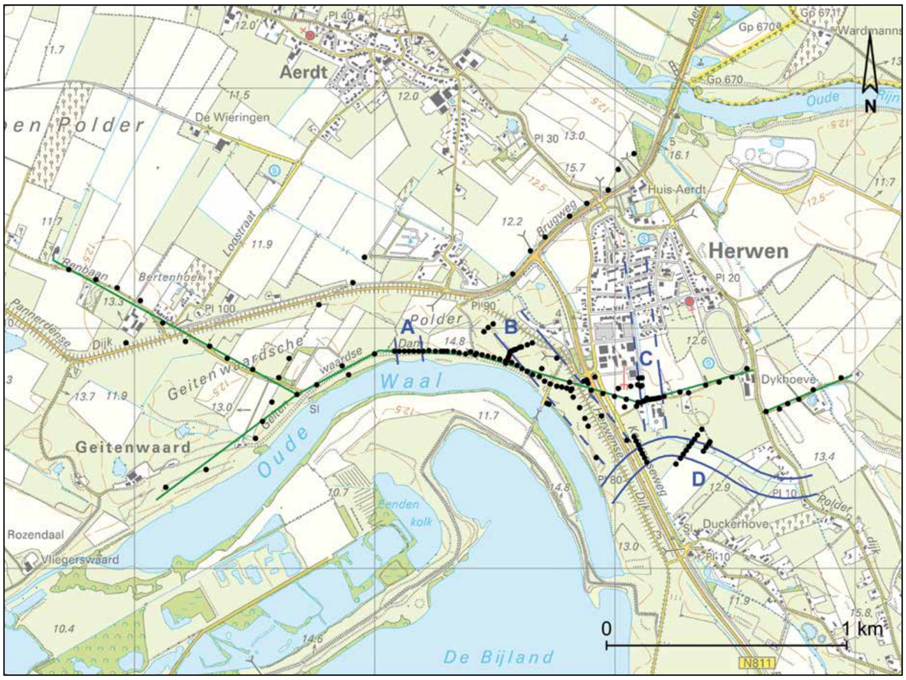


Figure 9. Position of 4 recently discovered residual gullies near Herwen. Black dots are the positions of the cores. Source: Verhagen et al., 2017.

watercourse has some kinks. This may be interpreted as the ancient crossing over the major residual gully in the old road of Aerdt to the medieval settlement of Herwen.

Also part of the deflected drainage channel made around 1900, namely the south-north segment south of the current village of Herwen, was positioned in a residual gully (C). It is possible that this gully already contained a local ditch, which was enlarged at the time of the drainage configuration. From the Heuvelakkersestraat westward the watercourse consists of relatively long straight sections that are supposedly dug in the low-lying basin in the period of the land reclamations (late Middle Ages).

Through our analysis of old maps, it is clear that prior to the construction of the Pannerden Canal the Three Village Polder had its own drainage system, allowing waters to flow north-west into the Lower-Rhine (Figure 6, a/b). This conclusion is supported by the presence of the transversal dike between the Roswaard and the Waal on maps prior to AD 1701; this dike separated the drainage systems of the Three Village Polder and the rest of Betuwe and was transformed into part of the retrenchment in 1701 (Van de Ven, 2007, 36).

The construction of transverse dikes is associated with the dramatic increase in the activity of the river Waal following the Elisabeth flood (“St. Elisabeths Vloed”) of AD 1421 in the western part of the delta. Along the Waal, water seepage and the associated risk of dike breaches increased following this event (Van de Ven 2007, 11-19; Van Hemmen & Heunks, 2015). From the 15th century a number of cross dikes were constructed, for example the Aalsdijk at Buren and at a later stage the Spaniard dike between Upper and Lower Betuwe. Even before AD 1490 regional authorities must have planned to build the Over-Betuwse Dwarsdijk, east of Doornenburg between the point where the Deukerdijk joins the Luijendijk and the Waaldike directly west of Pannerden (Van Schilfgaarde, 1932).

The separate drainage system of the Three Village Polder before AD 1701 draining into the Lower-Rhine seems contrary to the statement of AD 1552 that the Linge starts at Lobith and the oral tradition of "Lingse Graaf", also mentioned on the map of 1937 as "Linsen Graaf". Etymology has to provide an explanation here: both the name Linge and Linsen may be corruptions of the Medieval Dutch "Lingene": filth ("drek"), mud ("modder") (Schönfeld, 1955, 262-263).

The name "Linsen Graaf" is only known for the most upstream part of the watercourse. As the watercourse of the Three Village Polder would have been a cut off part of the Linge, why don't we observe the name "Linsen Graaf" along other parts of the watercourse? Furthermore, the statement of AD 1552 that the Linge had its origin near Lobith has not been confirmed. No other historical sources mention the presence of the Linge east of Doornenburg / Pannerden.

Therefore we assume that the flow of water from the Three Village Polder has always been separated from the waters draining the rest of the Betuwe. However, it cannot be proved that the movement of the meander of the Roswaard has not disrupted the medieval course of a combined drainage system, but evidence for this is not forthcoming at the present time.

Another question is whether the northward encroachment of the big Waal Meander has had an impact on the course of the drainage system in the area. From the results presented in this study it is conceivable that only small parts of the watercourse had to be shifted to the north / east, becoming necessary by the building of the new dike. It is likely that the shift further eastward at a later date was motivated by increased water seepage at the foot of the dike, due to the gradually increasing elevation of the dikes at that time.

Summarizing we conclude that the main drainage system in the Three Village Polder consists of some parts which have utilised ancient residual gullies and other parts which have been dug freshly in the low-lying flood basin area. This provides a parallel with the situation of the Linge in the Betuwe. There are no reasons to assume that the Linge channel originally started in the Three Village Polder in the vicinity of Herwen or Lobith. The main arguments supporting this conclusion are the existence of the transversal dike east of Doornenburg and the north-western drainage of the Three Village Polder before the construction of the retrenchment in AD 1701 and the Pannerden Canal in AD 1707.

The mention in AD 1552 in a petition of inhabitants of the Lower Betuwe that the Linge started at Lobith can be seen as a mistake and was probably made because of the distance, meaning that one was not properly informed about the actual situation near Herwen and Lobith. Furthermore, Lobith is situated outside of the Three Village Polder, so the drainage system could not have started easily there. In addition no other historical sources mention the presence of the Linge east of Doornenburg / Pannerden, although one cannot completely exclude the possibility that the situation during the Middle Ages (i.e. before the construction of the transversal dike) was different from that of the 17th century.

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Appendix 1

Table of consulted maps:

nr	date	map name
1	1705	N. de Fer, Le Cours du Rhein depuis Rheinberg jusque a Arnhem
2	1573	Christiaen 'sGrooten, Atlas of the Spanish Netherlands, Royal Library Brussels, inv. nr. 21569, sheet XVII
3	1633	N.N., De waterleiding van het Huis te Doornenburg tot de Grift. RAG 0124 Hof van Gelre en Zutphen, Alg. Kaartenverzameling no. 431, inv.nr. 5133
4	1771-1800	Kaart van de kerspelen Herwen en Aerdt, mitsgaders de Hooge en Vrije Heerlijkheid Pannerden, 1700-1800, Gelders Archief, 0873 Verpondingskaarten, nr. 84
5	1694	Gerard Passavant, Caarte van de bandijken der Waal en Nederrijnstroom bij Panderen… RAG 0124 Hof Van Gelre en Zutphen, Alg. Kaartenverzameling no. 319, inv.nr. 5669
6	1703	Gerard Passavant, Caart van het retranchement tot Pannerden, 1703, RAG 0003 Archief gedeputeerden van Nijmegen, inv.nr. 1009
7	1707	Gerard Passavant, Caerten van 't retrenchement tot Panderen (18 juli 1707), RAG 0011 College tot Beneficiëring van Nederrijn en IJssel, inv.nr. 262
8	1756	W. Leenen, Caart figuratif van den Rhijnstroom, RAG 0012 Gelderse Rekenkamer, inv.nr. 652
9	1937	Kaart Verruiming Hoofdwaterleidingen, Oud Archief Polderdistrict Oude Rijn, sheet 1
10	1866	Bonneblad 1866, Kadaster, map number 513
11	1810	Kaart van de landen gelegen in de gemeente van Aart, 1810. Gelders Archief, 0873 Verpondingskaarten, nr. 85
12	1943	Kaart aanleg kwelkaden, Oud Archief Polderdistrict Oude Rijn, inv. nr. 123
13	1903	Bonneblad 1903, Kadaster, map number 535
14	1770	Kaart vertoonende de waare gedaante van de Bylandsche Waard. Gelders Archief, 0509 Kaartenverzameling 1192

Where bio- and geochemistry meet

Organic residues in copper corrosion products?

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Abstract

We suspect that the mineral corrosion products which form on the surface of archaeological copper alloy objects might provide a suitable locus for the preservation of organic residues, thus offering new insights into the ritual or mundane use of copper vessels. A preliminary study was therefore carried out to extract the organic compounds from the corrosion products on five copper alloy vessels from two rich Roman burials excavated in Kent (England). In two of the five vessels, we identified more organic compounds on the interior of the vessel than on the exterior, suggesting that organic residues can be preserved within the corrosion products of archaeological copper alloy objects. Although much more work is needed to confirm this, we suggest that this might open up the possibility of extending the study of the use of vessels via the identification of organic residues to include metal forms.

Research design

From the 1970s onwards, archaeologists have been able to infer the use of ceramic vessels from an analysis of the organic residues preserved, either invisibly absorbed into the ceramic fabric (Condamin *et al.*, 1976), or visibly on the surface (Evans & Biek, 1977; Rottländer & Schlichtherle, 1979). Since then, 'residue analysis' has become a relatively common procedure on archaeological ceramics. Over time, the number of loci for the potential identification of archaeological residues has been extended to include soils and sediments, visible resinous deposits (used for hafting, sealing ceramic vessels, and waterproofing), the remains of organic material on the surface of stone tools, and the contents of glass vessels (Evershed, 2008). With a few exceptions, however, such as when a sealed metal container has visibly preserved its organic content (*e.g.*, Evershed *et al.*, 2004; Stacey, 2011), metal objects have rarely

Small Find No.	Grave No.	Context	Vessel Types and Forms	Sample No.	Sample Location	Sample type
681	6260	6231	Cauldron/Wine-Mixing Bowl (Eggers 1951 Form 33)	KRM 146	Interior	Corrosion
				KRM 147	Exterior	Corrosion
683	6260	6232	Ewer (Nuber's Hagenow Service)	KRM 157	Exterior -brass base[a]	Corrosion
689	6260	6262	Patera (Nuber's Millingen Service)	KRM 152	Interior	Soil/Corrosion
				KRM 153	Interior	Corrosion
				KRM 154	Exterior	Corrosion
1549	6635	6661	Patera (Nuber's Hagenow Service)	KRM 148	Interior	Corrosion
				KRM 149	Interior	Corrosion
				KRM 150	Exterior *btw vessels[b]	Corrosion
				KRM 151	Exterior *deposit[c]	Corrosion
				KRM 158	Interior	Soil/Corrosion
				KRM 159	Interior	Soil/Corrosion
				KRM 160	Interior	Soil/Corrosion
				KRM 161	Interior	Soil/Corrosion
				KRM 162	Exterior *btw vessels	Soil/Corrosion
				KRM 163	Exterior *btw vessels	Soil/Corrosion
				KRM 164	Exterior *deposit	Corrosion
				KRM 165	Exterior *deposit	Corrosion
				KRM 166	Exterior	Soil/Corrosion
				KRM 167	Interior	Soil/Corrosion
1550	6635	6663	Ewer (Nuber's Millingen Service)	KRM 155	Interior	Corrosion
				KRM 156	Exterior	Corrosion

Table 1. Samples of copper alloy corrosion products.

been considered as suitable targets for organic residue analysis. This is despite the known biocidal properties of copper, and the fact that macroscopic organic materials such as textile fibres or wood can be preserved either within the corrosion products produced by archaeological copper alloys, or as casts within the corrosion layer ('mineral-preserved organics': Watson, 1988). We suggest that the corrosion products which form on the surface of archaeological copper alloy objects might provide a suitable locus for the preservation of organic residues, thus offering new insights into the ritual or mundane use of copper vessels. Here we provide a summary of the work done by Merriman (2014) on five excavated Roman copper alloy vessels, which suggests that this idea might be worth pursuing.

The samples were taken from five copper alloy vessel finds within high-status Roman graves (features 6260 and 6635, see Table 1) dated to between 43 and 70 CE, excavated on the A2 Pepperhill to Cobham road-scheme project (Kent, England). This work was conducted in 2006 to 2007 by Oxford Archaeology on behalf of The National Highways Agency for Skanska Construction Limited (Allen *et al.*, 2012). Several burials were excavated, including a large high-status cremation (grave 6260), two high-status graves (graves 6635 and 6645), and six other cremation burials. The corrosion samples were taken from five copper alloy vessels consisting of one cauldron, two ewers, and two pateras during conservation of the objects.

The vessels were lifted in a block by the site conservator and taken directly to a conservation lab. Cyclododecane (henceforth CDD) was used on-site to protect and support fragile surface deposits, and also in the laboratory. Other support materials used both for lifting and supporting throughout the conservation treatment of the fragile ewers and pateras consisted of surrounding soil, aluminium foil, plaster of Paris and silicone rubber. Sampling of the corrosion products happened throughout the conservation laboratory processes, as surfaces were revealed. Care was taken to sample corrosion products prior to applying interventive materials, but contamination of some samples was inevitable because physical support of one side of the vessel was required throughout the micro-excavation processes of the other. CDD was volatised from surfaces using directed hot air.

Twenty-two corrosion samples were mechanically removed from the five vessels. Where possible, both internal and external surfaces of the same vessel were sampled. Samples were removed using a scalpel under the microscope (x10). The corrosion products were not voluminous, and some burial deposits/soil was so closely associated with the corrosion matrix that it was not possible to physically separate them. In the laboratory, each sample was weighed, and extracted with 2:1 chloroform:methanol under ultrasonication. The extract was centrifuged, decanted, dried, weighed, and then derivatized with the direct FAME protocol (O'Fallon *et al.*, 2007). The insoluble residue was dried and then directly extracted and derivatised with the same FAME protocol. Each of the $CHCl^3$:MeOH-extracted and FAME-extracted residues were then analysed via GC-MS. The GC-MS chromatograms were used for qualitative data only.

Summary of results

Because of the contaminated nature of the samples, we do not present the detailed results here (for details, see Merriman, 2014). Most of the samples produced only plasticisers and siloxanes (Table 2). However, the GC-MS profiles of two interior samples from Patera 689 showed a series of straight chain alkanoic methyl esters with even-numbered carbon chain lengths ranging from 12 to 28, the unsaturated stearic and oleic acids, and a number of dicarboxylic acids with 16, 18, 20, and 22 carbons. In addition, one sample produced methyl dehydroabietate, a resin biomarker. One internal and one external sample from Ewer 1550 showed a marked difference in yield. The external sample had a low yield and contained only small amounts of C16:0 and C18:0. The internal sample produced a yield over four times that of the external sample. The GC-MS profile contained a series of alkanoic acids with even numbered carbon chains ranging from 16 to 26 carbons and shows evidence of both a dicarboxylic acid (hexadecanedioic acid) and the CDD consolidant. All of the internal samples taken from Patera 1549 resulted in significant yields. Each contained a series of alkanes ranging in carbon chain length from C20 to C31. All samples therefore show a significant difference between the interior and exterior of the patera, potentially associated with the contents of the patera during use.

Sample	Sample Weight (g)	Total Extract (g)	Total Yield (mg/g)	% Extracted in $CHCl^3$	% Extracted by FAME	GC-MS Peaks Observed
KRM 146	0.06010	0.00029	4.83	100.0	0	Hexadecanoic acid ester
KRM 147	0.00741	0.00025	33.7	84.0	16.0	Hexadecanoic Acid, Methyl Ester Secondary: Bis(2-ethylhexyl) Phthalate
KRM 157	0.01835	0.00381	208	3.9	96.1	Hexadecanoic Acid, Methyl Ester Secondary: Octadecanoic Acid, Methyl Ester
KRM 152	2.77372	0.00373	1.34	55.0	45.0	Hexadecanoic Acid, Methyl Ester Secondary: Octadecanoic Acid, Methyl Ester Other Peaks: Alkanoic Acid Methyl Esters: $C^{12:0}$, $C^{14:0}$, $C^{15:0}$, $C^{16:0}$, $C^{18:0}$, $C^{20:0}$, $C^{22:0}$, $C^{23:0,}$ $C^{24:0,}$ $C^{26:0}$, $C^{28:0}$ Alkenoic Acids: $C^{18:1}$, $C^{18:2}$ Diacids: C^{16}, C^{18}, C^{20}, C^{22} Methyl Dehydroabietate – resin biomarker
KRM 153	0.53361	0.00932	17.5	99.0	1.0	Hexadecanoic Acid, Methyl Ester Secondary: Octadecanoic acid, Methyl Ester Other Peaks: Alkanoic Acid Methyl Esters: $C^{14:0}$, $C^{15:0}$, $C^{16:0}$, $C^{18:0}$, $C^{20:0}$, $C^{22:0}$, $C^{24:0}$ Alkenoic Acid Methyl Esters: $C^{18:1}$ Diacids: C^{16} Consolidant: Cyclododecane
KRM 154	0.00416	0.00118	284	81.4	18.6	Siloxanes and plasticisers
KRM 148	0.03280	0.01375	419	99.4	0.7	Hexadecanoic Acid Methyl Ester Secondary: Octadecanoic Acid Methyl Ester Other Peaks: Alkanes: $C^{20:0}$, $C^{24:0}$, $C^{25:0}$, $C^{26:0}$, $C^{27:0}$, $C^{28:0}$, $C^{29:0}$, $C^{30:0}$, $C^{31:0}$ Plasticiser
KRM 149	0.05667	0.00183	32.3	97.3	2.7	Hexadecenoic Acid, Methyl Ester Secondary: Octadecanoic Acid, Methyl Ester Other Peaks: Long chain alkanes
KRM 150	0.00006	failed				
KRM 151	0.00486	0.00287	591	21.6	78.4	Undecane
KRM 158	0.53938	0.00578	10.7	92.4	7.6	Heptacosane Secondary: Octacosane Other Peaks: Alkanoic Acid Methyl Esters: $C^{12:0}$, $C^{14:0}$, C16:0, $C^{18:0}$ Alkanes: C^{19}, C^{20}, C^{24}, C^{25}, C^{26}, C^{27}, C^{28}, $C^{29,}$ $C^{30,}$ C^{31}. C^{34}, C^{36} Consolidant: Cyclododecane

Sample	Sample Weight (g)	Total Extract (g)	Total Yield (mg/g)	% Extracted in $CHCl^3$	% Extracted by FAME	GC-MS Peaks Observed
KRM 159	2.44891	0.01800	7.35	48.1	51.9	Heptacosane Secondary: Octacosane Other Peaks: Alkanoic Acid Methyl Esters: $C^{16:0}$, $C^{18:0}$ Alkanes: C^{20}, C^{21}, C^{24}, C^{25}, C^{26}, C^{27}, C^{28}, $C^{29,}$ $C^{30,}$ C^{31}. C^{32}, C^{34}, C^{36} Consolidant: Cyclododecane
KRM 160	0.36184	0.00709	19.6	96.3	3.7	Hexadecanoic Acid, Methyl Ester Secondary: Octadecanoic Acid, Methyl Ester Other Peaks: Alkanoic Acid Methyl Esters: $C^{12:0}$, $C^{14:0}$, $C^{16:0}$, $C^{18:0}$ Alkanes: C^{20}, C^{24}, C^{25}, C^{26}, C^{27}, C^{28}, $C^{29,}$ $C^{30,}$ C^{31}. C^{34}, C^{36} Consolidant: Cyclododecane
KRM 161	1.19642	0.01297	10.8	72.2	27.8	Heptacosane Secondary: Octacosane Other Peaks: Alkanoic Acid Methyl Esters: $C^{16:0}$, $C^{18:0}$ Alkanes: C^{20}, C^{21}, C^{24}, C^{25}, C^{26}, C^{27}, C^{28}, $C^{29,}$ $C^{30,}$ C^{31}. C^{32}, C^{34}, C^{36} Consolidant: Cyclododecane
KRM 162	0.19477	0.01139	58.5	97.5	2.5	Hexadecanoic Acid, Methyl Ester Secondary: Octadecanoic Acid, Methyl Ester Other Peaks: Alkanoic Acid Methyl Esters: $C^{12:0}$, $C^{16:0}$, $C^{18:0}$, $C^{20:0}$, $C^{22:0}$, $C^{23:0}$, $C^{24:0,}$ $C^{25:0}$, $C^{26:0}$, $C^{27:0}$, $C^{28:0}$
KRM 163	0.91464	0.00934	10.2	90.6	9.4	Hexacosanoic Acid, Methyl Ester Secondary: Hexadecanoic Acid, Methyl Ester Other Peaks: Alkanoic Acid Methyl Esters: $C^{16:0}$, $C^{18:0}$, $C^{20:0}$, $C^{22:0}$, $C^{23:0}$, $C^{24:0}$, $C^{25:0}$, $C^{26:0}$, $C^{27:0}$, $C^{28:0}$
KRM 164	0.00065	0.00026	385	76.0	24.0	Undecane Secondary: Plasticisers
KRM 165	0.00649	failed				
KRM 166	2.24249	0.00093	0.41	80.7	19.3	Hexadecanoic Acid, Methyl Ester Secondary: C18:0 Octadecanoic Acid, Methyl Ester Other Peaks: Octadecenoic Acid, Methyl Ester C18:1 Alkanoic Acid Methyl Esters: $C^{16:0}$, $C^{18:0}$, $C^{20:0}$, $C^{22:0}$, $C^{24:0}$, $C^{26:0}$
KRM 167	1.42412	0.00349	2.45	82.5	17.5	Hexadecanoic Acid, Methyl Ester Secondary: Octadecanoic Acid Methyl Ester Other Peaks: Alkanoic Acid Methyl Esters: $C^{16:0}$, $C^{18:0}$, $C^{20:0}$, $C^{22:0}$, $C^{24:0}$, $C^{26:0}$ Diacids: Hexanedioic Acid, Dimethyl Ester
KRM 155	0.15555	0.00056	3.60	87.5	12.5	Hexadecanoic Acid, Methyl Ester Secondary: Octadecanoic Acid, Methyl Ester Other Peaks: Alkanoic Acid Methyl Esters: $C^{16:0}$, $C^{18:0}$, $C^{20:0}$, $C^{22:0}$, $C^{24:0}$, $C^{26:0}$ Consolidant: Cyclododecane.
KRM 156	0.03934	0.00011	0.79	72.7	27.3	Undecane, Hexadecanoic Acid, Methyl Ester Secondary: Octadecanoic Acid, Methyl Ester

Table 2. Sequential extraction and summary of GC-MS results.

Discussion

From this pilot project, it would appear that significant differences in yield and organic constituents can be seen when the internal and external surfaces of two of the five Roman vessels are compared, suggestive of the preservation of organic material within the copper corrosion products. We are repeating this work on some freshly-excavated Roman metal objects, which have not been conserved. This should allow us to isolate cleaner corrosion samples, and improve the analytical protocol to include the use of an internal standard in the chromatography to quantify the amounts of individual compounds, and thus help decide whether the residues are present at significant levels. If these findings can be verified, then it is possible that, because copper is toxic to microbes, copper vessels might in some cases provide an even better context for organic preservation than ceramics.

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Endnotes

a Ewer 683 originally had a brass base that had been soldered on, but was found detached upon excavation. This exterior corrosion sample was taken from the vessel, near to the location of the base attachment.

b "Btw vessels" = between ceramic vessels: Patera 1549 overlay several ceramic vessels: (Vessel 1553, a platter, local copy of Gaulish form; Vessel 1555, a platter, local; Vessel 1598, a platter, local copy of Gaulish form). This suggests the possibility that these external samples might not be "clean" if the patera was in contact with any contents of the platters below.

c Corrosion deposits that did not visually match the rest of the patina.: 151: a brown deposit near the handle; 164: an ultramarine deposit.

INTERDISCIPLINARITY BETWEEN HUMANITIES AND SCIENCE

Henk Kars was appointed as first Chair of Archaeometry in The Netherlands in 1994. From 2002 he was full time professor at the Vrije Universiteit Amsterdam, interim Director of CLUE, and founder and Managing Director of the Institute for Geo- and Bioarchaeology. This festschrift volume incorporates original publications in the field straddling the Sciences and Humanities produced by various former PhD-students, post-docs and colleagues.

Landscape archaeology is described in the first cultural landscapes of Europe as a mysterious outcome, while the historical record of surface water flow of the central Netherlands is reviewed. The south-western Netherlands are historically analysed since military inundations during the Eighty Year's War. The palaeolandscapes of the eastern Netherlands are reconstructed to locate the origins of the river Linge. The long time scale is considered in a 220.000 year overview of landscape development and habitation history in Flevoland.

Bioarchaeology is represented in a review of the current state of isotope research in The Netherlands and a correlation between bio- and geochemistry meets an analysis of organic residues in copper corrosion products. Archaeometry reveals the colour of Dutch archaeological textures. The relevance of a quartzite Neolithic axe found near to Huizen, The Netherlands is described.

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