Quaternary Science Reviews 166 (2017) 227–265

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Late Holocene lowland fluvial archives and geoarchaeology: Utrecht's case study of Rhine river abandonment under Roman and Medieval settlement

Marieke van Dinter [a, b, *], Kim M. Cohen [a, c, d], Wim Z. Hoek [a], Esther Stouthamer [a], Esther Jansma [a, e], Hans Middelkoop [a]

[a] Department of Physical Geography, Faculty of Geosciences, Utrecht University, Heidelberglaan 2, 3584 CS, Utrecht, The Netherlands
[b] ADC Archeoprojecten, Nijverheidsweg-Noord 114, 3812 PN, Amersfoort, The Netherlands
[c] Department of Applied Geology and Geophysics, Deltares Research Institute, Princetonlaan 6, 3584 CB, Utrecht, The Netherlands
[d] Department of Geomodelling, TNO - Geological Survey of the Netherlands, Princetonlaan 6, 3584 CB, Utrecht, The Netherlands
[e] Cultural Heritage Agency of The Netherlands, Smallepad 5, 3811 MG, Amersfoort, The Netherlands

ARTICLE INFO

Article history:
Received 31 March 2016
Received in revised form
24 October 2016
Accepted 5 December 2016
Available online 4 February 2017

Keywords:
Geoarchaeology
Fluvial archives
Late Holocene
Rivers
Human occupation
Deltaic avulsion
Channel abandonment

ABSTRACT

Fluvial lowlands have become attractive human settling areas all around the world over the last few millennia. Because rivers kept changing their course and networks due to avulsion, the sedimentary sequences in these areas are archives of both fluvial geomorphological and archaeological development. We integrated geological and archaeological datasets to demonstrate the concurrence of the gradual abandonment of a major Rhine channel (Utrecht, The Netherlands), the development of human habitation in the area, and the interactions between them.

The Utrecht case study highlights the stage-wise abandonment of a natural river channel, due to avulsion, coincident with intensifying human occupation in Roman and Early Medieval times (1st millennium AD). The analyses make maximum use of very rich data sets available for the study area and the tight age control that the geo-archaeological dataset facilitates, offering extra means of time-control to document the pacing of the abandonment process. This allows us to quantify change in river dimensions and meander style and to provide discharge estimates for successive stages of the abandonment phase over a 1000-year period of abandonment succession, from mature river to eventual Late Medieval overbuilt canal when the Rhine branch had lost even more discharge.

Continued geomorphic development during this period - which includes the 'Dark Ages' (450-1000 AD) - appears to have been crucial in the development of Utrecht from Roman army fortress to Medieval ecclesial centre. The settlement dynamics in and around the city of Utrecht changed during the various phases of abandonment. In the bifurcating network of river branches forming the Rhine-Meuse delta, the main Rhine branch hosted the Roman limes military border and transport route. The Rhine- Vecht bifurcation at Utrecht provided an excellent location to raise a Roman fort. Continued geomorphic activity during abandonment in Early Medieval times was characterised by enhanced overbank sedimentation and shifts in the position of bifurcations. River flooding became more incidental in this stage, and alluvial-ridge occupancy became sensitive to flooding events for several centuries. We conclude by demonstrating that similar human-river interactions during Roman times occurred in several other deltas within the former Roman empire, with differences depending on the position of a settlement within the delta, the overall hydrological situation, and the ability of societies to control the changing environment.

1. Introduction

Rivers provide fresh water, open landscapes and transport routes for humans and as such have been repeatedly occupied

* Corresponding author. Department of Physical Geography, Faculty of Geosciences, Utrecht University, Heidelberglaan 2, 3584 CS, Utrecht, The Netherlands.
E-mail address: m.vandinter@uu.nl (M. van Dinter).

http://dx.doi.org/10.1016/j.quascirev.2016.12.003
0277-3791/

environments through all archaeological periods (Hill, 2014). The relations between fluvial archives and their archaeological content have shown major changes over time (e.g. Ferring, 1986; Brown, 1997). Important differences on the Eurasian continent occurred between the eras of and preceding the Neanderthals (Early and Middle Paleolithic of the Pleistocene interglacials and glacials; e.g. Roebroeks, 2001; McNabb, 2007; Cohen et al., 2012a; Bridgland and White, 2015), the times of Home Sapiens hunter-gatherer subsistence (Late Paleolithic and Mesolithic of the Lateglacial and Early Holocene; e.g. Kelly, 1983; Louwe Kooijmans et al., 2005), the subsequent Neolithic revolution towards agricultural subsistence which enhanced permanent settlements (Middle Holocene; e.g. Butzer, 1970; Van Andel and Runnels, 1995; Bonsall et al., 2002; Turney and Brown, 2007), and the Late Holocene with increasingly developed catchment deforestation, growing population and urbanization, expanding trade and accelerating cultural exchange (e.g. Kaplan et al., 2009; Gates, 2011). With growing human presence and its impact in the catchments and rivers in the hinterland, especially in the last few millennia river discharge regimes changed as well, with larger fluxes of sediment supplied to the lowlands (e.g. Hoffmann et al., 2007). Further river-engineering changes such as the construction of dikes downstream and dams upstream caused the sedimentation regimes to change once more (e.g. Hesselink et al., 2003; Hudson et al., 2008; Syvitski et al., 2005, 2009).

Rivers are notoriously effective at reworking their past fluvial archives, eroding and redepositing their alluvium including the archaeological materials contained here (e.g. Brown, 1997). This is particularly true for valley reaches that over longer time intervals produce terrace sequences and for deposition in active channels. These processes create surfaces on which archaeology can accumulate afterwards and in such cases fluvial geomorphological patterns are informative for archaeological site distribution, especially on neighbouring terrace edges (e.g. Howard and Macklin, 1999; Bettis et al., 2008). In the lower delta-plain reaches of rivers, however, the downstream control of post-glacial sea-level rise and wide glacial-inherited valleys have caused extensive Late-Holocene records to have become preserved and accessible for geological and archaeological research. These areas can be especially rich in well-preserved archaeological finds (e.g. Edelman, 1950; Willems, 1986; Ferring, 1992). These finds are located in overbank deposits, in the tops of bars and not in the least, in deposits from abandonment and post-abandonment stages. In the latter case the alluvial ridges provide subtle high grounds in an otherwise regularly flooded plain.

In most deltas worldwide, including those of classic civilization centres such as Mesopotamia (e.g. Jacobsen, 1995; Wilkinson, 2000), the Egyptian Nile Delta (e.g. Coutellier and Stanley, 1987; Trampier et al., 2013; Pennington et al., 2016; Macklin et al., 2015; Pennington and Thomas, 2016), the Maya lowlands (e.g. Von Nagy, 1997; Liendo et al., 2014; Gunn and Folan, 2000; Liendo et al., 2014; Nooren et al., 2014) and the Indus (e.g. McIntosh, 2008; Giosan et al., 2012; Syvitski et al., 2013), besides the modern active river branches multiple former river branches of Late-Holocene age have been identified. These are the parts of fluvial reaches where long-sustained coeval geomorphological and human activity has taken place, creating spatially extensive and continuous fluvial archives of alluvial ridges with a very rich embedded archaeological record. In these areas rivers continuously changed their course and networks due to avulsion, creating new and abandoning older channels. In addition in these areas cultures changed, and distinct cultural periods emerged and succeeded. The dating of such periods is often very precise, sometimes with an uncertainty of a few years only, and outperforms that of sites dated exclusively with geological dating methods. Both from an archaeological and geomorphological perspective deltaic lowlands therefore provide rich archives for the study of the interaction between river processes and human occupation.

The study of human-fluvial landscape interactions requires an interdisciplinary approach integrating geological and archaeological datasets derived from fluvial archives. In the present study we exemplify this for the case of The Netherlands, where the rise of the Roman/Medieval city of Utrecht coincided with a shifting bifurcation and changing channel dimensions and meander lengths during a 1000-yr abandonment phase of the main river in the Lower Rhine Delta.

Avulsion is a principal process in the creation of new channels and the abandonment of existing channels in deltas and fluvial plains. It is a process that is seldom observed on a human time scale since it usually takes several human generations for the new channel to fully capture the water discharge (Jones and Hajek, 2007). Over the last 30 years research on avulsions in lowland settings mainly has focused on newly formed channels and related sedimentary products such as crevasse splays and avulsion belts (e.g. Smith et al., 1989; Smith and Perez-Arlucea, 1994; Stouthamer, 2001; Slingerland and Smith, 2004; Makaske et al., 2007), and on the quantification of avulsion frequencies, which most frequently is based on dating abandoned channels in order to identify channel relocation events (e.g. Törnqvist, 1994; Stouthamer and Berendsen, 2000; Makaske et al., 2002; Stouthamer, 2005; Fontana et al., 2008).

The pace of avulsion processes strongly varies depending on constraints such as basin configuration, local and regional gradients, and dynamics of bends and in-channel bars (e.g. Mackey and Bridge, 1995; Jones and Schumm, 1999; Slingerland and Smith, 2004; Stouthamer, 2005; Kleinhans et al., 2013). Studies of the Dutch Rhine-Meuse delta, an exceptional region because of its complete coverage of the Holocene avulsion history including avulsion duration (e.g. Berendsen and Stouthamer, 2001; Stouthamer and Berendsen, 2000; Gouw and Erkens, 2007; Stouthamer et al., 2011; Toonen et al., 2012), show that new and old channels often co-functioned for a few hundred years (Stouthamer and Berendsen, 2001).

Younger secondary channels developed ‘relatively rapidly’ (Jones and Schumm, 1999), but the majority of the discharge remained routed through the older course. The larger channels were the longest-lived courses which functioned as relatively conservative trunk channels (Stouthamer et al., 2011). In the few cases that a major avulsion led to full abandonment of a trunk channel in the Rhine-Meuse delta, the process took a long time to complete (Stouthamer and Berendsen, 2000; Toonen et al., 2012). One reason that large and old main channels did not easily become completely abandoned, is that fully plugging a former trunk channel demands considerable amounts of bed sediment to be trapped at its entrance. This not only takes time, but also requires sustained delivery of this sediment by the flow of water that is diverted over a bifurcation at the avulsion node. The instable morphodynamics of a bifurcating river causes the quantities of water and sediment delivered to the competing branches to oscillate (Kleinhans et al., 2008, 2011; 2013). This causes alternating phases of deposition (plugging, narrowing) and erosion (deepening, re-widening) of the channel, never closing either of the two branches, a situation that can persist for many hundreds to a few thousands of years. During this time interval the sedimentary signals of discharge loss and branch abandonment become visible over many meander wave lengths downstream in the abandoned branch, i.e. over reaches of tens of kilometres. The combined down- and upstream feedback effects of multiple bifurcations of different age occurring concurrently in the delta cause further complexity of the abandonment mechanisms of main branches.

The Utrecht case study demonstrates the slow pacing and staged natural river development over the full duration of abandonment, coincident with intensifying human occupation. The analyses focus on a 1000-year period, making maximum use of the tight age control enabled by geo-archaeological dataset integration (see the rich dataset accompanying this paper). This allowed us to quantify changes in river dimensions and meander style and to provide discharge estimates for successive stages of the abandonment phase. River researchers benefit from the interdisciplinary incorporation of geoarchaeological data since it leads to age-control on the phasing, and archaeologists benefit since it enables them to develop a more detailed insight in autogenic landscape change. This in turn creates awareness of situations in which inhabitants in the past actively must have countered unwanted change or in which people opportunistically seized opportunities provided by autonomous river development. In this manner this interdisciplinary approach enables more complete explanations of the timing and duration of successive patterns of human settlement observed along the former river.

2. Setting of the study area

2.1. Abandonment of the Utrecht Rhine

A major avulsion case in The Netherlands in the last 3000 years is marked by the abandonment of the Kromme Rijn and Oude Rijn branch in the northwestern part of the Rhine Delta (Fig. 1). This branch, running through Utrecht and debouching into the North Sea at Katwijk, is the main artery of the Utrecht river system (e.g. Berendsen, 1982; Berendsen and Stouthamer, 2001). Names, identification numbers and dates for the period of sedimentary activity of the various channel belts (ch.b.) that compose the Utrecht river system were introduced by these authors (updated Cohen et al., 2012b) and are followed here. This long-lived system groups multiple partly successive channel belts (Fig. 2), that began functioning in the Middle Holocene, some 6500 years ago (Hijma and Cohen, 2011), and had become the single main Rhine channel by 5000 cal BP (Stouthamer and Berendsen, 2000; Cohen et al., 2012b). Due to a series of upstream avulsions the former Rhine trunk channel gradually lost discharge to the new distributaries Waal, Lek and IJssel during the 1st millennium AD (Fig. 1), i.e. beginning in the Roman Period and completing in Medieval times.

The abandonment phase is well registered in the preserved meander morphology of the last stages of activity as well as in the sedimentary build-up of its channel fill, albeit that large parts of the channel belt nowadays are built upon. In the 12th century AD, when dikes were being placed along the larger channels, the Kromme Rijn and Oude Rijn branch had reduced to a very minor channel in terms of carrying discharge (Berendsen, 1982). While losing discharge the branch maintained its importance as a transport route. Furthermore its relatively high and inhabitable levees formed a dry land zone running through otherwise swampy surroundings which were reclaimed by drainage during the Middle Ages (e.g. Borger and Ligtendag, 1998). To enable land reclamations in the flood basins the silted-up Kromme Rijn-Oude Rijn channel was disconnected from the Nederrijn channel in AD 1122 by the construction of a dam at the avulsion node at Wijk bij Duurstede (Dekker, 1980). This meant that the Rhine branch through Utrecht, unlike the other water carrying rivers of that time, was not to be embanked. This historical event of upstream dam construction marks the end of the abandonment process of the Oude Rijn branch as presented in this paper.

Throughout the abandonment phase, settlement on and utilisation of the Kromme Rijn and Oude Rijn alluvial ridge concurred with sedimentary activity. During the Roman occupation (21 BC - AD 450; *Germania Inferior*) the branch was used as a main transport corridor and eventually functioned as a military border, the *limes*, until c. AD 270 (Haalebos, 1997; Polak, 2009; Sommer, 2009; Van Dinter, 2013). During the Early Middle Ages (AD 450–1050) it continued to function as a major trading route (Van Es and Verwers, 2010; Dijkstra, 2011; Jansma and Van Lanen, 2016; Van Lanen et al., 2016). This abundant inhabitation history has left a rich archaeological record which complements the sedimentary record of the abandonment phase.

A long tradition of archaeological research exists that also includes reconstruction of former river positions, mainly because of the relations between the river, its alluvial ridge and the layout of this part of the Roman *limes*. Results are available for the city of Utrecht and its surroundings (e.g. Ozinga et al., 1989; Polak and Wynia, 1991; Polak et al., 2004), for the area further downstream along the Oude Rijn (e.g. Haalebos, 1977; Blom and Vos, 2008; Van Dinter, 2013), and for areas in the vicinity of the upstream avulsion node (at Wijk bij Duurstede; Figs. 1 and 2), including the site of early Medieval trade centre *Dorestad* (e,g, Van Es and Verwers, 1980, 2009; 2010, 2015; Dekker, 1983; Van Es, 1984, 1990, 1994; Hessing and Steenbeek, 1990; Verwers, 1994; Dijkstra, 2004, 2012; Sier et al., 2004; Williams, 2010, 2013; Kosian et al., 2016).

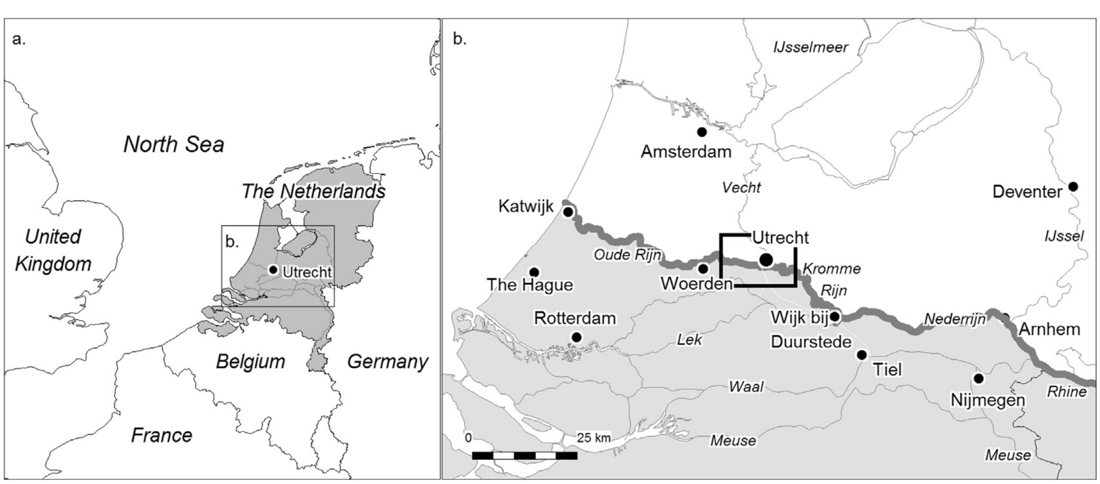

Fig. 1. Location of the study area (box): a. in the central part of the Netherlands, b. near the city of Utrecht along the river Kromme Rijn – Oude Rijn (box); shaded area is the Roman province *Germania Inferior* at end of the first century AD.

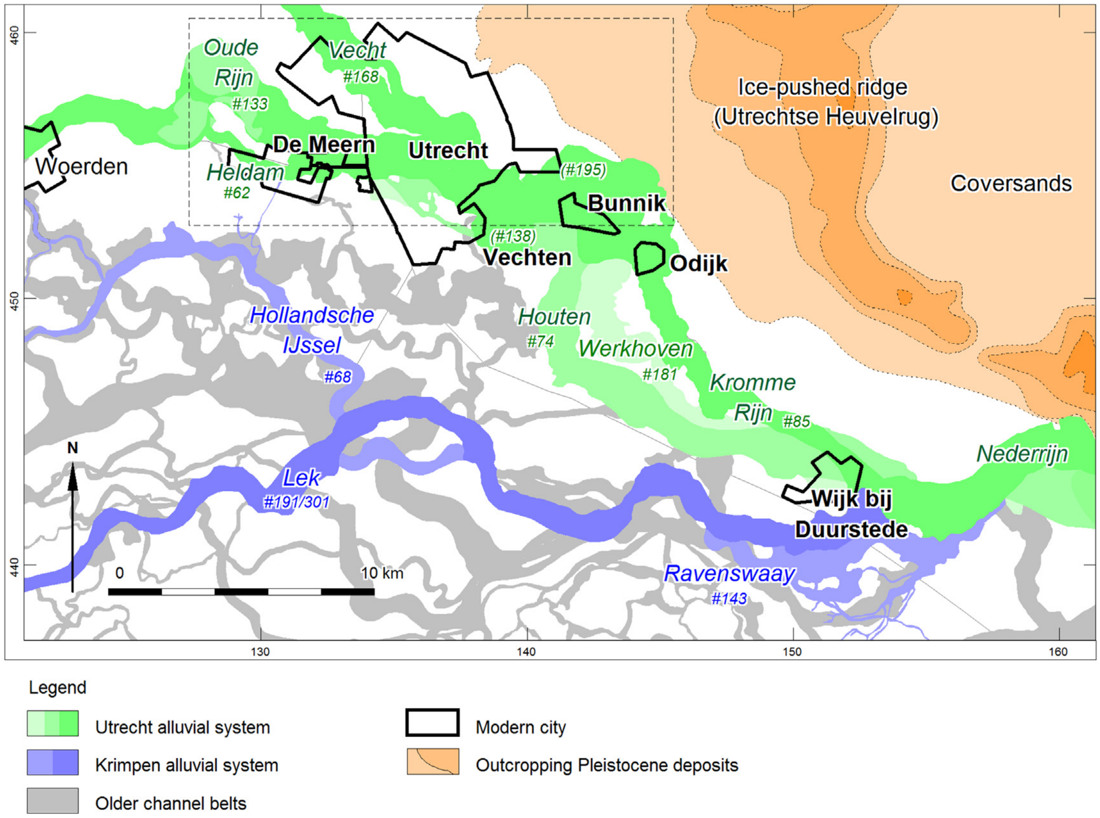

Fig. 2. The palaeogeographical situation between Wijk bij Duurstede and Woerden during the Roman and Medieval periods (source data: Cohen et al. (2012a, b). Older alluvial systems are indicated in lighter colour tones. The box indicates the study area (Fig. 4).

Dorestad was one of the principal ports of the Carolingian realm in northwestern Europe (AD 725–900; *Annales Bertiniani, Annales Fuldenses, Annales Xantenses*). During the last two decades intensified (geo)archaeological research especially in and around Utrecht has generated new data regarding river activity and the settlement history of the channel belt (i.e. Graafstal, 2002; Nokkert et al., 2009; Hoegen, 2013; Aarts, 2012; Den Hartog, 2009a; 2010; 2013a, 2013b). However, the geomorphological development of the Roman and Medieval fluvial landscape, the pacing and sedimentological process knowledge of channel abandonment and the cultural response to changes in modes of river activity still remain to be explored.

This study makes use of the enriched geological-geomorphological and archaeological datasets that exist for the Oude Rijn and Kromme Rijn channel belt from the sources cited above. These data enabled a detailed reconstruction of the abandonment phase of the Oude Rijn and the analysis of anthropogenic interaction with the river environment.

2.2. Avulsion history at delta scale

The study area is situated in the northwestern part of the Rhine-Meuse delta and centres around the city of Utrecht (Fig. 2). Downstream of Utrecht, the Oude Rijn (ch.b. #133) was active since ~5730 ^{14}C yr BP (6500 cal BP, ~4500 BC; dating confirmed at multiple locations). The Utrecht channel belt traverses an area north of the Late-Glacial and Early-Holocene Rhine palaeovalley, with a dominantly sandy Pleistocene subsurface. To the east of the study area, Middle Pleistocene sand outcrops as ice-pushed ridges from the penultimate glaciation (Figs. 2 and 3; Utrechtse Heuvelrug). The study area overlies outwash deposits from that same glaciation (Saalian, 150 ka), which were reworked by the Rhine during part of the last glacial (Middle Weichselian, 60–35 ka) and afterwards were blanketed with cover sands (35–12 ka; Busschers et al., 2007). At a distance from active rivers a peat cover developed during the Middle Holocene as an effect of relative sea-level rise and seepage received from the ice-pushed ridge (Cohen, 2005; Van Loon et al., 2009; Van Asselen, 2011). The avulsions giving rise to the Utrecht channel belt system invaded and dissected this peat-on-cover-sand landscape along the northern rim of the Rhine-Meuse delta (Berendsen, 1982; Berendsen and Stouthamer, 2001). Availability of Pleistocene sand at shallow depth (on the shoulder of a palaeo-valley) and constant groundwater seepage in addition to Rhine discharge (hydrological connection to flanking topography) are factors explaining the well-developed meander morphology in the study area. The average thickness of the Holocene flood-basin deposits is ~1 m directly east of the city of Utrecht, increasing to roughly 4 m west of Utrecht near De Meern (Fig. 2).

Upstream of Utrecht, three channel belts successively have fed the Oude Rijn, each diverging from the avulsion node at Wijk bij Duurstede and all converging at Utrecht (Berendsen, 1982). In chronological order these are, the Werkhoven (ch.b. #181), Houten (ch.b. #74), and Kromme Rijn (ch.b. #85) channel belts (Fig. 2; Berendsen, 1982, 1990). By ~2500 ^{14}C yr BP the Kromme Rijn and Oude Rijn had become the main Rhine channel (Cohen et al., 2012b: ch.b. #74 and #85). In the city of Utrecht the Vecht channel belt (ch.b. #10 and #168) bifurcates northward. West of Utrecht the Heldam (#62) channel belt over a distance of ~5 km runs parallel to the main Oude Rijn (#133) channel belt. The sedimentology of the Oude Rijn channel belt is modestly influenced by tides from about 10 km downstream of Utrecht (Martinius and Van den Berg et al., 2012), whereas in Roman times the tidal influence was felt along

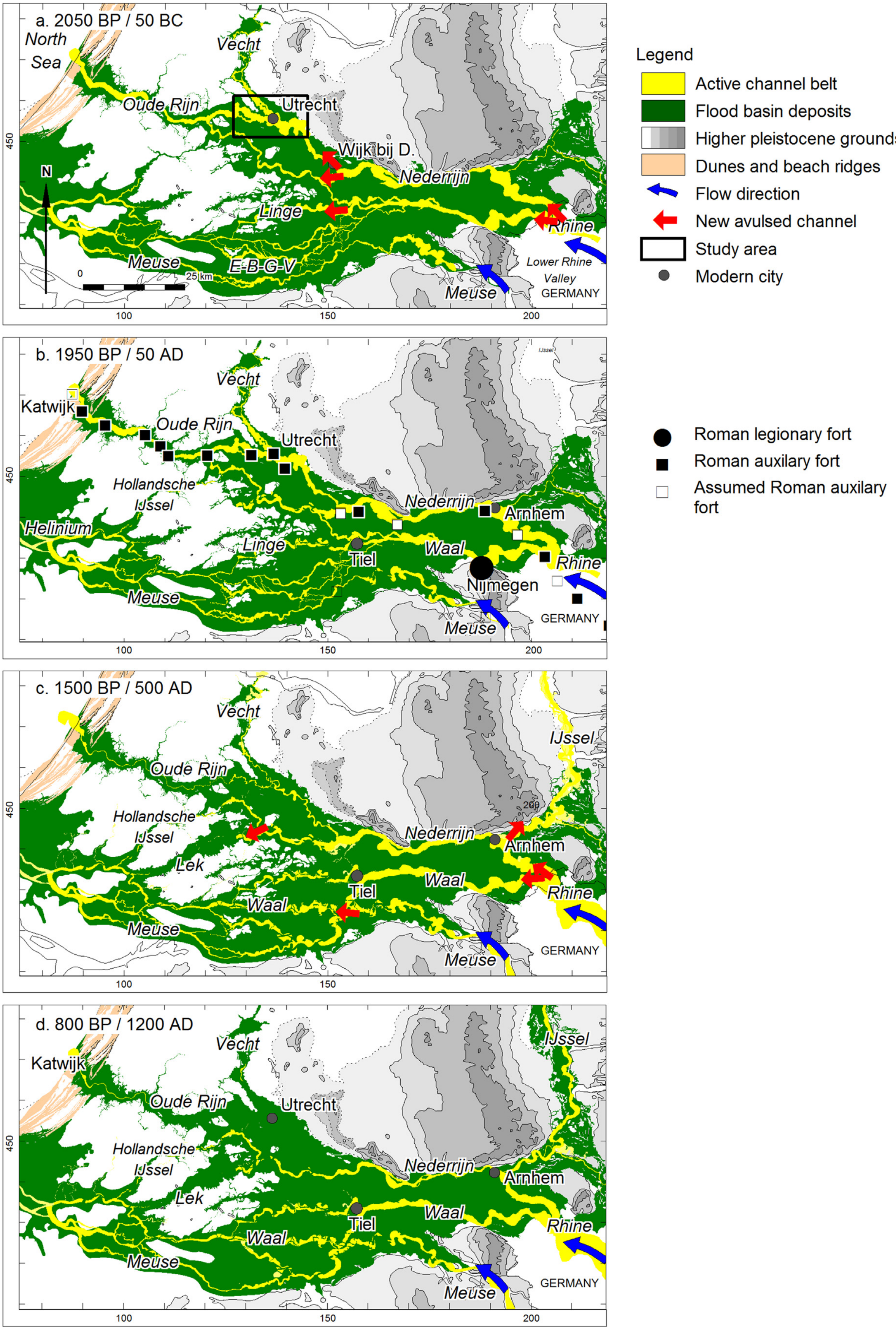

Fig. 3. Palaeogeographical situation of Rhine-Meuse delta in a. 2050 BP (~50 BC), b. 1900 BP (~AD 100), c. 1500 BP (~AD 550), d. 800 BP (~AD 1150) (after Cohen et al., 2012a, b; Roman forts: after Polak, 2009; E-B-G-V = Echt-Bruchem-Gameren-Velddriel system.

the channel until Woerden (Van Dinter, 2013). Our study area begins immediately upstream of these tidal-influenced reaches.

During the 2nd millennium BC the Oude Rijn branch was the only permanent channel connecting the inland delta plain to the North Sea (Berendsen and Stouthamer, 2001; Gouw and Erkens, 2007; Gouw, 2008; Stouthamer et al., 2011) and at that time essentially carried the full discharge of the Rhine. Due to upstream avulsions the Oude Rijn consecutively lost part of the Rhine discharge from the 1st millennium BC onwards. Discharge was first lost around 850 BC due to the formation of the river Vecht (Fig. 3a; Törnqvist, 1993; Weerts et al., 2002; Bos et al., 2009; Cohen et al., 2012b: ch.b. #10 and #168; ~2800 ^{14}C yr BP), which resulted from an avulsion that occurred at Utrecht (Fig. 2). However, given the size of the Vecht branches and its lake deltas this constituted a relatively small amount of discharge loss (Bos et al., 2009; Bos, 2010).

In contrast, the discharge decrease induced by a later series of upstream avulsions near Wijk bij Duurstede was much larger and ultimately led to the abandonment of the Utrecht river system (cf. Berendsen, 1982) in favour of the Krimpen river system that still is functioning today (Figs. 2 and 3b). Initially, part of the water flow of the Nederrijn drained into the Hollandsche IJssel (Fig. 2; Stouthamer, 2001; Cohen et al., 2012b: Ravensway, ch.b. #143: 2200–1500 ^{14}C yr BP; 2220 ± 35 BP (GrN-8708), but since ~ 1950 BP increasing amounts of water were discharged through the Lek (ch.b. #191/301: 1950 ± 30 BP (GrN-8707), 1805 ± 50 BP (GrN-7577)).

In the course of time, large changes in river pattern upstream of Wijk bij Duurstede also affected the water discharge of the Utrecht system (Fig. 3b–d). The Nederrijn already started to receive less water just before the Roman Period, because an avulsion occurred near the present day city of Tiel (Fig. 3b; Cohen et al., 2012b: Linge, ch.b. # 97: 2160–643 ^{14}C yr BP; 2210 ± 40 BP (UtC 1482); 2160 ± 60 BP (UtC 1717), 2035 ± 50 BP(GrN-8371). In the Late Roman Period, another avulsion occurred, close to Tiel, further downstream along the Waal (Fig. 3c). This resulted in an increased discharge of the Waal channel belt downstream of Tiel (ch.b. #174: since 1625 ^{14}C yr BP), the formation of a connection with the river Meuse and the ending of the Est-Bruchem-Gameren-Velddriel system (Cohen et al., 2012b; start of Waal: 1655 ± 50 BP (GrN-13504) and 1600 ± 50 BP (UtC-1899)). Furthermore, the river Gelderse IJssel came into existence in the Early Medieval Period (Fig. 3c; Cohen et al., 2009, 2012b: ch. b. #50: since ~1700 BP; Makaske et al., 2008; Groothedde, 2010, 2013), thereby further reducing the discharge of the Nederrijn downstream of Arnhem (Fig. 3).

Different perceptions of the magnitude of discharge carried by the Utrecht Rhine around the time of its damming in AD 1122 have been published. Some authors have postulated that the damming only put an end to an already on-going natural process of abandonment that had begun in Roman times (e.g. Vink, 1954; Berendsen, 1982; Kleinhans et al., 2013: suppl. information). Others, mainly archaeologists and historians, until recently assumed that the Lek became the larger Rhine branch after the 9th century only, and inferred that the Kromme Rijn was a fairly broad waterway at the time of the 12th century damming (e.g. Verwers, 1994; Van Es and Verwers, 2009). Nonetheless the effect of the changing delta river network during the Middle Ages nowadays is more and more considered also in archaeological studies (e.g. Kosian et al., 2013, 2016; Groenewoudt et al., 2016).

2.3. Settlement history of Utrecht and its surroundings

The history of the city of Utrecht is well known and has been extensively documented (e.g. Van Asch van Wijck, 1838; De Bruijn, 1994, 2008; Broer and de Bruijn, 1995; Stöver, 1997; Van Rooijen and Wynia, 1998; Van Rooijen, 1999, 2010; De Groot, 2000; Van Vliet, 2000a, 2000b, 2002; Renes, 2005; De Kam et al., 2014). The standard Dutch archaeological time periods relevant for this paper are shown in Table 1. During the 1st century AD a Roman auxiliary fort was erected along the river Oude Rhine, guarding the bifurcation with the river Vecht (Fig. 3b; Ozinga et al., 1989; Montforts, 1995; Van Dinter, 2013). From the 7th century AD onwards, this fort became the residence of the Frankish settlers, initially in ~ AD 690 led by the Anglosaxon missionary Willibrord (De Bruijn, 1994; Stöver, 1997). Utrecht became a major ecclesiastical centre because of its episcopal chair and developed into an important Medieval political and trade settlement. After the damming of the river Kromme Rijn at Wijk bij Duurstede in AD 1122 the city lost its riverine supply route, which was solved by digging a canal towards the Lek/Holandsche IJssel soon afterwards (Dekker, 1980, 1990). In this manner riverine translocation and trade was preserved and the city continued its status as central regional market in the Medieval economy (Van Vliet, 2002; 2000b).

Two other Roman forts, *castella*, were present in the immediate surroundings of Utrecht directly along the river, the first 5 km upstream of Utrecht near Vechten and the second 9 km downstream in De Meern (Figs. 2 and 3b). These fortifications were part of a chain of forts built on the left bank of the Rhine between Vechten and the North-Sea coast at Katwijk around AD 40 (Van Es, 1981; Bechert and Willems, 1995; Haalebos, 1997; Polak, 2009). By the end of the first century AD, this chain became the northwestern frontier of the Roman Empire, the so-called *limes* (Polak, 2009; Van Dinter, 2013). The *castellum* near Vechten was erected on the outer bank of the river Rhine during an earlier campaign shortly after the start of the 1st century AD (Polak and Wynia, 1991; Zandstra and Polak, 2012). This fort is larger than the other forts in the area and therefore appears to have served as a command centre of the *limes* segment west of the legionary fortresses at Nijmegen and Xanten (Germany). In the late 2nd century it was most likely larger than the other forts in the area and measured 2.6 ha - versus 1 ha for the other forts along the Oude Rijn. The Roman fort in De Meern was situated at the junction of the alluvial ridges of the Oude Rijn and the Heldam channel belts (Jongkees and Isings, 1963; Kalee and Isings, 1984; De Jager, 2000; Van der Gaauw and Van Londen, 1992; Van Dinter, 2013). The *limes* road, built at the end of the 1st century AD to connect the chain of forts over land, was mainly situated on the Heldam alluvial ridge (Haarhuis, 1999a, 1999b, 1999c; Graafstal, 2002; Luksen-IJtsma, 2010).

The Roman *castella* lost their importance when the northwestern part of the *limes* in the Rhine-Meuse delta was evacuated (AD ~260–270). The Roman reign in The Netherlands (Germania Inferior) ended in ~AD 405–406 (Van Es, 1981, 1994). The main difference between the Utrecht, Vechten and De Meern forts is that the Utrecht locality regained importance in Medieval times, whereas the others lost institutional use.

In AD 723 Charles Martel, the Prince of the Franks and Mayor of the Palace, donated the strongholds of Vechten and Utrecht and

Table 1
Standard subdivision of the Roman and Medieval periods in the Netherlands (Anonymous, 1992); * = dynasty period. Italics are sub group of early Medieval Periodable.

Late Iron Age	250–12 BC
Early Roman Period	12 BC–AD 70
Middle Roman period	AD 70–270
Late Roman Period	AD 270–450
Early Medieval Period	AD 450–1050
Merovingian period *	AD *447–751*
Carolingian Period *	AD *751–987*
Late Medieval Period	AD 1050–1500

their surroundings to the Church of Utrecht (*Diplomata Belgica* I, nr. 173, 175 and 176). Archaeological information about the Early Middle Ages from the surroundings of Utrecht is scarce (Haarhuis and Graafstal, 1993), although recently excavations have begun in these surroundings to reveal the settlement history and landscape development for this period (e.g. Nokkert et al., 2009; Den Hartog, 2009a; 2010). These excavations have shown that new settlements arose during the 6th century along the river channel of the Oude Rijn, of which the majority persisted during the 7th and 8th centuries. Most were abandoned before the 9th century AD, whereupon the countryside appears to have been nearly deserted during the 9th and 10th centuries, which was the time of Viking raids and evacuation of the bishop seat in ~ AD 850–930 (Van Rooijen, 2010). After the bishop's return in the 10th century, the population increased and Utrecht once again became a centre of religion, politics and trade. This culminated in a large walled 12th-century Medieval city (De Bruijn, 1994). The episcopal property of the Church of Utrecht was split up during the 10th and 11th centuries (Specht, 1695 and 1696; De Bruijn, 1994). During this period the number of convents, monasteries and secular settlements on the alluvial ridges in the area increased rapidly. The city also hosted a residence (*Pfalz)* for the emperor of the Holy Roman Empire. The floodplains and peat areas next to the alluvial ridges were colonized from the 11th century onwards after the bishop of Utrecht had granted concessions to groups of colonists (Dekker, 1983; Hendrikx, 1987; Buitelaar, 1993).

The damming of the Rhine near Wijk bij Duurstede in AD 1122 would have resulted in the loss of riverine trading routes to Utrecht. Therefore, bishop Godebald (AD 1114–1127) not only granted city rights to the civilians of Utrecht in AD 1122, but also permitted the construction of canals. The Medieval city was allowed to erect a defence wall and trench (*OSU* I nr. 308; De Bruijn, 1994). Two natural segments of the Medieval Rhine, respectively located ~700 m north and 1 km south of the former fort, were used to delimit the city in the north and south, thereby forming slightly curving boundaries (Apps. F, G). Two straight canals were dug between these channels to form the east and west boundaries enclosing an area of ~125 ha (Van Vliet, 2000a). In addition, a canal was dug within the city between AD 1122–1127: the Oudegracht or *novum fossatum* (*OSU* I nr. 322). Finally a ~8 km long canal, named Vaartse Rijn, was dug in order to restore a connection with the Hollandsche IJssel (and Lek) river to the south (Figs. 8, A4, A6 and A8).

In summary, the alluvial ridges of the Kromme Rijn and Oude Rijn were semi-permanently inhabited throughout the studied time interval. During the 2nd millennium AD, land in the wider surroundings was reclaimed and Utrecht became a permanent city on an abandoned alluvial ridge.

3. Combining geological and archaeological data

The study of the abandonment phases of the Kromme Rijn and Oude Rijn requires a detailed reconstruction of the palaeogeographical development. To this end we first produced a geological-geomorphological map of the area, mainly in order to delimit the channel belts and to reveal existing residual channels within these belts (Section 3.1). To provide tight age control these channel belts and residual channels were dated using various geological and archaeological dating techniques (Section 3.2; Tables 3–5; extensive detail is provided in the Appendix, which contains entries at channel belt and site level). Occasionally, the direction of channel migration has been exposed in sections during archaeological researches. Subsequently, the position and migration of the former river channels through time were reconstructed, thereby revealing the chronological development of the meander lengths and amplitudes (Section 3.3). Finally, the original channel bathymetry and the palaeo-discharge of the channels during the abandonment phase were reconstructed (Section 3.3). The reconstruction of the interaction between landscape development (river activity) and human occupation during the abandonment phase was based on the reconstruction of settlement history of the area (Section 3.4).

Table 2
Flow Velocities and Discharge of the river Rhine near the Dutch-German border in 1790 and 1792 (after Hesselink et al., 2006: cross section river Boven Rijn - a,A). * = bankfull discharge.

	v (m/s)			Q (m3/s)
	Min.	Max.	Average	
AD 1790	0.85	1.45	1.1 ± 0.13	1.745
AD 1792*	0.65	1.85	1.3 ± 0.22	3.370

Overall, a large amount of legacy data and earlier compiled maps were analysed and supplemented with data from more recent studies carried out during the last two decades up to mid-2014. Here we only refer to overview publications and peer-reviewed archaeological literature.

3.1. Geological-geomorphological mapping

To reconstruct the palaeogeographical development of the study area during the Roman and Medieval periods we mapped and dated the morphological features in both the rural and urbanized parts (Fig. 4). This reconstruction ties in with existing reconstructions at delta scale and with full Holocene coverage (Berendsen and Stouthamer, 2001) and with associated mapping-and-dating GIS databases (Cohen et al., 2012b). Particular attention was paid to the position of the residual channels and to their respective ages.

The palaeogeographical reconstructions in the rural areas are mainly based on soil, geological, lithogenetic and geomorphological maps (Berendsen, 1982; Buringh and Van der Knaap, 1952; Stichting voor Bodemkartering, 1976; Van de Meene et al., 1988). These maps have regional coverage and reveal the detailed distribution of the meander belts, levees, crevasse-splays and flood basins, with the exception of the urbanized areas. The mappings are based on an extensive database of Utrecht University containing over 150–300 shallow (2–5 m depth) borehole descriptions per km^2 (Berendsen, 1982; Berendsen and Stouthamer, 2001; Berendsen et al., 2007). These corings were performed with hand auger equipment and described in a uniform way. The boundaries of the mapped features were improved by analysis of LIDAR data of national coverage (Appendix: Figs. A5a, A5b; Rijkswaterstaat-AGI, 2005; Berendsen and Volleberg, 2007; De Boer et al., 2008; Van Dinter, 2013).

For the reconstructions in the urbanized areas, we studied and re-evaluated maps resulting from earlier analyses of the core descriptions database of the municipality of Utrecht (Wansleeben, 1982; Nales and Vis, 2003). In addition, historic topographical maps were studied to locate curved ditches and roads, and to assess in which cases these are indicative for the presence of residual channels (Fig. 4a; Van Deventer, 1569/70; Blaeu, 1633–1635, 1649; Verstraelen, 1629; Specht, 1696; Anonymous, 1873, 1874, 1875).

Descriptive geological information from archaeological excavations in the area was used to verify the mapped boundaries of the geomorphological units. In addition, this resource was important for documenting the dimensions (width, depth) of (residual) channels and the directions of channel migration in time and space *within* the channel belt (Fig. 4b). A major part of the palaeogeographical reconstruction work was comprised of deriving this information from the source data and recompiling it into maps and figures (Figs. 4–6).

Table 3
Results of [14]C-dates in the study area. For location and references see Fig. 4 and the local data Appendix Part A. The OxCal programme v4.2 (Bronk Ramsey, 2009) and the IntCal13 calibration dataset (Reimer et al., 2013) were used to acquire the ages BC/AD.

C14 nr	Laboratory nr	BP ± 1ó	delta C13	Sample name	Xcoor (m)	Ycoord (m)	Sample depth (m NAP)	Ground level (m NAP)	Sample depth (cm-ground level)	Sediment	Material	Seed/wood	Alluvial ridge	Base/top/middle	Reference	Opmerkingen
C1	GrA 18392	1940 ± 35	n.a.	Wachttoren Gemeentewerf	128910	456160	−1.05	0.45	150	Clayey peat	Seeds	Biax	Oude Rijn	Base	Dielemans, 2014	Residual channel
C2	GrA 43211	1645 ± 35	−27.31	Laan van Chartreuse	135413	457670	−0.55	0.9	145	Humic clay	Seeds	8 Ranunculus acris/repens, 2 Ranunculus scleratus, 2 Oeanthe aquatica, 2 Carex acuta/ngra type, 1 Cirsium/Craduus, 1 Lycopus europaeus	Vecht	Base	Den Hartog, 2013c; Diependaal, 2008	Swale
C3	GrA 43213	1005 ± 35	−29.2	LR55-809	129858	456896	−1.75	0.05	180	Humic clay	Seeds	seeds	Oude Rijn	Base	Den Hartog, 2010a	Residual channel
C4	GrA 43216	2200 ± 35	−30.7	LR62-568	131179	455607	−0.47	1.53	200	Clayey peat	Seeds	seeds	Oude Rijn	Levee	Aarts, 2012	Levee
C5	GrA 43287	1385 ± 30	−27.3	LR62-699	131269	455682	−0.58	1.47	205	Gyttja	Seeds	seeds	Oude Rijn	Base	Aarts, 2012	Residual channel
C6	GrA 43292	1610 ± 30	−24.8	LR65-22	128477	457589	−1.4	0.8	220	Gyttja	Seeds	1 Carex sp.; 3 Carex utricle; 1 Valeriana sp.; 1 Rumex sp,; 1.5 Thalictrum	Oude Rijn	Base	Hoegen, 2013	Residual channel
C7	GrA 43293	715 ± 30	−26.95	Marnixlaan 15	135037	457979	−0.05	1.66	171	Clayey peat	Seeds	7 Oenanthe aquatica seeds	Vecht	Base	Den Hartog, 2013b	Residual channel
C8	GrA 43295	650 ± 30	−28.98	Marnixlaan 16	135104	457957	−0.24	1.66	190	Humic clay	Seeds	10 Ranunculus acris/repens, 5 Rumex spec, 1 Sambucus nigra, 1 Rubus fructicosus, 1 Cirsium/Craduus, 1 Troliius arvensis seeds	Vecht	Base	Den Hartog, 2013b	Swale
C9	GrA 44779	1400 ± 50	−27.3	LR62-698	131269	455682	−0.28	1.47	175	Clayey peat	Seeds		Oude Rijn	Top peat	Aarts, 2012	Residual channel
C10	GrA 50004	880 ± 35	−27.34	Twijnstraat Utrecht	136920	454920	1.50	4.6	310	Sand	Seeds	Ranunculus acris/repens 2x; Stachys arvensis/palustris 1x	Oude Rijn	Top	Griffioen, 2011	Final stage channel deposits
C11	GrA 50882	1840 ± 100	−26.49	Zeister meander	142427	455426	0.63	1.9	127	Gyttja	Seeds	leaf remains 9x, Alnus fruit 0,5x; Phragmites australis 1x; Alisma plantago-aquatica 1x; Rumex conglomeratus 1x; Persicaria minor 1x	Zeister	Base	Unpublished	Residual channel
C12	GrA 50892	360 ± 50	n.a.	Mauritsstraat Ed Weiss I	138220	455780	−0.18	1.5	168	Clayey peat	Seeds	Persicaria hydropiper 4,5x, cf. embryo 2x; Polygonum aviculare 2x; Fallopia concolvulus 4x; Urtica dioica 5x; Lythtum salicaria 1x; Alisma plantago-aquatica 2x	Vecht	Top peat	Unpublished	Residual channel
C13	GrA 50894	880 ± 70	−26.99	Mauritsstraat Ed Weiss III	138220	455780	−1.12	1.5	262	Gyttja	Seeds	Rumex maritimus 1x; Rumex sp. 1x (met kapotte perianth); Rumex cf. conglomeratus 1x; Salix calyptra 1x; Sonchus asper 1x; Ranunculus acris/repens 1x; Ranunculus sceleratus 1x; Poa palustris 1x; topje met knopje van Calluna? 1x	Vecht	Base, gyttja	Unpublished	Residual channel

C14	GrA 50896	560 ± 270	n.a.	Minkade Utrecht	137502	455200	2.20	2.98	78	Humic clay	Seeds	Sambucus 30x fragmenten,	Vecht	Base, rejected	Unpublished	Rejected, error too large
C15	GrA 53568	1965 ± 40	−28.17	Fectio 300	139441	452288	−1.2	1.8	300	Peaty clay	Seeds		OudWulverbroek	Middle	Van den Bos et al., 2014	Residual channel
C16	GrA 55151	1900 ± 30	−28.14	Fectio 196	139441	452288	−0.16	1.8	196	Peaty clay	Seeds		OudWulverbroek	Top	Van den Bos et al., 2014	Residual channel
C17	GrA 55152	1940 ± 30	−29.59	Fectio 411	139441	452288	−2.31	1.8	411	Gyttja	Seeds		OudWulverbroek	Base	Van den Bos et al., 2014	Residual channel
C18	GrA 55196	1700 ± 30	−25.19	VLHi2 spoor 1013	129475	457645	−0.9	0.8	170	Clayey peat	Seeds		Oude Rijn	Base	Porreij-Lyklema, 2013	Residual channel
C19	GrN 04371	2930 ± 60		Bunnik excavation	140500	455400	exact location unknown; −0.06	1.80	86		Charcoal		Zeist onset		In Berendsen, 1982, 138−139: Vogel and Waterbolk 1972: 39	Charcoal in vegetation horizon on clayey peat
C20	GrN 06377	3625 ± 60		Utrecht WA 1970 Willem Arntsz	137025	455195	exact location unknown	n.a.	n.a.	N.a.	Wood		Oude Rijn	N.a.	CIO Groningen database	Tree in residual gully
C21	GrN 06633	1880 ± 35		Utrecht, V&D, fuik	136305	455895	−4	4.5	850	Sand	Wood	willow	Oude Rijn	In channel deposits	ABKU 1926-1972, Achter Clarenburg	Fish trap in channel deposits
C22	GrN 11339	1565 ± 25		Visschersplein 1981	136645	455675	n.a. c. 1.50	n.a. c. 3.0	n.a. c.150	n.a.	Wood		Oude Rijn		ABKU 1981; CIO Groningen database	Wooden pallisade along residual channel
C23	GrN 11340	2200 ± 80		Pieterskerkhof 10-11	137055	455930	c 0.1.0	3	c. 200	n.a.	Charcoal		Oude Rijn		ABKU 1982	Levee
C24	GrN 11341	1930 ± 50		Pieterskerkhof 10-11	137055	455930	c. 0.7	3	c. 230	n.a.	Charcoal		Oude Rijn		ABKU 1982	Levee
C25	GrN 11342	1240 ± 25		Utrecht Oudkerkhof skelet	136770	456020	−2.4	n.a.	n.a.	n.a.	Bone		Oude Rijn		ABKU 1976−77; CIO Groningen database	Inhumation
C26	GrN 13709	1205 ± 25		Utrecht boat 1-1	135040	457955	n.a.	n.a.	n.a.	n.a.	Wood (from boat)		Oude Rijn		CIO Groningen database	River migration
C27	GrN 17542	1845 ± 50		Mare I	130390	453650	−4.20	−0.70	350		Bone		De Mare/Heldam		Berendsen, 1990	Residual channel
C28	GrN 18106	4135 ± 40		Vechten 2	140637	452635	0.60	2.40	180		Wood and leaves		Werkhoven	Base	Berendsen and Wynia 1993	In sandy channel fill
C29	GrN 18107	2590 ± 70		Vechten 3	140640	452567	1.00	2.40	140		Wood		Houten	Base	Berendsen and Wynia 1993	In sandy channel fill
C30	GrN 20345	1210 ± 25		Utrecht Waterstraat 1	136315	456405	exact location unknown	n.a.	n.a.	n.a.	Wood (from boat)		Vecht		Van de Moortel, 2009	Dendro late 10th, river migration
C31	GrN 20346	1198 ± 23		Utrecht Waterstraat 2	136315	456405	exact location unknown	n.a.	n.a.	n.a.	Wood (from boat)		Vecht		Van de Moortel, 2009	Dendro late 10th, river migration
C32	GrN 20942	940 ± 40		Utrecht Lange Lauwerstraat moss	136655	456410	n.a.	n.a.	n.a.	n.a.	Wood (from boat)		Vecht		Van de Moortel, 2009	River migration

(*continued on next page*)

Table 3 (*continued*)

C14 nr	Laboratory nr	BP ± 1σ	delta C13	Sample name	Xcoor (m)	Ycoord (m)	Sample depth (m NAP)	Ground level (m NAP)	Sample depth (cm-ground level)	Sediment	Material	Seed/wood	Alluvial ridge	Base/top/middle	Reference	Opmerkingen
C33	GrN 20945	1090 ± 30		Utrecht Waterstraat 3	136315	456405	exact location unknown	n.a.	n.a.	n.a.	Wood (from boat)		Vecht		Van de Moortel, 2009	Dendro late 10th, river migration
C34	GrN 22748	5520 ± 35		Vechten-De Mast M2	140029	451506	−4.1	1.60	570	Peat on E/TF	Peat		GW-level	Base	Berendsen and Stouthamer 2001	GW-level
C35	GrN 22822	5400 ± 35		Vechten-De Mast M2	140029	451506	−4.1	1.60	570	Wood in peat on E/TF	Wood		GW-level	Base	Berendsen and Stouthamer 2001	GW-level
C36	KIA 37442	3065 ± 25	−26.8	LR57-144	130967	455691	−0.33	0.87	120	Gyttja	Wood		Oude Rijn	Base	Meijer, 2009	Landing-stage in residual gully
C37	KIA 37443	3030 ± 30	−26.6	LR57-174	130966	455690	−0.83	0.87	170	Gyttja	Wood		Oude Rijn	Base	Meijer, 2009	Landing-stage in residual gully
C39	KIA 37444	3075 ± 30	−19.2	LR57-212	130975	455686	−1.2	0.8	200	Gyttja	Bone, collagen		Oude Rijn	Base	Meijer, 2009	Residual channel
C40	KIA 37445	3010 ± 30	−21.6	LR57-246	130994	455692	−0.5	0.8	130	Gyttja	Bone, collagen		Oude Rijn	Base	Meijer, 2009	Residual channel
C41	KIA 43434	3555 ± 25	−26.3	LR67-27	132715	453740	−1.05	0.08	113	Clayey peat	Seeds	Carex urntjes (4), Conium maculatum (24), Stachys sylvatica (3), Solanum nigrum (17), Carex hirta/riparia (2), Carex sp charred (1), Mentha aquatica/arvensis (19), Brassicaceae (1	Oude Rijn	Base	Dielemans, 2013b	Residual channel
C42	KIA 43435	3600 ± 30	−26	LR67-137B	132620	453940	−1.85	0.1	195	Gyttja	Seeds	Stachys (1), Carex hirta/riparia (5), Carex acuta type (2), Carex urntjes (2), Mentha aquatica/arvensis (1), Alisma plantago-aquatica (1), Poaceae (7), Papaver sp (1), cf. Carum ventriculatum (2), Salix sp. knopje (1), Typha sp. (1)	Oude Rijn	Base	Dielemans, 2013b	Residual channel
C43	KIA 49507	1850 ± 30	−25.3	UTRT2-10-177	136980	455840	0.5	2	150	peaty clay	Seeds		Oude Rijn	Base	Van Benthem, in press.	Swale
C44	Poz 20984	1810 ± 30	−32.1	V239, S149, schelpenpad	138970	451920	0.6	1.3	70		Wood underneath path of shells		OudWulverbroek	base ~ start residual	Heiden and Koot, 2009	Next to residual channel
C45	Poz 20986	960 ± 30	−28.8	V339, S174, restgeul B	139000	451833	−0.2	1.6	180		Wood			Middle	Heiden and Koot, 2009	Residual channel
C46	Poz 20987	1890 ± 30	−28	V278 S149, schelpenpad	138970	451920	0.6	1.3	70		Wood underneath path of shells		OudWulverbroek	Base ~ start residual	Heiden and Koot, 2009	Next to residual channel

C49	Poz 20988	1750 ± 30	−28.6	V43, S8, restgeul A	138985	451880	0.5	1.3	80		Wood		OudWulverbroek	Top	Heiden and Koot, 2009	Pole in residual channel
C50	Poz 21012	870 ± 30	−22.2	V396, S168.2, restgeul B	139000	451833	−0.2	1.6	180		Bone			Middle	Heiden and Koot, 2009	Residual channel
C51	SUERC 27873	1050 ± 30	−28.9	LR65-15	128355	457590	−1.2	0.9	210	gyttja	Seeds	Persicaria lapathifolia, Ranunculus acris/repens, Polygonum aviculare, Stellaria media	Oude Rijn	Base	Hoegen, 2013	Residual channel
C52	SUERC 27874	1070 ± 30	−28.9	LR65-134	128755	457690	−1	0.7	170	gyttja	Seeds	Persicaria lapathifolia, Ranunculus acris/repens, Polygonum aviculare, Stellaria media	Oude Rijn	Base	Hoegen, 2013	Residual channel
C53	SUERC 30355	1950 ± 35	−25.6	AML 188	135024	453886	−0.7	0.1	80	clay	Wood	Oak	Oude Rijn	Top	Dieleman and Van der Kamp, 2012	Post in residual channel
C54	SUERC 30356	3940 ± 35	−26.7	AML 069	135018	453900	−0.1	0.1	20	Clay	Wood	Oak	Oude Rijn		Dieleman and Van der Kamp, 2012	Trunk in channel deposits
C55	SUERC 30357	2305 ± 35	−27.2	AML 110	135006	453895	−1	0.1	110	Clay	Wood	Willow	Oude Rijn	Middle	Dieleman and Van der Kamp, 2012	eel-buck in residual channel
C56	SUERC 30358	1910 ± 35	−25	AML 059	135015	453889	−0.5	0.1	60	Clay	Wood	Oak	Oude Rijn	Top	Dieleman and Van der Kamp, 2012	Trunk in channel deposits
C57	SUERC 30667	3075 ± 30	−34	AML 071	135013	453893	−1.7	0.1	180	Clayey peat	Seeds	*Oenanthe aquatica, Carex spec, Schoenoplectus lacustris, Alopecuris geniculatus*	Oude Rijn	Base peat	Dieleman and Van der Kamp, 2012	Residual channel; high delta C13 value
C58	SUERC 30668	2500 ± 30	−25	AML 073	135013	453893	−1.28	0.1	138	Clayey peat	Seeds	*Oenanthe aquatica, Laminaceae, Ranunculus scleratus, Solanum nigrum.*	Oude Rijn	Top peat	Dieleman and Van der Kamp, 2012	Residual channel
C59	SUERC 40863	3200 ± 35	−25.2	DSL-31	136713	452959	−0.4	1	140	Peat	Seeds	1 Carex acuta/nigra type, 2 Schoenoplectus lacustris, 1 Atriplex patula/prostrate, 4 Chenopodium album, 1 Persicaria minor, 7 Solanum nigrum, 2 Stellaria media, 2 Carduus cf. Crispus, 1 Plantago major, 1Polygonum aviculare, 1 Rumex crispus type, 14 Ranunculus acris/repens, 1 Hordeum vulgare	Oude Rijn	Top peat	Dielemans, 2014	Residual channel
C60	SUERC 40864	3415 ± 35	−25.8	DSL-33	136713	452959	−1	1	200	Humic clay	Seeds	1 Carex hirta/riparia type, 2 Mentha aquatica/arvensis, 1 Ranunculus sp., 14 Schoenoplectus lacustris, 1 Persicaria minor	Oude Rijn	Base	Dielemans, 2014	Residual channel
C61	SUERC 40865	3475 ± 35	−30.9	DSL-109	136705	452928	−0.2	1	120	Sitly clay	Wood	Willow	Oude Rijn		Dielemans, 2014	>35 m long wicker work (fence) in final phase of channel deposits
C62	SUERC 41368	1770 ± 30	−26.1	Zeist-11-94:28 −32	144780	455040	c. 4	5.0	c. 100	Peaty clay	Seeds	various Cyperaceae taxa	Zeist	Base	Vermue and Molthof, 2014	Crevasse channel

(*continued on next page*)

Table 3 (*continued*)

C14 nr	Laboratory nr	BP ± 1σ	delta C13	Sample name	Xcoor (m)	Ycoord (m)	Sample depth (m NAP)	Ground level (m NAP)	Sample depth (cm-ground level)	Sediment	Material	Seed/wood	Alluvial ridge	Base/top/middle	Reference	Opmerkingen
C63	SUERC 41369	1270 ± 30	−26.1	Zeist-11-94:16−20	144780	455040	c. 4.12	5.0	c. 88	Peaty clay	Seeds	Carex and Ranunculus	Zeist	top	Vermue and Molthof, 2014	Crevasse channel
C64	SUERC 53120	2027 ± 24	−28.1	LR84-121	132959	456426	−0.8	0.6	140	Humic clay	Wood		Oude Rijn crevasse		Den Hartog in prep. b	Pole in crevasse channel
C65	SUERC 53121	1983 ± 26	−27.3	LR84-122	132958	456429	−1	0.6	160	Humic clay	Wood		Oude Rijn crevasse		Den Hartog in prep. b	Pole in crevasse channel
C66	SUERC 53122	2167 ± 27	−27.5	LR84-208	132960	456418	−1	0.6	160	Humic clay	Wood		Oude Rijn crevasse		Den Hartog in prep. b	Pole in crevasse channel
C67	SUERC 54219	1772 ± 30	−25	LR84-41	132657	456420	−0.9	1	190	peaty clay	Seeds		Oude Rijn crevasse	Top peat	Den Hartog in prep. b	Residual channel
C68	SUERC 54220	1981 ± 30	−28.6	LR84-43	132657	456420	−1.28	1	228	Peaty clay	Seeds		Oude Rijn crevasse	Base	Den Hartog in prep. b	Residual channel
C69	Ua 36484	1640 ± 35	−29.7	LR55-802	129833	456995	−0.7	0.55	135	Gyttja	Seeds	Salix remains	Oude Rijn	Base	Den Hartog, 2010a	Start medieval channel depsoits/late roman residual channel
C70	UtC unknown	1610 ± 30	n.a.	Pieterskerkhof graves	137045	455930	n.a.	n.a.	n.a.		Bone				De Groot, 1991	Burial
C71	UtC 06948	3103 ± 34	34	Heldammer 256	129400	454910	−1.5	−0.2	130	Peat	Seeds	26 Carex rostrata, 33 Typha, 14 Mentha aquatica, 1 Oenanthe aquatica, 1 Alisma plantago aquatica (Top of Alnus peat overlying Phragmites peat and gyttja)	Heldam crevasse channel	Alnus peat	Cohen et al., 2012a, b	Crevasse channel, overlying Phragmites peat
C72	UtC 06975	3830 ± 90	90	Heldammer 255	129400	454910	−1.87	−0.2	167	Peat	Seeds	5 Sagittaria sagittifolia, 2 Oenanthe aquatica, 2 Carex sp., 2 Potentilla, 1 Ranunclus scleratus (Phragmites peat)	Heldam crevasse channel	Phragmites peat	Cohen et al., 2012a, b	Crevasse channel
C73	UtC 06978	1930 ± 60	n.a.	Schip De Meern 1	129843	454807	0.45	1.85	140	Humic clay	Seeds		Heldam 2	Base	Van Dinter and Graafstal, 2007	Residual channel
C74	UtC 10334	1414 ± 48	−34.4	LR8 sleuf 10	132633	456133	−1	0.95	191−200	Humic clay	Seeds		Oude Rijn	Base	Berendsen and Stouthamer, 2001	Residual channel
C75	UtC 11139	1774 ± 35	−29.9	Zeist PTT-2	144880	454752	3.12	4.5	138−140	Gyttja-peat	Seeds		Zeist	Base	Cohen et al., 2012a, b	Residual channel
C76	UtC 11184	3973 ± 38	−25.7	Heldam 6 7-39-375	128759	455762	−3.51	0.2	369−371	Peaty clay	Seeds		Heldam		Berendsen and Stouthamer, 2001	Onset Oude Rijn; levee deposits in floodbasin

C77	UtC 11183	4221 ± 37	−25.4	Heldam 5 7-39-311	128759	455762	−2.85	0.2	300 −320	Peaty clay	Seeds		Heldam		Berendsen and Stouthamer, 2001	1th onset Heldam; levee deposits in floodbasin
C78	UtC 11182	4053 ± 43	−25.6	Heldam 4 7-39-270	128759	455762	−2.5	0.2	260 −280	Peaty clay	Seeds		Heldam		Berendsen and Stouthamer, 2001	1th ending Heldam; levee deposits in floodbasin
C79	UtC 11181	3840 ± 45	−24.6	Heldam 3 7-39-226	128759	455762	−2.06	0.2	220 −245	Peaty clay	Seeds		Heldam		Berendsen and Stouthamer, 2001	2nd onset; levee deposits in floodbasin
C80	UtC 11180	3465 ± 41	−24.7	Heldam 2 7-39-193	128759	455762	−1.73	0.2	175 −200	Peaty clay	Seeds		Heldam		Berendsen and Stouthamer, 2001	2nd ending Heldam; levee deposits in floodbasin
C81	UtC 11179	2907 ± 31	−25.5	Heldam 1 7-39-150	128759	455762	−1.3	0.2	140 −165	Peaty clay	Seeds		Heldam		Berendsen and Stouthamer, 2001	3td onset Heldam: levee deposits in floodbasin
C82	UtC 11990	4444 ± 38	−28.1	Heldam 7	128459	455762	−3.47	0.2	367	Peat	Seeds		Heldam		Berendsen and Stouthamer, 2001	Final date of first phase Oude Rijn
C83	UtC 11991	4990 ± 45	−28	Heldam 8	128459	455762	−3.62	0.2	382	Peat	Seeds		Heldam		Berendsen and Stouthamer, 2001	GW-level
C84	UtC 12175	952 ± 28	−23	LR36-3	132626	456200	−1.4	1	240	clayey peat	seeds	cereal grain	Oude Rijn	base	Van der Kamp, in prep. b/Den Hartog, in prep. b	Residual channel
C85	UtC 12176	1190 ± 70	−30	LR36-15	132333	456518	−3.04	1	404	Clayey peat	Seeds	Uncharred plant remains	Oude Rijn	Base	Van der Kamp, in prep. b/Den Hartog, in prep. b	Residual channel
C86	UtC 12429	1846 ± 31	−28.2	DMN-120 schip NISA de Meern 1	129855	454800	−2.03	1.17	320	Humic clay	Seeds		Heldam 2	Base	Van Dinter and Graafstal, 2007	Residual channel
C87	UtC 13086	3142 ± 33	−26.7	LR39-3	130050	454760	1.17	4.37	320	Gyttja	Seeds	Hanneke lijst …	Heldam 1	Base	Langeveld & Luksen-IJtsma, 2010	Residual channel
C88	UtC 13249	2733 ± 37	−30.9	LR39-1	130050	454756	−0.9	1.2	210	Clayey peat	Seeds	3 Alisma plantago-aquatica, 1 Carex vesicaria, 3 Eleocharis palustris, 6 Hypericum cf. perforatum, 1 Mentha aquatic, 1 Oenanthe aquatic, 2 Poaceae, 1 Poa sp., 1 Polygonum cf. minus, 1 Rorippa palustris, 1 Scrophularia cf. umbrosa	Heldam 1	Top peat	Langeveld & Luksen-IJtsma, 2010	Residual channel

(*continued on next page*)

Table 3 (*continued*)

C14 nr	Laboratory nr	BP ± 1σ	delta C13	Sample name	Xcoor (m)	Ycoord (m)	Sample depth (m NAP)	Ground level (m NAP)	Sample depth (cm-ground level)	Sediment	Material	Seed/wood	Alluvial ridge	Base/top/middle	Reference	Opmerkingen
C89	UtC 13250	3082 ± 38	−29.4	LR39-2	130050	454756	−1.6	1.2	280	Clayey peat	Seeds	2 Carex sp., 1 Cruciferae/ Galium?, 2 Phagmites australis, 2 Rumex sp.	Heldam 1	Base peat	Langeveld & Luksen-IJtsma, 2010	Residual channel
C90	UtC 13251	1935 ± 27	−26.6	LR42-3	132964	456491	−1.45	0.7	215	mollusc layer	seeds	1 Sambucus sp., 6 Solanum dulcamara	Oude Rijn	Base	Den Hartog, 2009a, b	Residual channel
C91	UtC 13315	1557 ± 37	−28.3	t Zand-2	132477	456543	−1.27	0.78	205	Clayey peat	Seeds	5 Atriplex sp., 2 Chenopodium sp., 2 Epilobium hirsutum, 1 Polygonum cf lapathifolium, 5 Ranunculus cf. acris/ repens, 4 Ranunculus sceleratus, 2 Stellaria media, 1 Urtica dioica	Oude Rijn	Base peat	Jansen and Leijnse, 2005	Residual channel
C92	UtC 13357	1315 ± 33	−27.6	t Zand-1	132477	456543	−1.03	0.78	181	Clayey peat	Seeds	7 Alisma plantago-aquatica, 1 Carex sp., 3 Oenanthe aquatic, 1 Ranunculus cf. acris/ repens, 5 Salix sp., 1 Sonchus sp.	Oude Rijn	Top peat	Jansen and Leijnse, 2005	Residual channel
C93	UtC 13358	1615 ± 31	−26.7	LR42-1	132964	456491	−0.97	0.7	167	Clayey peat	Seeds	1 Carduus/Cirsium, 1 Chenopodium sp., 1 Compositae, 1 Polygonum cf lapathifolium, 2 Ranunculus cf. acris/ repens, 5 Rumex sp., 1 Solanum dulcamara, 1 Sonchus sp., 1 Stellaria medi, 1 Urtica dioica, 1 Valeriana sp.	Oude Rijn	Top peat	Den Hartog, 2009a, b	Residual channel
C94	UtC 13359	1792 ± 31	−24.8	LR42-2	132964	456491	−1.31	0.7	201	Gyttja	Seeds	1 Berula erecta, 5 Carex sp. nutlet, 1 Carduus/Cirsium, 1 Eleocharis palustris, 3 Phagmites australis, 1 Solanum dulcamara,	Oude Rijn	Base	Den Hartog, 2009a, b	Residual channel
C95	Utc 14930	2546 ± 33	−23	LR57-060	130982	455688	−1.28	0.02	130	Clayey peat	Seeds	*Phragmites australis*	Oude Rijn	Top peat	Meijer, 2009	Residual channel
C96	UtC 14931	2821 ± 32	−23.9	LR57-100	130982	455688	−1.68	0.02	170	Clayey peat	Seeds	*Phragmites australis*	Oude Rijn	Base peat	Meijer, 2009	Residual channel
C97	UtC 14932	2134 ± 30	−27.2	LR57-099	131168	455699	−1	0.5	150	Sandy clay	Wood		Oude Rijn	Active	Meijer, 2009	Post in channel; active
C98	UtC 14933	792 ± 27	−24.6	Croeselaan - Rabobank	135945	455275	−0.6	2.4	300	Gyttja	Seeds	Seeds	Oude Rijn	Base	Unpublished	Residual channel
C99	UtC 14934	2491 ± 33	−27.8	Lombok	135560	456055	−0.8	2.2	300	humic clay	Seeds	Salix 3 bud, Rumex maritimus/palustris; Rumex sp., Persicaria hydropiper 2, Persicaria lapathifolia, Carex acuta/ elata, Cirsium arvense/ palustre 2 fruits, Atriplex patula/prostata vrucht, Ranunculus scleratus zaad	Oude Rijn	Base	Den Hartog, 2013	Residual channel

C100	UtC 14935	1821 ± 34	−26.9	PK5100 Pieterskerkhof	136960	455950	2.15	4.15	200	humic clay	Charcoal		Oude Rijn	base	Luksen-IJtsma, 2010	Residual channel
C101	UtC 14936	2761 ± 33	−24.3	LR52	129085	459020	−0.9	0.5	140	clayey peat	Seeds	Phragmites	Oude Rijn	?	Unpublished	Residual channel
C102	UtC 14937	912 ± 28	−27.4	Ahornstraat-8	135530	457130	−0.4	1.7	210	Gyttja	Seeds	*Triticum dicoccon, Rumex acetosela, Rumex hydrolapathum, Rumex palustris, Stellaria media, Ranunculus scleratus*	Vecht	Base	Den Hartog, 2013b	Residual channel
C103	UtC 15137	2481 ± 30	−28	LR55-19	129640	457025	−1	0.7	170	Clayey peat	Seeds	Salix seed	Oude Rijn	Base	Den Hartog, 2010	Residual channel
C104	UtC 15138	3815 ± 30	−23.6	LR60-21	131603	454530	1.78	2.15	37	Silty clay	Charcoal		Crevassecomplex Heldam 1		Weterings and Meijer, 2011	Top levee
Houten final phase, T8																
C105	GrA 23920	2230 ± 40	−20.07	HOUN03-VNR1180	141193	448059	2.5	0.45	215		Bone		Houten	Base	Dijkstra and van Benthem, 2004	Burial at edge of residual channel
C106	KIA 22134	2149 ± 37	−29.51	HOUN03-VNR1442MP	141210	448055	2.5	1.05	100		Seeds		Houten	Base	Dijkstra and van Benthem, 2004	Residual channel
Houten final phase, T14																
C107	GrN 26049	2070 ± 45	−25.88	HTNV000035	141220	446900	c. 1.5	2.3	c. 80		Charcoal		Houten last phase	Middle	Krist et al., 2001	Residual channel
C108	GrN 26050	2040 ± 45	−27.73	HTNV000076	141220	446900	c. 1.5	2.3	c. 80		Charcoal		Houten last phase	Middle	Krist et al., 2001	Residual channel
C109	GrN 26051	2070 ± 20	−27.56	HTNV00823	141220	446900	c. 1.5	2.3	c. 80		Wood		Houten last phase	Middle	Krist et al., 2001	Residual channel
C110	GrN 26095	1990 ± 30	−25.87	HTN000820	141220	446900	c. 1.5	2.3	c. 80		Wood		Houten last phase	Middle	Krist et al., 2001	Residual channel
C111	GrA 17490	2250 ± 50	−21.03	HTNV000180	141220	446900	c. 1.5	2.3	c. 80		Bone		Houten last phase	Middle	Krist et al., 2001	Burial at edge of residual channel
Wijk bij Duurstede																
C112	KIA 44269	1765 ± 35	−29.74	WIJD-07 2674	152074	443085	2.03	5.1	307	Humic clay	seeds		Seeds	Base	Dijkstra, 2012	Residual channel
C113	SUERC-42607	1864 ± 26	−25	WIJD3-10 1198-93	151460	443965	2.54	5	246	Humic clay	Seeds	Salix & Rumex etc.	Kromme Rijn	Base	Williams, 2004	Residual channel
C114	SUERC-42608	1589 ± 29	−26.9	WIJD3-10 1199-47	151460	443965	3	5	200	Humic clay	Seeds	Schoenoplectus lacustris, Alisma plantago-aquatica	Kromme Rijn	Top	Williams, 2004	Residual channel
C115	SUERC-42609	1710 ± 26	−24.7	WIJD3-10 603 −45,5	151667	443861	3.1	5	190	Humic clay	Seeds	Schoenoplectus lacustris	Kromme Rijn	Base	Williams, 2004	Residual channel
Oude Rijn downstream																
C116	UtC 11987	2653 ± 45	−27.8	Oude Rijn 1	123912	458047	−1.85	−1	85	Peat	Seeds		Oude Rijn	Kromme Rijn-Oude Rijn (last phase)	Berendsen and Stouthamer, 2001	Levee in flood basin deposits
C117	UtC 11988	2683 ± 42	−28.8	Oude Rijn 2A	123912	458047	−2.8	−1	180	Gyttja	Seeds		Oude Rijn	Final phase Houten-Oude Rijn	Berendsen and Stouthamer, 2001	Levee in flood basin deposits

(*continued on next page*)

Table 3 (*continued*)

C14 nr	Laboratory nr	BP ± 1ó	delta C13	Sample name	Xcoor (m)	Ycoord (m)	Sample depth (m NAP)	Ground level (m NAP)	Sample depth (cm-ground level)	Sediment	Material	Seed/wood	Alluvial ridge	Base/top/middle	Reference	Opmerkingen
C118	UtC 11989	3625 ± 37	−28.5	Oude Rijn 3A	123995	457855	−4.09	−0.85	324	peat	Seeds		Oude Rijn	First large-scale activity of Houten-Oude Rijn	Berendsen and Stouthamer, 2001	Levee in flood basin deposits

Table 4
Results of OSL-dated samples in the study area. Sample O8 is based on single grain analysis. For locations see Fig. 4 and the local data Appendix.

Nr.	Laboratory nr	OSL ± 1SD	Sediment	Sample name	Xcoor	Ycoord	Zcoord (m OD)	Surface (m OD)	Depth sample (cm)	Interpretation	Lit	PaleoDose (Gy)	Dose rate (Gy/ka)	Remarks
O1	Oxford X3017	1750 ± 150 before 2007	Sand	UTDH-339	136610	455499	1.86	4.3	244	Washover/flooding layer	Duurland, in press	3.04 ± 0.12	1.73 ± 0.12	Dated layer covers roman graves dating until first half of 3rd century AD
O2	Oxford X3529	1830 ± 360 before 2009	Sand	LR65-M14	128745	457623	−0.2	1.2	140	Channel deposits	Hoegen, 2013	3.67 ± 0.64	2.01 ± 0.23	
O3	Oxford X3530	2370 ± 370 before 2009	Sand	LR65-M15	128741	457602	0	1.35	135	Channel deposits	Hoegen, 2013	3.90 ± 0.42	1.65 ± 0.19	
O4	Oxford X3743	1420 ± 135 before 2009	Silty clay	UTRT-63	136475	456260	1.59	4	241	Washover/flooding layer	Verniers, 2010	2.75 ± 0.16	1.94 ± 0.14	High concentrations of thorium and uraniu (~x 3 as X3874)
O5	Oxford X3874	2600 ± 310 before 2010	Sandy clay	UTRT2-30	136130	456030	0.6	2.3	170	Washover/flooding layer	Bouma, 2011	3.14 ± 0.18	1.34 ± 0.09	Partial bleaching not excluded
O6	Risø 082104	5350 ± 310 before 2008	Sand	LR57-429	130993	455708	−0.4	0.85	125	Channel deposits	Meijer, 2009	8.11 ± 0.31	1.51 ± 0.06	Rejected, too old, stratigraphically impossible
O7	NCL 7110025	1700 ± 151 before 2011	Silty clay	UTKE-OSL3	135050	454700	0.3	1.5	120	Levee deposits	Briels, 2011; Wallinga and Johns, 2011	4.95 ± 0.41	2.91 ± 0.09	
O8	NCL 7110026	2330 ± 151 before 2011	Silty clay	UTKE-OSL4	135050	454700	−0.15	1.5	165	Channel deposits	Briels, 2011; Wallinga and Johns, 2011	5.91 ± 0.20	2.53 ± 0.15	
O9	NCL 7614044	2060 ± 130 before 2013	Sand	BAAC-Ganzenmarkt_vnr.167	136664	456065	1.38	5.2	382	Top pointbar	Van der Mark, in prep.	4.20 ± 0,20	2.01 ± 0,08	

Table 5
Overview of dimensions (width and depth) used for the reconstruction of active channel and residual channel dimensions (values in bold are those used for calculations in Fig. 9) and age-control. For references, see the local data Appendix Part A, for locations see Appendix Part B and Fig. 4.

Section	Channel belt	Residual channel		Channel deposits			Dating	14C Dating nr.	Archaeological finds	Reference
		Width (m)	Depth (m)	Base (m OD)	Base (m OD)	Base (m below surface)				
A	Zeist	**115**	2	–1	–6	**–8**	Roman	GrA 50882	No finds	Van Munster, 2012
B1 (section C)	Oudwulverbroek	**110**	**7**	–6	–	–	Roman	GrA 53568, GrA 55151, GrA 55152	Roman	Jansen et al., 2014; Van den Bos et al., 2014
B2 (section A)	Oudwulverbroek	**130**	5	–3.5	–	–	id.		Roman	Jansen et al., 2014; Van den Bos et al., 2014
C.	Oudwulverbroek	>30	2	–1.3	–	–	Probably Roman		No finds	Warning, 2008; Verniers and Van Dinter, 2011
D	Vecht	**50** (old ditch pattern)	1.5	–1.1	–	–	Late medieval	GrA 50894	Late medieval	Unpublished
E	Oude Rijn	–			–	–	Late medieval river movement	GrA 50004	no finds	Griffioen, 2011
F	Oude Rijn	5	1.5	–0.3	–	–	Late medieval	UtC 14935	Late medieval	Van Veen, 2010
G	Oude Rijn	-	–	–	–	–	Late medieval river movement		Late medieval	Den Hartog, 2013a
H1	Oude Rijn	-	–	–	–	–	Roman river edge		Roman	Luksen-IJtsma, 2010
H2	Oude Rijn	-	–	–	–	–	Post Roman river activity	GrN 11340; GrN 11341	Early Medieval	ABKU 1982: Pieterskerkhof 10-11
H3	Oude Rijn	–	–	–	–5.5	**–7**	Pre Roman; probably Late Iron age		no finds, but below Roman fort	Kloosterman & Hoegen, in prep.
I1	Oude Rijn	**165–180**	>3.5	>–2	–	–	Pre Early medieval; probably Roman		no finds	Kalisvaart, 2012b; Van Mousch, in prep.
I2	Oude Rijn	22	2	0	–	–	Late Medieval		re-deposited roman and early medieval finds; late medieval finds in vegetation horizon	ABKU 1926–1972: Achter Clarenburg; Dominicus & Van den Berg, 1971
I3	Oude Rijn	5	1.5		–	–	Early medieval	dendrodate UT 600010-60	Early Medieval	Jansma 2013; Van Mousch, in prep.
I4	Oude Rijn	–			–	–	Early medieval river movement		Early Medieval	AKPU 2004 2005: Rijnkade
J	Oude Rijn	10	2	–	–	–	Late medieval	UtC 14933	no finds	Unpublished; Van Deventer 1569; Verstralen 1629
K	Oude Rijn	10	1.5	–0.2	–	–	Late medieval		Late medieval	Den Hartog, 2013a
L1	Oude Rijn	–	–	–	–	–	Early medieval incision and late medieval river movement		Early medieval settlement; Late medieval	Nokkert et al., 2009
L2	Oude Rijn	10	2	–	–	–	Late medieval		Late medieval	Nokkert et al., 2009
M1	Oude Rijn	>8	~4	–3.1	-	-	Late medieval	UtC 12176	Late medieval	App. in Den Hartog, in prep. b or in Van der Kamp, in prep. b
M2	Oude Rijn	13	2	–1.3	-	-	Late medieval		Late medieval	App. in Den Hartog, in prep. b or in Van

(*continued on next page*)

Table 5 (*continued*)

Section	Channel belt	Residual channel		Channel deposits			Dating	14C Dating nr.	Archaeological finds	Reference
		Width (m)	Depth (m)	Base (m OD)	Base (m OD)	Base (m below surface)				
										der Kamp, in prep. b
M3	Oude Rijn	20	2	−1.25	-	-	Late medieval	UtC 12175	Late medieval	App. in Den Hartog, in prep. b or in Van der Kamp, in prep. b
M4	Oude Rijn	10	2	−1.9	−4.4	−5.2	early Roman	UtC 13315; UtC 13357; SUERC 54219; SUERC 54220	No finds	Jansen Leijnse, 2005; Den Hartog in prep. b
N phase a	Heldam	**70–100**[a]	-	-	4	−**3.5**	Roman: 1st c.		Roman	Aarts, 2012
N phase b	Heldam	40–50 [a]	–	–	2.5	−2	Roman: start 3rd c.		Roman	Aarts, 2012
N phase c = 2B	Heldam	10	1	−1	–	–	Roman: mid 3rd c.		Roman	Aarts, 2012; Jongkees and Isings, 1963
O phase 2	Heldam	**35–45**	**4.5–5**		–	–			Roman	Aarts, 2012
O phase 2B	Heldam	8	1	−2	–	–	Roman: mid 3rd c.	UtC 12429; UtC 06978	Roman	Van Dinter and Graafstal, 2007
P phase 2	Heldam		–	–	−6	−**7**			Roman	Nales and Vis, 2003
P phase 2B	Heldam	8	1	−2	–	–	Roman: mid 3rd c.		Roman	Dielemans, 2014a
Q	Oude Rijn	-	>1.5	>−1.5	–	-	Early medieval incision	Ua 36484	Early and Late medieval	Den Hartog, 2010
R1	Oude Rijn	>10	3	−1	–	–	Late roman/Early medieval	GrA 43292	no finds	Hoegen, 2013
R2	Oude Rijn	20	2.5	−0.8	–	–	Late medieval	SUERC 27873; SUERC 27874	Late medieval	Hoegen, 2013
S	Vecht	–	–	–	–	–	Late medieval river movement ?		Late medieval ?	ABKU 1982: Oude Gracht 136
T	Vecht	–	>…..	>…..	–	–	Late medieval river movement	GrN 20345; GrN 20346; GrN 20945	Late medieval	ABKU 81: Jan Meijenstraat en Waterstraat; ABKU 1986 Jacobstraat; Van de Moortel, 2009
U	Vecht	25	2.5	−2.5	–	–	Late medieval		Late medieval	Den Hartog 2009c
V	Vecht	13	~−1−1.5	−0.4	–	–	Late medieval	UtC 14937	Late medieval	Unpublished
W	Vecht	~10	~1	−0.55	–	–	Late Roman/Early medieval	GrA 43211	no finds	Diependaal, 2008; Den Hartog, 2013c
X	Vecht	~10	~1	−0.05	–	–	Late medieval	GrA 43293; GrA 43295	Late medieval	Den Hartog, 2013c

[a] Active channel.

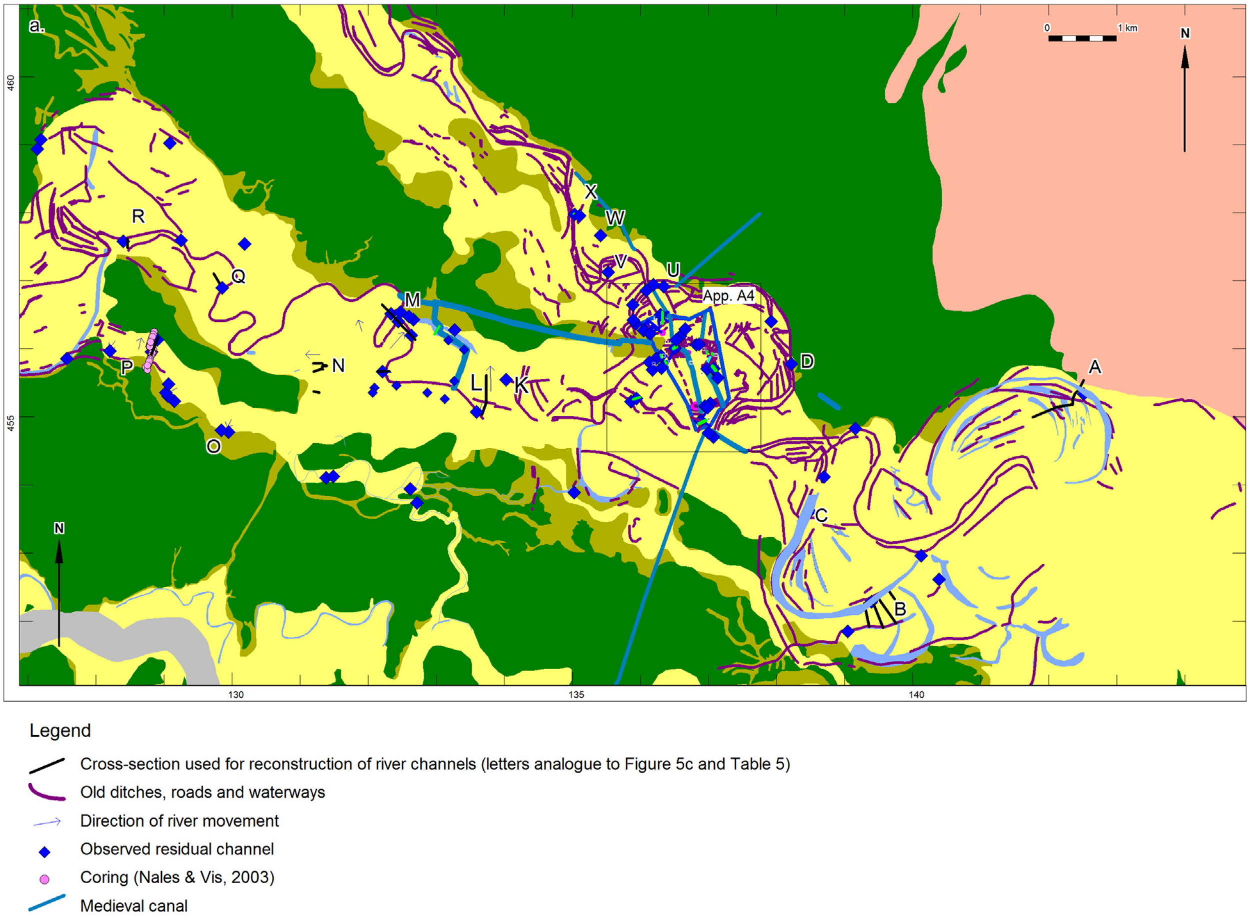

Fig. 4. Geomorphological map of the study area. a. with location of cross-sections (Fig. 5c), used for the reconstruction of river channels (capitalised labels corresponding to Table 5), directly observed residual channels, and indirect observations of these channels as curved ditches, roads and waterways. Detailed maps for the medieval city subarea are found in the Appendix (Part A, Fig. A4). b. with locations of archaeological excavations and surveys (centre coordinates), ^{14}C and OSL sample sites. More detailed maps are part of the Appendix (Part A, Figs. A1–3).

3.2. Age control

The results from the many archaeological excavations in the area were used to provide tight age control of the mapped geomorphological elements. Archaeological artefacts such as pottery and metal finds usually can be dated quite accurately, particularly when produced during the Roman and Medieval periods. Dealing with an assemblage of artefacts usually reduces the dating range of the finds to a few decades with a maximum of one century. Likewise, the time frame during which the various channels were abandoned and filled in is constrained by archaeological dates from accumulated waste in the residual channel fills. This approach yields more accurate results than radiocarbon and OSL dating of geological material alone. In addition dendrochronological dates of sunken vessels which sometimes contain preserved archaeological remains yielded estimates of the period of channel activity (e.g. Jansma and Morel, 2007; Groot and Morel, 2007; Jansma, 2013; Jansma et al., 2014; Manders, 2011; Manders and Hoegen, 2011; Brouwers et al., 2013, 2015). Finally, at some locations excavated bank revetments showed the presence of (residual) channels (Van Rooijen, 2010; Ypma et al., 2014). These revetments consist of a series of vertical wooden poles, usually holding a board or wicker work in order to stabilize the river bank and to support mooring. The revetments were not intended to defend against erosion.

Archaeological finds uncovered in natural levee deposits are usually not reworked and therefore were considered to reveal the period of river-bank formation. In contrast, artefacts excavated in channel deposits are either considered to have been re-deposited from the vicinity, and thus to pre-date sedimentation, or to have been have been thrown into or lost in the river, thus representing the formation period of the deposits. In addition, the age of archaeological settlements and finds discovered in paleosols (vegetation horizons) formed in the top of levee deposits, which indicates a former surface, provided *terminus ante-quem* dates of the levee formation.

The spatial extent of a (buried) weak soil horizon was used to map the pre-Medieval channel belt parts. Artefacts in this palaeosol show that it was formed during the Roman period in the top of the adjacent and older channel belts in the area. This palaeosol is easily recognizable by its dark grey to black colour and is characterised by the absence of calcium carbonate, which indicates a period of soil formation and limited sedimentation.

The first step was to analyse the archaeological excavations that have been carried out by the Utrecht Archaeological Service in the Medieval city of Utrecht and its direct surroundings since the early 1900s (Fig. 4b; Appendix: records 1–205 of Table A1). Relevant geological information of these sites was obtained from the short descriptions of the excavation results, which mainly have been published in the annals of the municipality of Utrecht. In addition, geological information was acquired from the archaeological reports of excavations that were carried out in the urban areas and the rural surroundings by archaeological companies (Fig. 4b;

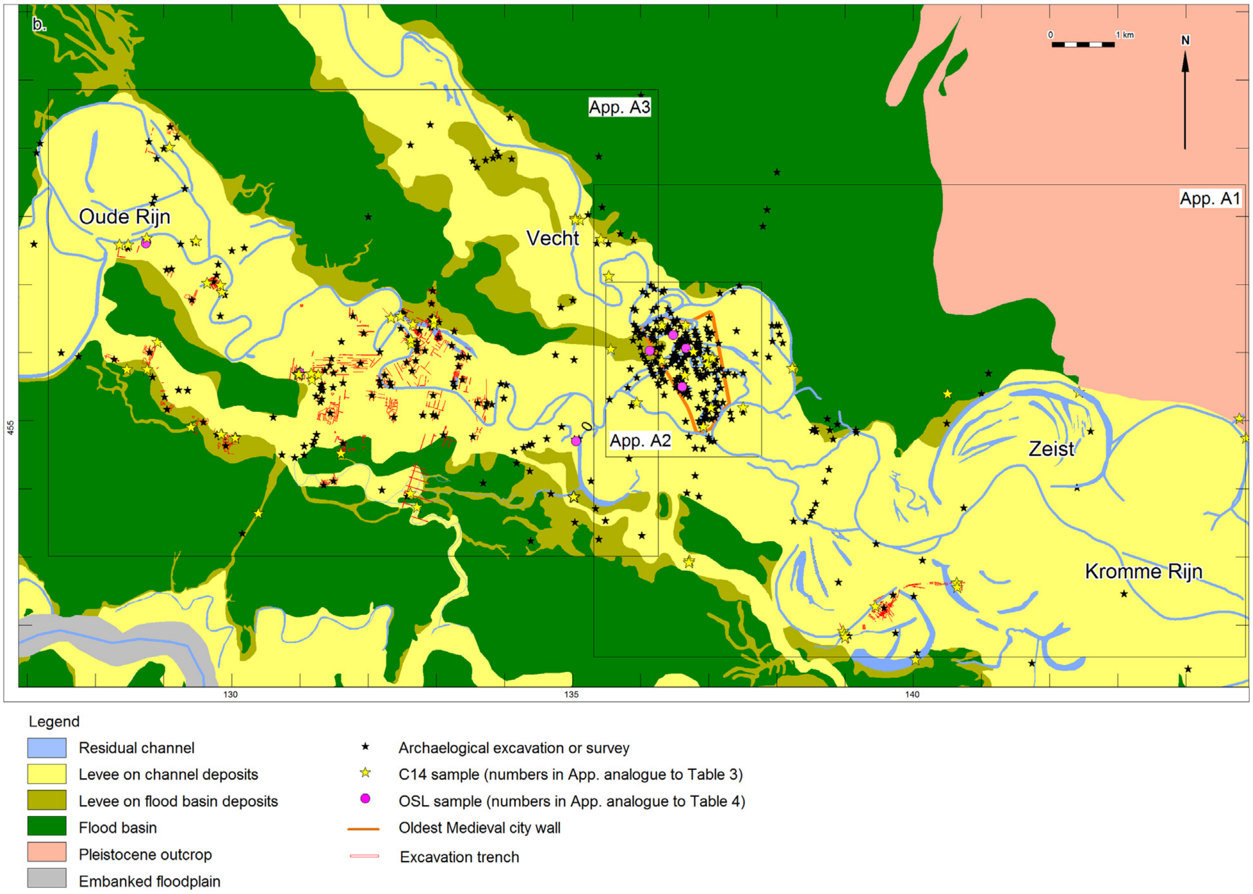

Fig. 4. (*continued*).

Appendix: records 206–431 of Table A1).

During the last decades the Utrecht Archaeological Service also conducted a number of large-scale archaeological studies by to the west of the city of Utrecht in the new residential area around De Meern, 'Leidsche Rijn', which now covers ~25 km^2 (Figs. 2 and 4b; Appendix: records 414–503 of Table A1). Geological research constituted a major aspect of these studies and at each excavation the cross-sectional architecture was logged for lithology and sedimentology, and the facies distributions were interpreted lithogenetically. Age control was obtained in these studies by radiocarbon and optical stimulated luminescence (OSL) dating, and by the chrono-typological study of the archaeological finds.

To estimate the period of abandonment of the various river channels a combination of dating techniques was used, thereby chronologically constraining the abandonment phases within narrow boundaries (Tables 2–4; sandy strata: OSL-dating and ^{14}C-dating of enclosed organic mats, dendrochronological dating of boats; residual channel fill: ^{14}C and archaeological dating of muddy, organic and/or anthropogenic waste). The results of individually dated residual channel fragments throughout the Roman and Medieval periods were integrated into a palaeogeographical reconstruction following the abandonment of the Kromme Rijn-Oude Rijn and the Vecht channel belts. This reconstruction complements and improves the existing chronology of the avulsion history of the central Rhine-Meuse delta (Berendsen, 1982; Stouthamer and Berendsen, 2000; Berendsen and Stouthamer, 2001; Cohen et al., 2012b), which focused on the earlier parts of the Middle and Late Holocene (up to Roman times), mostly relied on ^{14}C-dating, and intrinsically assumed a relatively fast pacing of avulsion and abandonment.

3.3. Reconstruction of channel geometry and palaeo-discharge

The various sources revealed the ages and locations of residual channels (Fig. 4) and provided information about the dimensions of the former active river channels (Table 5) and/or the direction of channel migration. This resulted in the reconstruction of the position of the former river channels in the research area through time as well as the meander length and amplitude of the successive river channels. The palaeogeographical reconstructions distinguish a sequence of stages of which the chronological boundaries primarily are based on morphological changes, and which also show the corresponding changes within the archaeological record.

Fig. 5 shows the principles deployed in reconstructions of former channel dimensions from lithological cross-sections (Fig. 5a and b), as well as selected key examples of actual studied cross-sections (Fig. 5c, ordered by location and age; also see Table 5). The depths of former channels (Table 5) were estimated from the thickness of channel-bed deposits (corings reaching to thalweg channel-lag deposits) and the depth of the base of residual channel fills, where these are metres thick and the transition signals sudden abandonment and subsequent quick transformation into an oxbow lake (cf. Constantine et al., 2010; Toonen et al., 2012), such as in the Oudwulverbroek example (Fig. 5c: section B; based on Jansen et al., 2014; Van den Bos et al., 2014). The width of former channels (Table 5) was estimated from the planform geometry of oxbow lake residual topography (trench exposure + borehole-based mapping, LiDAR data), presence of relatively fine-grained fill deposits

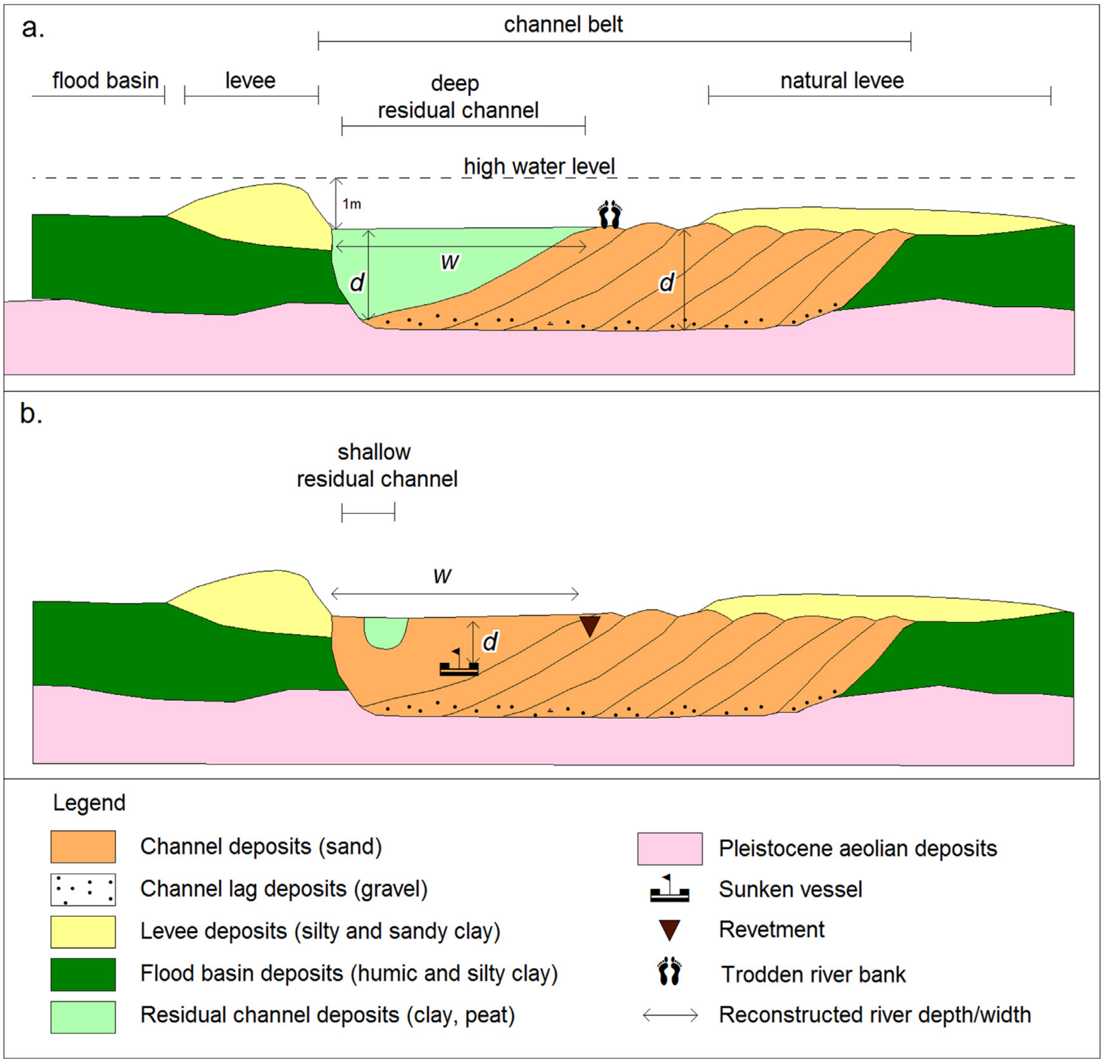

Fig. 5. a. and b. Schematic cross-section showing method of reconstruction of channel dimensions; c. Selection of cross-sections (capitalised labels corresponding to Table 5), ordered east to west and from Roman to Medieval period, showing dimensions of the river channels in time and space. For locations of sections, see Fig. 4 and the local data Appendix (Part B, Fig. A5).

(sedimentary architecture), the presence of revetments and trodden river banks (archaeological indicators), and the distance between curved older roads and ditches (inferred topographic inheritance).

Next, the relative channel erosive capacity was reconstructed based on the observed changes in channel morphology and activity. An absolute palaeo-discharge at bank full discharge estimate was not reconstructed because flow velocities cannot be directly compared to modern ones because of major engineering works. However, 18th-century flow velocity measurements in the Rhine branches in the upper delta, performed before major engineering works such as cut offs and groynes took place (Table 2; Hesselink et al., 2006), probably yield a reasonable indication for the beginning abandonment stage of the Oude Rijn at the start of the Roman Period with estimated flow velocities of ~1 m/s in the centre of the channel and 0.5 m/s in riparian areas.

3.4. *Reconstruction of settlement history*

The reconstruction of the settlement history is based on the results of all archaeological excavations and surveys in this area. The occupancy of archaeological sites on the Utrecht alluvial ridge is usually dated with a confidence range of ~25–50 years.

The outline of the Roman forts in the area is known from a number of excavations and surveys in and around the forts (Vechten: Polak and Wynia, 1991; Zandstra and Polak, 2012; Utrecht: Ozinga et al., 1989; De Meern: Vollgraff and Van Hoorn, 1941; Jongkees and Isings, 1963; Kalee, 1982; Kalee and Isings, 1980, 1984; Van der Gaauw and Van Londen, 1992). Likewise, the contours of the civil Roman settlements that developed in time around these forts, generally called *vici*, have been reconstructed in previous studies in various detail (Vechten: Vos, 1997; De Haan, 2004; Utrecht: Ozinga et al., 1989; Montforts, 1991, 1995; De Meern: Haarhuis and Graafstal, 1993; Van der Gaauw and Van Londen, 1992; De Jager, 2000; Langeveld et al., 2010; Langeveld, in press.). The location of the Roman watchtowers in between the forts was derived from Van Dinter (2013), and the distribution of the rural settlements in the Roman period was obtained from Haarhuis and Graafstal (1993), Kooistra et al. (2013) and Van Dinter (2013). The presence of several Roman grave yards in the vicinity of the forts was demonstrated by Polak (1997), De Haan (2004), Langeveld et al. (2010), and Duurland (in press.). The reconstruction of the Roman road was based on Luksen-IJtsma (2010), and has been slightly adapted based on recent excavations.

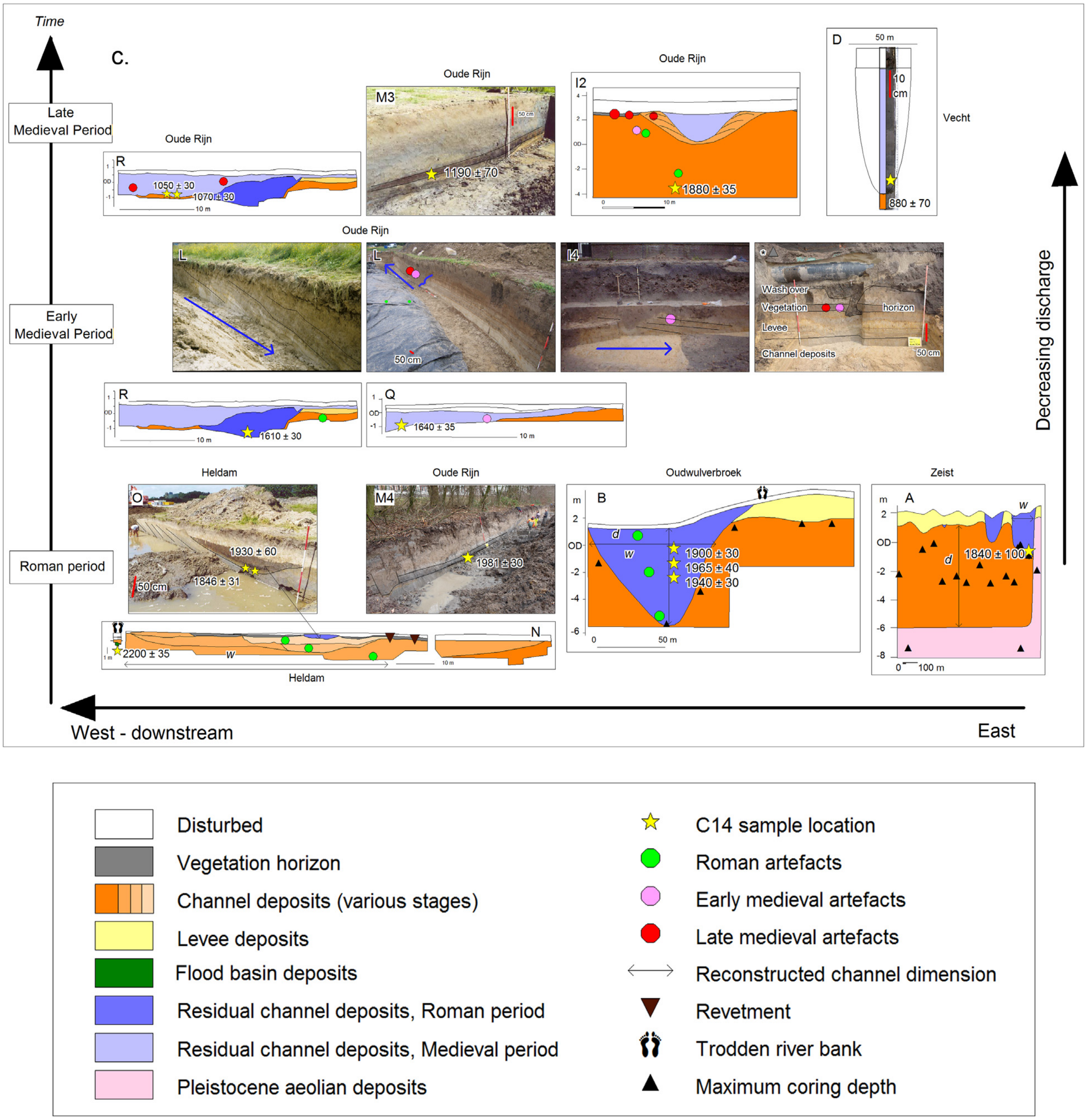

Fig. 5. (*continued*).

The distribution of the Early Medieval settlements between AD 500 and 800 was derived from Nokkert et al. (2009), complemented with data from Den Hartog (2010) and Van Rooijen (2010). A property list drawn up by bishop Radbod in AD 914 to reclaim the church possessions before his return to Utrecht, the *commemoratio de rebus Sancti Martini Traiectensis ecclesie* (Hendrikx, 1987; De Bruijn, 2008), was consulted in order to hypothetically link its content to archaeological finds. The locations of Medieval settlements between AD 800 and 1200 were based on Haarhuis and Graafstal (1993), Van Rooijen (2010), Van der Kamp (2005a, 2005b, 2006a, 2011, 2013), Den Hartog (2009b, 2013c), and Dielemans (2010). The location of Late Medieval churches and the extent of their ecclesiastical properties were obtained from Hoekstra (1989) and De Bruijn (1994).

4. Palaeographical development and habitation history

This section describes the palaeogeographical reconstruction of (i) the landscape development and (ii) settlement pattern. River dynamics are discussed in downstream direction (from east to west) and in chronological order. To create an overview a channel belt age map was compiled (Fig. 6). This map integrates the various sources described above, thereby updating previous reconstructions (Berendsen and Stouthamer, 2001; Cohen et al., 2012a, b), and shows the width and age of the various channel belt segments associated with activity of the youngest channel belt (red colors) within the long-lived channel belt (yellowish colours). Fig. 7 provides an overview of the period of activity of the main distributaries on a time axis. Channel belt segment numbering (#IDs) follows Berendsen and Stouthamer (2001) and Cohen et al.

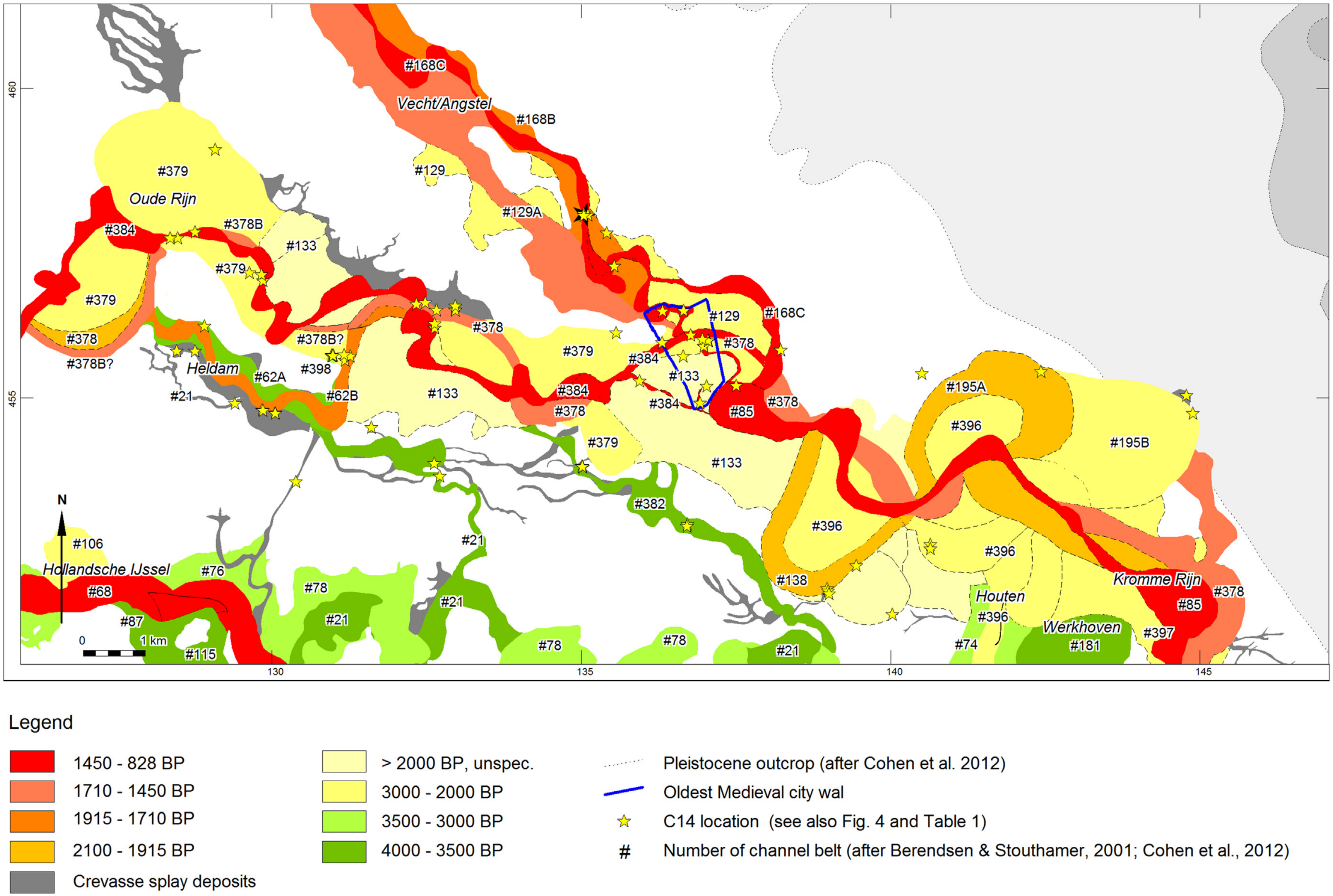

Fig. 6. Updated map of the channel belt age for the study area (Channel belt #ID's serve cross-reference to Fig. 7, descriptions in Appendix Part B, and earlier mapping cited therein). Stars show locations of 14C dating control (Table 3).

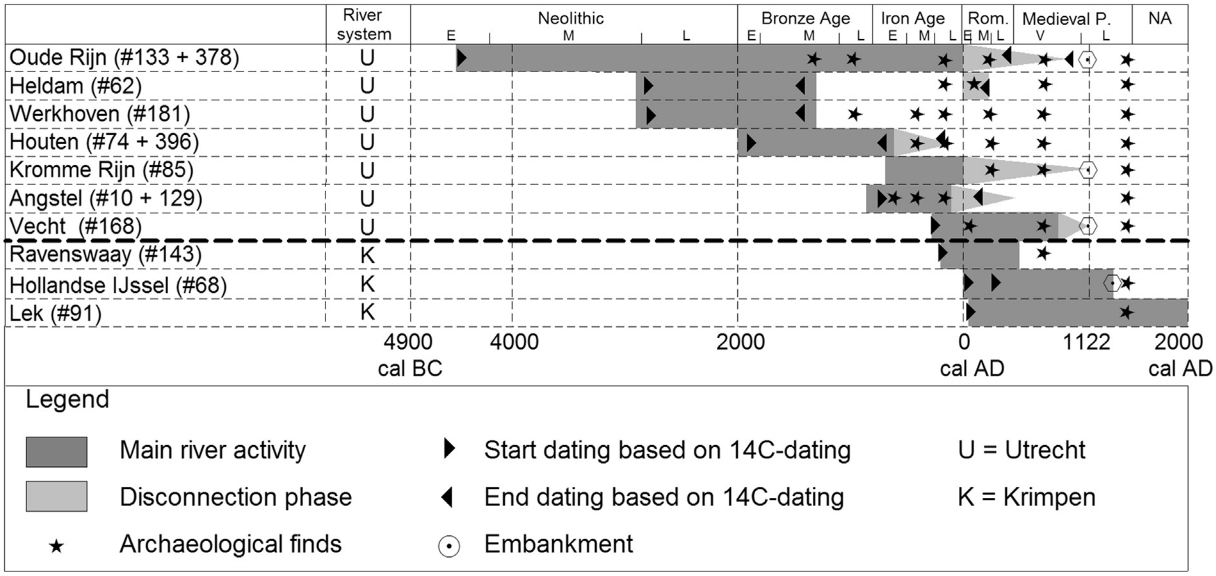

Fig. 7. Period of activity of the main channel belts (Fig. 6) affecting the study area in the Late Holocene.

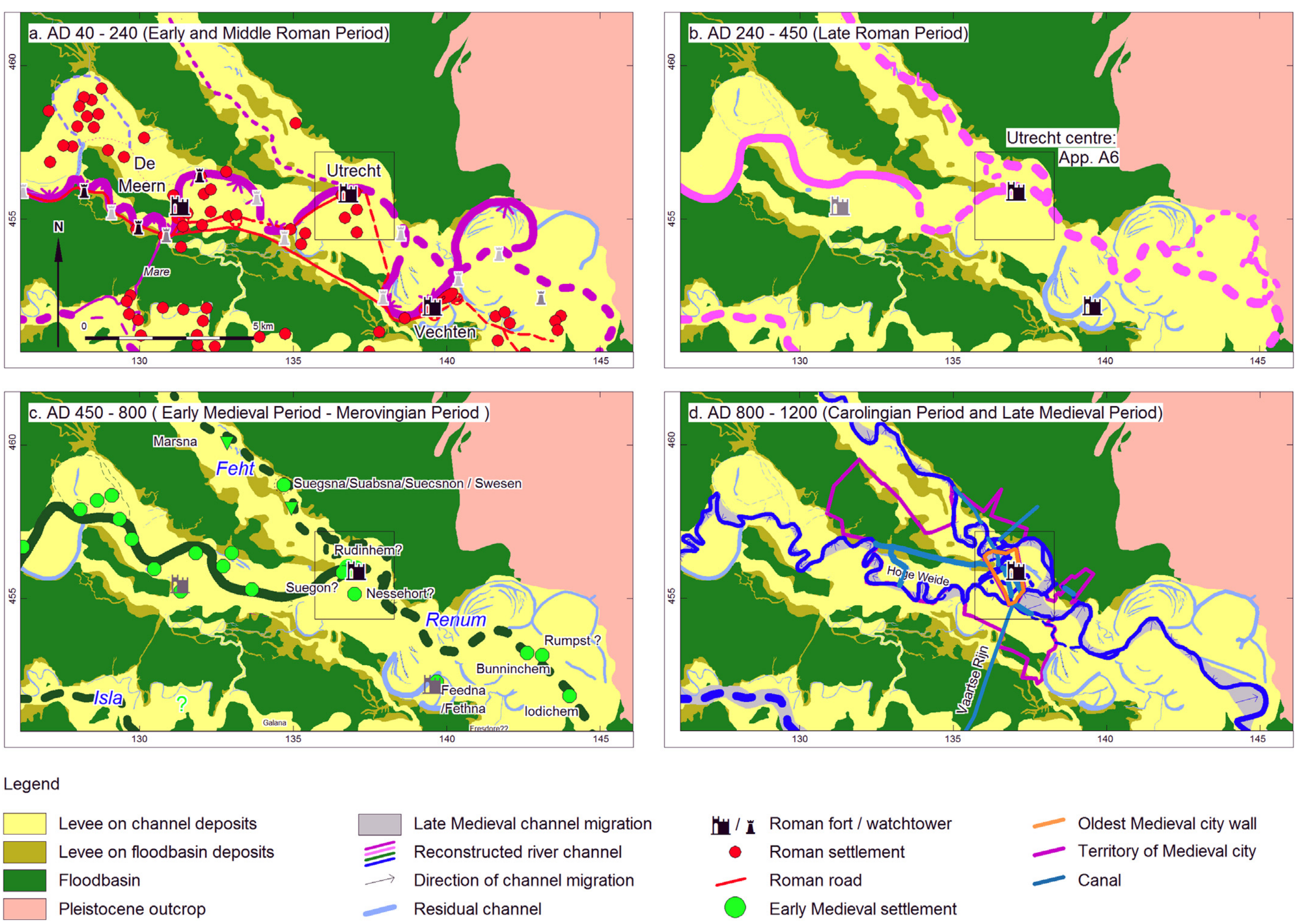

Fig. 8. Palaeogeographical maps of the study area with river channels and settlements. a. AD 40–240 (Early and Middle Roman Period), b. AD 240–450 (Late Roman Period), c. AD 500–800 (Early Medieval Period - Merovingian Period) and d. AD 800–1200 (Carolingian Period and early part of Late Medieval Period).

(2012a, b).

4.1. Early and middle Roman Period (AD 40–240)

4.1.1. River and landscape

During the first two centuries AD (Fig. 8a), relatively large and wide meanders characterized the Rhine channel upstream of Utrecht. Examples are the so-called Zeist (#195) and Oudwulverbroek (#138) with a meander length of ~4.5 km and an amplitude of ~ 1–1.5 km. The sinuosity index was ~1.5. The Roman fort in Vechten was situated on the outer bank of the latter meander. The channel in front of it was ~100 m wide and 7 m deep. This channel, however, hardly migrated and the large meander bends should be considered as a relic from earlier Iron Age stages when the river discharge had been larger because the competing avulsive distributaries of the Krimpen system (Figs. 2 and 3) had not yet established. The meanders were most likely cut off simultaneously in the second half of 1st century AD and rapidly silted up during the Roman occupation. In the same period a darkened palaeosol developed on the alluvial ridges regionally; this soil is characterized by an A-horizon with black colour and without calcium carbonates, overlying an immature illuviated B-horizon (Berendsen, 1982; Schoute, 1984; Steenbeek, 1990). The paleosol is preserved below overbank deposits from later stages of the abandonment phase. This paleosol indicates that the first centuries AD were characterized by a prolonged period of low overbank sedimentation, i.e. limited river activity outside the active channel, whereas its preservation indicates increased overbank sedimentation later on. It is interesting to note that all Early and Middle Roman rural settlements are positioned on this soil horizon.

With the cut-offs during the Roman Period, the river developed a straighter course. The cut-off channel shows a weakly meandering channel with some in-channel bars within a ~300 m wide zone (Appendix: Fig. A5b). This indicates that the new channel was in disequilibrium with the river discharge, demonstrating that the river discharge further diminished during the Middle Roman Period. This is in agreement with the avulsion history of the wider delta, with the Lek and Waal distributaries gaining importance at this time (Fig. 3). The sand-choked channel bed morphology in the channel fill of the Zeist (#195) meanders (upstream of Utrecht) probably originates from the 2nd to (early) 3rd centuries AD.

The bifurcation of the Rhine into Oude Rijn and Vecht was situated ~7 km downstream of the fort near Vechten, right in front of the Utrecht fort. Just upstream of the bifurcation, the river channel was ~5–6 m deep and ~100–120 m wide. During the Roman occupation phase the river migrated several tens of meters northward, facilitating an enlargement of the Roman fort in a northern direction at the start of the 3rd century AD. Just downstream of the bifurcation, the Oude Rijn river channel was ~160 m wide and most likely only ~3–3.5 m deep. Similar to the cut-off reach described upstream, a sand-bar choked river bed developed here. The morphology and width of the river Vecht at this time is unclear since no evidently Roman age segment of this river has been identified so far. Presumably, the distribution of discharge over the bifurcation began to tip towards the Vecht channel in this particular period, as suggested by a contemporary shallowing of the channel of the Oude Rijn downstream of the Utrecht fort (Fig. 5).

In the western part of the research area, the Heldam channel belt (#62B) was the main active channel at this time, whereas the Oude Rijn's main alluvial ridge to the north only seems to have hosted residual channels. The activity of the Heldam channel marks a reoccupation phase of this channel belt, which appears to have started early in the 1st century AD. The river channel was ~90 m wide and ~4 m deep in front of the Roman fort in De Meern, while it

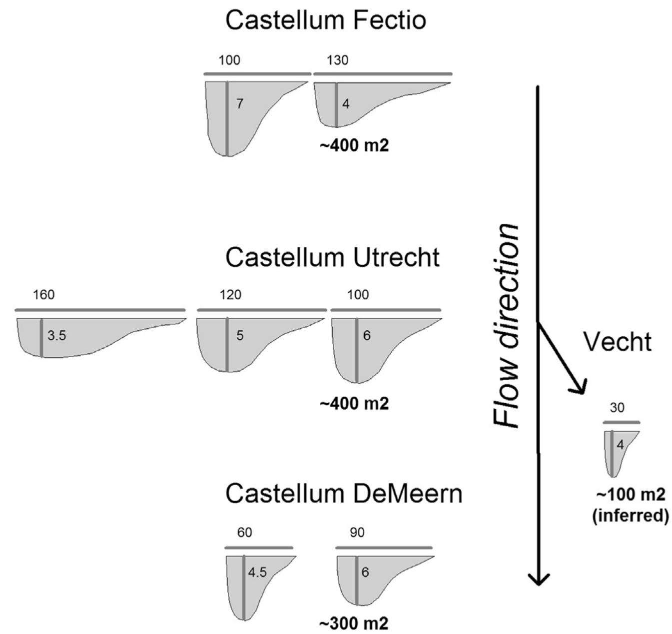

Fig. 9. Dimensions of the Rhine river channels in the 1st century AD (the time of founding of the Roman forts). Cross-sectional wet area (in m^2, calculated for a water level ~1 m below top of levees) is shown for three positions downstream the main river, and for the Vecht distributary. Note vertical exaggeration: graphically the areas do not add up, numerically they do.

was ~6 m deep and only ~60 m wide further downstream (Figs. 4 and 5: section O). The channel dimensions were only modestly smaller than those of coeval channels upstream of the river Vecht bifurcation. Based on cross-sectional hydraulic considerations (width: 4.5–6 m; depth: 60–90 m), the Heldam channel alone was able to transport all the discharge routed westward over the Oude Rijn-Vecht bifurcation. Hence, the dimensions of the river Vecht in Roman times were estimated from the differences in cross-sectional area, which was about 100 m^2, implying a depth of ~4 m and a width of depth and ~25 m (Fig. 9).

The river Heldam (Fig. 6) shifted over a distance of maximum 200 m in a downstream direction and laterally over ~50–150 m, thereby forming pronounced meander bends with a length of ~1 km and an amplitude of ~300 m. By the end of the 2nd century/early 3rd century the Heldam river channel started to silt up and in the second quarter of the 3rd century this river branch was completely abandoned, leaving a small residual channel of ~10 m wide and 1 m deep. Channel migration continued during the abandonment phase and at some locations the shallow river channel even migrated slightly out of its sandy channel belt.

At ~1 km south of the fort in De Meern a southwesterly orientated crevasse channel, the Mare, was active. Its channel was ~3.5 m deep and 15 m wide. Presumably a relatively short canal was dug to link this channel to a crevasse channel from the IJsselveld - Schuurenburg (#76) channel. In this manner, the Mare canal connected the Rhine to the young Hollandsche IJssel (#68) channel of that time.

4.1.2. Settlement pattern

Three strategically-situated Roman forts were built in the research area during the 1st century AD on similar locations as those of the *limes* forts further downstream along the Oude Rijn (Van Dinter, 2013). The Oudwulverbroek meander, along which the Roman fort in Vechten was situated, was probably cut off in the second half of 1st century AD and rapidly silted up during the

Roman occupation phase, mainly because the residual channel functioned as a dump area (Van den Bos et al., 2014).

Watchtowers were built between the *castella* during the second part of the 1st century AD to complete the river view (Van Dinter, 2013). Several tower sites have been discovered so far. One of these, on the Heldam alluvial ridge, was relocated in response to river-bend migration during Roman occupancy (Langeveld and Luksen-IJtsma, 2010; Van Dinter, 2013).

In addition, a Roman road, the *via militaris*, was constructed on the levees south of the river Rhine from the end of the 1st century onwards following a straight line if possible and cutting short river bends (Van Dinter, 2013). Channel migration during the 2nd century caused (partial) destruction of road parts. Subsequently, bypasses were built to overcome the damage (Van Dinter, 2013). The *castella* were linked to the *via militaris* by secondary roads. In the second half of the 2nd century, the road segment just east of fort De Meern was swept away by the river (probably due to bend migration undercutting the road). A new road was built further to the south, partly making use of the alluvial ridge of the small Hoograven channel belt (#382).

Soon after the construction of the military forts, *vici* were established close by Kooistra et al. (2013). A small *vicus* east of Vechten seems to have been present from the start and the earliest *vici* of De Meern and Utrecht seem to date to the middle of the 1st century. Large-scale development of *vici* only occurred from the end of the 1st century onwards with the creation of the province of *Germania Inferior* by Emperor Domitian - in the 80's AD (Kooistra et al., 2013). These *vici* flourished in the 2nd century and burial grounds were created in the surroundings of all the forts. Moreover, the presence of a Roman bath complex was demonstrated directly north of the fort in De Meern. This upstream location is typical for the bath houses of the chain of Roman forts along the Oude Rijn, most likely because in this manner fresh river water was available instead of water contaminated with sewage water and dirt from the fort.

Native settlements were scattered across the alluvial ridges. These rural settlements mainly relied on an agrarian system based on mixed farming (Kooistra, 1996; Groot, 2008; Groot and Kooistra, 2009; Groot et al., 2009). Not all settlements were inhabited simultaneously and some settlements already were inhabited before the large-scale arrival of the Roman army in the area from the '40s AD onwards. Recent research has shown that the number of settlements in the central river delta region increased during the first two centuries A.D. (Willems, 1986; Groot et al., 2009; Vos, 2009). Changes of the settlement structures indicate that the settlements quickly adapted their economy and were able to produce substantial surplus, supplying the Roman soldiers and the *vicani* with food and other commodities (Kooistra, 1996, 2012; Groot, 2008; Groot and Kooistra, 2009; Groot et al., 2009; Kooistra et al., 2013; Van Dinter et al., 2013). Most settlements in the research area date to the late 1st and the 2nd century AD and consisted of one or two simultaneously-inhabited byre houses.

4.2. Late Roman Period (AD 240–450)

4.2.1. River and landscape

During this period (Fig. 8b), no major sedimentation occurred on the alluvial ridges as later early-Medieval settlements and archaeological finds are positioned in the same black palaeosol as the one in which the Early and Middle Roman Period sites have been discovered. The Rhine channel upstream of Utrecht was still confined to the ~300 m sand-choked river bed. During this period the discharge of the Utrecht river system further decreased due to continued development of the Krimpen system (Figs. 2 and 3), which in addition to the Lek (#191), Hollandse IJssel (#168) and Linge (#97) now included the river Waal (#174) as a new developing branch.

Nevertheless, changes also occurred in the river network downstream of Utrecht, most notably in the 3rd century AD. After AD 230–240, the Heldam channel accumulated residual channel fill. This indicates it no longer functioned and implies that water was routed through a new channel formed in the Oude Rijn channel belt to the north (Fig. 8b). Possibly, also the connection of Rhine and Vecht changed at this time. A new feeding bifurcation developed ~1.5 km upstream of the Roman fort. It is also possible that the shifting of this particular location started later, in the beginning of the 6th century AD (see 4.3).

4.2.2. Settlement pattern

Archaeological evidence from the Late Roman Period in the area, i.e. the late 3rd, 4th and early 5th centuries, is scarce. Large-scale inhabitations of the forts and *vici* along the Oude Rijn seem to have continued into the first quarter of the 3rd century (Kemmers, 2008). The finds of the later period, especially dating after AD 275, are sparse and do not seem to indicate permanent occupancy. Habitation in the Utrecht area continued on a small scale only in and around the Roman forts (Haarhuis and Graafstal, 1993; Lidt de Jeude, 1973; Montforts, 1995; Van den Berg et al., 2012 and Polak, 2014). There is no evidence in this area of rural settlement structures dating to the Late Roman Period.

4.3. Early Medieval Period - Merovingian Period (AD 450–800)

4.3.1. River and landscape

By AD 500 (Fig. 8c), the river had cut off several of its bends both upstream and downstream of Utrecht. Furthermore, the new bifurcation location of the rivers Rhine and Vecht had established. The Vecht carried an increasingly larger proportion of the discharge - fed to it from upstream.

At some locations along the Oude Rijn channel, such as in Utrecht, the river bed remained choked with sand. Downstream of the former Roman fort, a complex sandy channel fill architecture developed within the wider zone of the channel activity from Roman times (Fig. 9). The fill complex reveals the activity of coexistent shallow (2–3.5 m deep) migrating channels. Recently, a vessel now termed the '*Utrecht 6*' was unearthed in one of these channels. It was dendrochronologically dated to ca. AD 680 (Jansma, 2013), and its position indicates that shortly after the last quarter of the 7th century this channel started to silt up (Leijnse and Van Mousch, in press). From then on a channel located more to the north was the only one carrying discharge. The uninterrupted presence of the river bank next to an early-Medieval settlement west of Utrecht shows that here the river hardly moved for over ~300 years (Nokkert et al., 2009).

4.3.2. Settlement pattern

Evidence of occupancy of the former Roman forts in the area and their surroundings dating to the 5th century is scarce (Van Rooijen, 2010; Haarhuis and Graafstal, 1993; De Groot, 2007; Hessing et al., 1997). The small number of finds near the forts in Vechten and De Meern, mainly ceramics and metal, suggests that these forts only functioned as minor dwelling sites. The most likely cause is that the river along which they were situated was no longer active. This is in contrast to the fort in Utrecht, where finds also are sparse but here luxurious child burials dating to the second half of the 5th century were uncovered next to the castellum, indicating aristocratic presence (De Groot, 1991; Van Es, 1994; Van Rooijen, 1999, 2010). Also, a revetment unearthed ~200 m west of the fort in Utrecht and dated to the 5th or 6th century AD bears witness of human activity at this time.

From the 7th century onwards the fort in Utrecht became a major political and religious centre in northwestern Europe. Various archaeological remains, dating to the Merovingian (AD 447–750) and Carolingian (AD 751–987) periods (Table 1), show that human occupancy of the fort in Utrecht continued in this period (Van Rooijen, 2010). A settlement was erected west of the fort, a ditch system was dug south of it, and a Christian burial site dating to the 6th/7th centuries AD was established to the north. The shallow river in front of the fort might explain the Medieval name of Utrecht, *Traiectum (*f.e. *Vita Willibrodi archieppiscopi Traiectensis auctore Alcvino*, p. 120, cap. 5; *Diplomata Belgica* nr. 173, 175, 177, 178, 181 182; *Oorkondenboek van het Sticht Utrecht* (*OSU)* I nr. 35, 43, 45, 48, 62, 63; *Briefe des Bonifatius*: nr. 109), which is generally associated with a ford or crossing (Van Winter 1975; De Bruijn, 1994).

Rural settlements started to develop on the levees in the surrounding area from the first quarter of the 6th century onwards. These settlements were all situated on the highest ridges along a river or a re-activated residual channel, and consisted of several farm-houses (Nokkert et al., 2009; Den Hartog, 2010; Van der Kamp, in press) The settlements west of Utrecht decreased in size during the 8th century and were abandoned around the start of the 9th century. Data from the eastern part of the research area and the Vecht area are hardly present.

4.4. Carolingian Period and early Late Medieval Period (AD 800–1200)

4.4.1. River and landscape

The river Oude Rijn entered its final stage of discharge loss, shrinking channel bed and abandonment (Fig. 8d), starting with a last revival of channel migration at the start of the 9th century. This migration was the result of the routing of water through a bed that increasingly had become filled with sediment. Lateral migration mainly occurred within the zone with channel fill from the preceding Late-Roman and Merovingian stages, but in places the shallow river channel also eroded further outwards (Figs. 4 and 5: section L). The resulting river had very sharp bends, with a meander length of ~0.8 km, an amplitude of ~100–300 m and a sinuosity index of ~3. The channel was at least 4 m deep in the bends, but its width is unknown (Table 5: section M.1). In a relatively narrow zone, extending ~100–200 m along the channel (Fig. A5b), high natural levees developed.

The palaeosol that had formed in the top of the Oude Rijn channel belt in the southern part of the Medieval city of Utrecht (#133) became covered with crevasse-splay deposits during this period (Van Rooijen and Wynia, 1998). Within this splay complex at least three small channels were present, which departed from the Kromme Rijn meander that formed the southeastern boundary of the walled city (Fig. 6). The onset of this sedimentation period seems to coincide with the phase of river migration at the start of the 9th century. A Carolingian ditch system (8th–9th century) dug south of the fort in a level above the Roman soil soon filled up and subsequently was buried. The silting up of the crevasse channels coincided with that of the Vecht channels.

By the end of the 10th century the deepest part of the Oude Rijn channel started to collect an exclusively muddy fill, followed by the shallower river parts in the beginning of the 11th century. This indicates that at that time, most water received from the Kromme Rijn was routed *via* the Vecht and that the Oude Rijn channel through the city of Utrecht and beyond had become a standing-water body trapping flood sediment only. When the river was dammed upstream at Wijk bij Duurstede in AD 1122, some 100–200 years later, the Oude Rijn residual channel segments was just about 10 m wide and 1–2 m deep.

Like the Oude Rijn, in Carolingian to post-Carolingian times the channel of the river Vecht also started to show increased meandering activity. In this branch, however, this activity seems to have started 150–200 years later - in the second half of the 10th century or early in the 11th century AD. It is suggested that the increased meandering activity of the Vecht indicates the period when discharge received from upstream was passed through the Vecht channel only. The style of lateral migration and in-channel deposition is similar to that of the Oude Rijn in the previous centuries, showing that the volumes of carried discharge were comparably low.

The migration of the Vecht channel in the northwestern part of Medieval Utrecht is demonstrated by a series of elongated revetments following the rapid river migration in a northern direction (e.g., De Groot, 1997; Van Rooijen, 1999, 2010; Ypma et al., 2014). The oldest revetments date from the beginning of the 11th century. River migration continued into the first half of the 12th century, when the river started to silt up. A sunken river-going carrier, the Utrecht 1, dating to the early 11th century was excavated from the Vecht channel bed sediments in the northern part of the research area (Van de Moortel, 2009; Brouwers et al., 2015). However, a swale and a channel subsequently developed along it and their dating indicate that the Vecht river channel here silted up only in the 14th century (Den Hartog, 2013c). The 14th-century abandonment was the result of the construction of a canal to the east, the Nye Vecht in AD 1338–1339, in order to cut off the meanders of the Vecht (Appendix: Fig. A5; De Bruin et al., 2000). However, the most upstream stretch of the Vecht (connecting to the bifurcation) already began to silt up in the 12th century (880 ± 70 ^{14}C BP; GrA 50894). This demonstrates that the river discharge of the Vecht definitely was reduced by the dam construction at Wijk bij Duurstede in AD 1122. It can be concluded that the river damming at Wijk bij Duurstede merely was the final stage of an already on-going natural process of abandonment, as was already postulated by Vink (1954) and Berendsen (1982).

With the damming and embankment, sediment supply to the study area was strongly reduced. For this reason, it took several centuries for the residual channel east of the Medieval city wall to fill up completely. Consequently, after the damming the residual channel of the Kromme Rijn and Vecht continued to function as natural drains for groundwater seepage water from the nearby ice-pushed ridge (Van Loon et al., 2009).

4.4.2. Settlement pattern

Between AD 857 and ca. AD 925 the bishop and clergy temporary lived in exile (Hoekstra, 1989; De Bruijn, 1994; Van Rooijen, 1999). This is generally attributed to Viking attacks between AD 834 and 876 (De Bruijn, 1994, 1995; Broer and de Bruijn, 1997). However in Utrecht there are no archaeological indications for such attacks, which would have been recorded for example in the occurrence of layers of burned materials. Furthermore no attacks of Utrecht are mentioned in the *Vita Sancti Liudgeri*, written between AD 839–849. Therefore the bishop's exile also has been ascribed to the political situation of that time (Van der Tuuk, 2003). Since in addition archaeological evidence for habitation dating to the late 9th and early 10th century is lacking in the fort's surroundings, this suggests that the area was temporarily uninhabited. An alternative explanation for the bishop's departure from Utrecht in AD 857 is the occurrence of increased river flooding from AD 800 onwards (Van Rooijen, 1999, 2010), which caused unfavourable habitation conditions. These inundations probably also occurred upstream along the Kromme Rijn and thus further attributed to the fall of *Dorestad* (Kosian et al., 2016).

The main development of the city of Utrecht took place from the second quarter of the 10th century onwards after the bishop's

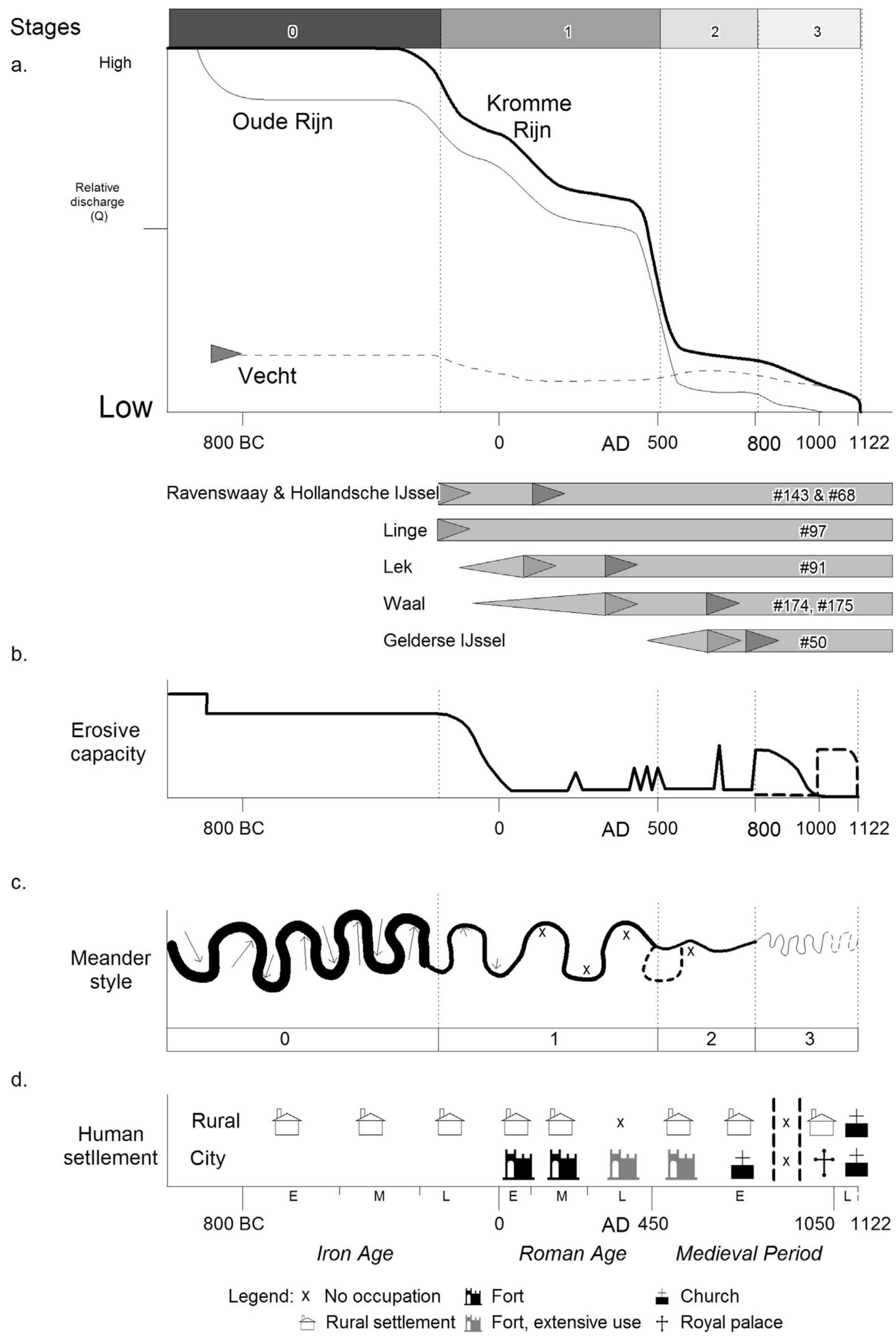

Fig. 10. Abandonment phases of the Utrecht system with a. relative discharge, b. erosive capacity (Peak floodings with recurrence time >100 yr according to Toonen et al., 2013; Cohen et al., 2016), c. development of river pattern and d. human settlement pattern.

return to the city. At the end of the 10th century, a settlement was erected along the river, ~500 m north of the fort (Hoekstra, 1989; De Groot, 1997; Van Rooijen, 1997; 1999; 2010). This settlement expanded during the 11th century into a large trading centre with quays and bank revetments extending over a length of several hundreds of meters along the river. This settlement only emerged after *Dorestad's* decline. According to Van Rooijen (2010) this centre was the *Stathe vicus* (*OSU*, nr. 322), a *portus* (harbour) that might have been burnt down during a Viking raid in AD 1007 (*Alpertus van Metz*) or AD 1010 (*Annales Egmundenses*). Previous studies situated this settlement along the river Vecht which was assumed to diverge from the river Rhine south of the fort (Fig. A8 in Appendix; e.g. Hoekstra, 1989; De Groot, 1991; De Bruijn, 1994; Van der Tuuk, 1996, 2001; Bruynel, 2001; Van Vliet, 2000a; Renes, 2005; Van Rooijen, 2010). This interpretation implied that no direct connection existed between the settlement and the river channel in front of the former fort. However, the present reconstruction shows that the river bend along which it was situated diverted from the Oude Rhine very close to the fort. The quays and revetments of this settlement indicate that the river channel migrated here over a length of ~300 m in a northern direction and finally started to silt up in the 12th century (Van Rooijen, 2010). By then, the settlement had become nearly abandoned.

Archaeological finds also indicate the nearby presence of other rural settlements in the 11th century, among others ~550 m and ~800 m south of the fort (Van Rooijen, 2010). These in part might be linked to the Medieval settlements mentioned in the *commemoratio de rebus Sancti Martini Traiectensis ecclesie* (Hendrikx, 1987; De Bruijn, 2008). Little is known about the Medieval rural settlement development in the eastern part of the research area. The *commemoratio* mentions a villa in Odijk (*Iodichem*) as well as properties in Bunnik (*Bunnichem*) and Vechten (*Feethna*). The bishop established a farmhouse with a chapel, a so-called *curtis*, at the fort in Vechten, but this *curtis* already became abandoned during the 12th century and was left to ruin (Hessing et al., 1997).

West of the city of Utrecht no rural settlements are known dating to the 9th and 10th centuries. This is probably due to the increased flooding frequency of the Oude Rijn starting in ~AD 800 onwards (Toonen et al., 2013), causing unfavourable habitation conditions and concurring with a collapse around AD 850 of the Rhine-based exchange system, which has been traced dendrochronologically through the provenance of river vessels and barrels (Jansma and Van Lanen, 2016; Van Lanen et al., 2016). At least one of the abandoned early-Medieval settlements west of Utrecht was partly eroded by later lateral river migration. Farm houses were rebuilt again on the alluvial ridges in the area only from the 11th century onwards, most likely under management of the various religious Chapters stationed in the city of Utrecht (Fig. 8d; Van der Kamp, 2011). The Roman fort in De Meern was most likely abandoned.

Soon after the damming of the Rhine near Wijk bij Duurstede, in AD 1122, canals were dug to delimit the city and to re-establish the riverine trading and translocation routes to Utrecht (De Bruijn, 1994; Van Vliet, 2000a). Residual channels were included in this canal system (Fig. 8d), resulting in remarkably winding trajectories. Residual channels were also incorporated in the southern and central parts of the *novum fossatum* (the Oudegracht), and in the ~1.5 km long canal along the Hoge Weide (Fig. 8d; Van der Kamp, 2011).

Between AD 1134 and 1165 the estuary of the Oude Rijn silted up (Van der Linden, 1990; Parlevliet, 2001). It is likely that, a sea dike was built in the former estuary to protect the hinterland area from flooding during storm surges. Subsequently, the former estuary became covered with dune sand. This silting up can thus be linked to the loss of river discharge towards the mouth of the Old Rhine, due to its damming upstream.

5. Abandonment phase stages and rise of the city of Utrecht

The combined use of geological and archaeological data, leads to a phased reconstruction of the abandonment of the Utrecht river system (Fig. 10), which it owed to a succession of distinct processes. Abandonment of the Kromme Rijn-Oude Rijn branch, as shown by alternating stepped and gradual changes in reduced channel dimensions and altered meandering style, took over 1000 years to complete and during this whole process, human activities concurred with the progressive abandonment. The changes of the river system strongly influenced the opportunities for human settlement and land use. People living along the river had to respond to the naturally-occurring morphological changes, not only during the Roman period when the channel was used to support and supply defensive military structures, but also during the Medieval phase of abandonment when the channel was used for trading and transport. The interaction between natural processes and human interference during the different phases of the ~1000 year lasting abandonment of the Kromme Rijn and Oude Rijn turns out to be crucial to understand the early development of the city of Utrecht.

The observed changes in channel morphology and activity allow reconstructing relative change in discharge and variability in the channel erosive capacity (Fig. 10). An absolute palaeo-discharge estimate was not reconstructed. Discharge - at all stages of abandonment primarily - fluctuated naturally with peak flows as well as seasonal and yearly variability. In addition, it must have varied due to progressive avulsion and bifurcation adjustments, as is revealed by the geomorphology and sedimentary architecture of the fluvial archive. To define stages of the abandonment process, distinct changes in the fluvial archive and the derived discharge change are pin-pointed (Fig. 10a–c), and lined up with settlement patterns (Fig. 10d).

5.1. Mature channel belt - dispersed rural settlements (stage 0, up to ~200 BC)

During the first millennia BC, the Oude Rijn was the largest distributary of the Rhine Delta. The bankfull discharge was likely about 2000 m^3 (2/3rd of the present Rhine bankfull discharge of 3000–3500 m^3; Middelkoop, 1997; Middelkoop and Van Haselen, 1999; Hesselink et al., 2006, Table 2). The ~300 m wide river channel formed large meander bends and gradually built up a 1.5–2 km wide alluvial ridge. The formation of the Angstel-Vecht channel belt as a minor distributary hardly affected the discharge of the mature Oude Rijn (Bos et al., 2009; Bos, 2010). During this phase, rural settlements were dispersed on the alluvial ridges. These settlements were built on the highest parts of the levees where they were safe from river flooding. These higher parts usually consisted of sandy clay soils, making the surrounding area suitable for cereal agriculture.

5.2. Waning discharge - Roman limes occupation and abandonment (stage 1, ~200 BC–AD 450)

The discharge of the Rhine started to decrease substantially. This occurred firstly due to successive avulsions upstream in the delta that reduced discharge through the Rhine channel feeding the Kromme Rijn (Fig. 3). First, the Linge (ch.b. #97, ~2200–2000 BP) and Ravenswaay-Hollandsche IJssel channel belts (#143, #68, ~2200–2000 BP) came into existence, later followed by the Waal ch.b. #175: ~2000 BP and ch.b. #174: ~1625 BP) and the gradually developing river IJssel (c. b. #50: ~1700 BP). In addition, the river Lek (ch.b. #191: ~1950 BP) started to develop, thereby further withdrawing discharge from the Kromme Rijn.

The decreasing discharge and a probably decreased flooding frequency increased the potential for human occupation of the alluvial ridge. However, during the Late Iron Age the number of rural settlements did not increase. After the establishment of the Roman *limes* along the Rhine from the middle of the 1st century AD onwards, the number of rural settlements increased strongly (Fig. 8a) (Kooistra et al., 2013; Van Dinter et al., 2013). When the *limes* was abandoned in the 3rd century AD, the countryside became depopulated, and occupation was restricted to the forts (Fig. 8b). As the natural boundary conditions for inhabitation had not changed, the settlement decline was determined by changes in the social-economic structure - such as the disappearance of the military organisation from this region - and not related to river development.

5.3. River dynamics due to peak flows - re-expansion and trading network (stage 2, ~AD 450–800)

By AD 450 the channel network in the entire Rhine Delta had

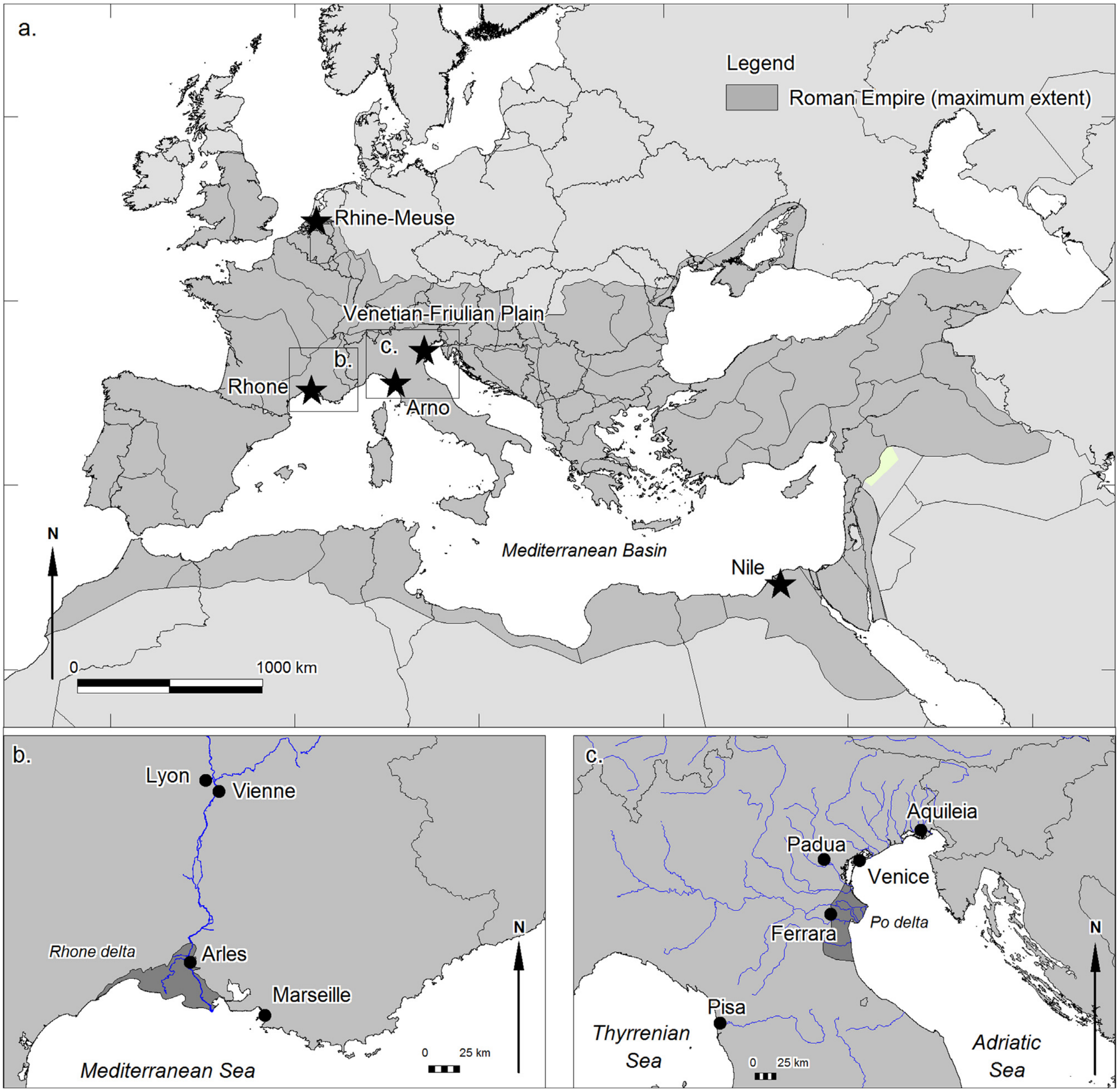

Fig. 11. Selected Mediterranean deltas, rivers and cities with major Roman and Medieval occupation.

definitely altered (Fig. 3c) and the bifurcated Kromme Rijn-Oude Rijn branch had lost most of its discharge (Fig. 10a). Around AD 500 several of the inherited large river bends were cut off by major peak discharges that occurred in the second half of the 5th century (Fig. 8c). These floods probably also affected the bifurcation site by changing the angle of the channel entrance, thereby further hindering the inflow into the Kromme Rijn (cf. Kleinhans et al., 2008). Because of low discharges during the subsequent period the river channel hardly changed position during the next 300 years. The discharge distribution and the oscillations between the discharge of the Oude Rijn and Vecht are difficult to reconstruct from our data, but it seems that the Vecht already captured the larger share of the discharge from this period onwards. Residual channel fills in the system may provide for more detailed discharge reconstruction in the near future (Toonen et al., 2012; Cohen et al., 2016).

Shortly after the river bend cut-offs in the 5th century, the alluvial ridge became inhabited again. Large rural settlements were erected on existing ridges directly along the river channel and reactivated channels. This change again must have had socio-political reasons since already before the short cut-off period the river activity was in a calm state. This settlement increase is also seen further downstream along the Oude Rijn (e.g. Hemminga et al., 2006; Dijkstra, 2011; Jezeer, 2011). It is unclear what relationship these settlements had with the inhabitants of the forts. River trade flourished again in the Merovingian period, now also including North-Sea trade (e.g. Jansma and Van Lanen, 2016; Van Lanen et al., 2016). From the 7th century onwards the fort in Utrecht became the seat of the Frankish settlers and a major ecclesiastical centre. Together with Dorestad it became a principal port of the Carolingian realm. The other forts in the area were not selected because they had lost their water supply route.

5.4. Final silting up - city development and intensified land reclamation (stage 3, ~AD 800–1122)

During this stage, the transport capacity of the Oude Rijn considerably decreased, with sand bars developing in the remaining channel and on top of the former point bars, resulting in shallowing, narrowing and final silting up of the river channel (cf. Toonen et al., 2012). From the start of the 9th century AD onwards the river channel of the Oude Rijn started to form very short and sharp meander bends, i.e. with decreasing meander length and increasing meander width. This river migration might have been caused by peak flows of the Rhine. The associated floodings probably made agricultural activities very difficult and most likely also negatively influenced exchange relations with the hinterland (Van Lanen et al., 2016), leading to abandonment of all rural settlements in the area. This most likely was followed by the self-chosen exile of the Utrecht clergy after AD 857.

By AD ~1000–1150 the flooding frequency decreased, while the Oude Rijn channel became abandoned completely. The residual channel started to fill up with clay and peat. The Vecht was the larger bifurcation channel at this time. The decreasing flooding frequency enabled the bishops to return to the fort in Utrecht, resulting in the re-establishment of Utrecht as an important Medieval political and trade settlement. The settlements next to the fort and subsequently established in the countryside started to expand steadily, profiting from the large church entourage and the land release. Subsequently the silting up stage of the river Vecht started with a likewise migration pattern.

The discharge of the Vecht seems to fade out relatively late, at the end of the 11th century or in the beginning of the 12th century AD (^{14}C-dating in Table 3: C13). Prior to this the Vecht still received fine-grained sediment from the Rhine during passage of peak discharge waves, whereas afterwards autochthonous organic deposition dominated the channel fill (Fig. 5c: Section D). This further supports the hypothesis that natural disconnection of the Kromme Rijn already had developed considerably over the centuries preceding its AD 1122 antropogenic damming at Wijk bij Duurstede. The damming affected the use of the Kromme Rhine as a shipping route to Utrecht, but the digging of canals (with locks) connecting the city of Utrecht and the river Vecht to the Lek/Hollandsche IJssel bifurcation solved this issue in the 12th century. In this manner the city could retain its regional market function. In the same period the floodplains were reclaimed by draining them with ditches and protecting the land from flooding by embankment. The reclaimed flood basins became progressively populated. Parts of these agricultural areas were incorporated in the territory of the city of Utrecht (Dekker, 1983; Hendrikx, 1987; Buitelaar, 1993).

6. Discussion: river avulsion and settlement history

To unravel the complex interplay between river development and settlement dynamics, an interdisciplinary attitude to research opens up multiple sources of data and evidence, and provides a more comprehensive understanding of past fluvial and human settlement development. Ideally, interdisciplinary research focusing on fluvial archives from Classic and Medieval Periods should integrate geological-geomorphological data (coring, LiDAR, sections) and theory, archaeological data (excavations and surveying) and theory, historic topographic mapping and available written information analysis. Regarding the Utrecht case, the first author was actively involved in archaeological excavations and visited many such sites to collect key information on fluvial setting and channel development as summarized in Fig. 4. This allowed complementary reconstruction of settlement characteristics, dimensions (width, depth) of (residual) channels, and the directions of channel migration in time and space within the channel belt.

In this section, we zoom out to the Rhine Delta at large and to some other deltas with major Roman and Medieval occupation around the Mediterranean Basin, respectively the Italian Po Delta in the Venetian-Friulian Plain and the river Arno in Tuscany, the Rhône delta in France, and the Egyptian Nile Delta (Fig. 11). In our comparisons of fluvial geo-archaeological patterns in lowland areas, we focus on the interaction between river development and its effect on settlement development during the Roman and Medieval periods. The central questions of this comparison are whether occupation along these rivers continued during and after channel abandonment, and what this insight can add to interpretation of the settlement history in these areas. We are aware that some of these river systems with enclosed settlements on the levees no longer were completely natural, however we have excluded more recent historical periods during which humans actively restricted flooding and channel migration by the construction of large-scale embankments, thus creating intensively river-managed situations. Moreover, we focus on large, abandoning channels because these usually take a long time to abandon completely and hence form relatively wide alluvial ridges with favourable surfaces for settlement.

6.1. Northwestern Europe

6.1.1. Rhine Delta (The Netherlands)

Within the Rhine Delta two bifurcations of importance occurred upstream of Utrecht that are relevant for the Roman and medieval situation: one at Wijk bij Duurstede (Early Medieval *Dorestad*; Fig. 2) and one further upstream at the delta apex, which just before the start of the Roman period shifted from a position near the city of Nijmegen (Roman *Ulpia Noviomagus Batavorum*) to its position at the Dutch-German border. The latter is the avulsion site of the rivers Waal (at Nijmegen, since around 3000 ^{14}C yr BP) and Nederrijn (at the border, since around 2500 ^{14}C yr BP). In Roman times, some 500–1000 years after its abandonment had started, this channel belt still was characterized by open residual channels (Teunissen, 1986; Toonen et al., 2012). Its alluvial ridge is considered to have been the most densely-populated part of the delta during the Roman Period (Willems, 1986; by most authors regarded as the location of the *Insula Batavorum* (Island of the Batavi) as mentioned in Caesars *Commentarii de Bello Gallico* (c. 50 BC)). Thus, similar to the Utrecht case, slow-paced abandonment and favourable settlement conditions are observed here. However, in the upper delta and in the Rhine and Meuse valleys, the development of Roman and Medieval river settlements mainly occurred on Pleistocene ice-pushed and river-terraced uplands adjacent to the Holocene floodplains. This settling along rivers and on higher Pleistocene grounds can be explained by the combination of the narrowness of the delta in this area, with the river cutting off the ice pushed hills. Further downstream, the delta widened and such settlement locations did not exist. Therefore, the location type chosen for the Roman city of Nijmegen - founded in the upper delta on the slope of a Pleistocene ice pushed hill (Fig. 3b) - contrasts with the location of the downstream delta city of Utrecht.

6.2. Mediterranean region

Parallels can be drawn between the Rhine Delta and deltas along the Mediterranean Basin, because many of the Mediterranean basins in part resemble the Rhine-Meuse Delta in terms of their geomorphological and geo-archaeological setting and with regard to levels of data density and the necessity of data integration. These basins contain abandoned main distributaries, which predominantly were settled in Roman times and afterwards continuously were occupied, culminating in a Late Medieval embanked situation.

6.2.1. *Venetian-Friulian Plain and Arno river coastal plain (Italy)*

As is the case with the Rhine-Meuse Delta, a body of literature exists describing Late Holocene geomorphology and Late Quaternary substrate for the Italian Venetian-Friulian Plain (Fig. 11; Adriatic Sea) occupied by the rivers Po (e.g. Marchetti, 2002; Bondesan et al., 2004; Stefani and Vincenzi, 2005; Amorosi et al., 2009; Stefani and Zuppiroli, 2010; Bianchini et al., 2014; Bruno et al., 2016), Reno-Savena (Bruno et al., 2013, 2016), Adige (e.g. Piovan et al., 2012; Mozzi et al., 2014; Corrò and Mozzi, in press), Brenta (e.g. Mozzi et al., 2010; Ninfo et al., 2011; Bondesan and Furlanetto, 2012), Piave (Carton et al., 2009; Bondesan and Furlanetto, 2012), Tagliamento (e.g. Spaliviero, 2003; Fontana, 2006; Fontana et al., 2008) and the Isonzo catchment on the eastern side of the Friulian Plain (e.g. Arnaud-Fassetta et al., 2003, 2010), and cross-comparisons between these rivers (e.g. Amorosi et al., 2009; Fontana et al., 2014; Rossato et al., 2015). The parallel extends further to the archaeological data densities at the present state of research, and a long research tradition in which Holocene geological and geomorphological research interacted frequently with archaeological surveys and excavations. This also applies to the Arno coastal plain in western Italy (Aguzzi et al., 2007; Sarti et al., 2010, 2012; Rossi et al., 2011; Amorosi et al., 2013; Bini et al., 2015).

The development of the cities of Ferrara, Padova and Aquileia - established along former branches of the rivers Po, Brenta and Isonzo-Torre respectively - have pre-Roman roots (except Ferrara) and subsequent city development during the Middle Ages. These therefore constitute near-ideal examples for comparison to the Utrecht case (Fig. 11c). The Ferrara region was well populated during the Roman period; however, it is the only city in the region not sharing a Roman or a pre-Roman origin (Amorosi et al., 2009; Stefani and Zuppiroli, 2010; Bianchini et al., 2014). The city nucleated in the 7th century on the northern levee of the then active river Po di Volano, at its confluence with the local river Reno and a few kilometres upstream of a major bifurcation of that period. These early phases of town formation were constricted to the shape of the natural levees of the active river. During the 12th century a new distributary channel developed flowing just north of Ferrara (Stefani and Zuppiroli, 2010). As the southern river demised in the centuries that followed, land reclamation works and protective dam construction were initiated, which enabled Ferrara to expand as a city. This development along a waning river branch, followed by land reclamation thus was remarkably similar to the Utrecht case.

The city of Padova began as an Iron-Age settlement and grew to be a larger river city already in the 6th century BC (Fogolari and Chieco Bianchi, 1981; De Min et al., 2005; Mozzi et al., 2010). In the 2nd century BC it had become one of the most important Roman cities in northeastern Italy. It was situated on an alluvial ridge of the river Brenta. The avulsion of the river Brenta towards its modern course some 20 km upstream and the subsequent abandonment of the Padova meandering channel occurred early in the 1st millennium BC. Padova's expansion into a pre-Roman urban nucleus occurred approximately 500 years after this avulsion commenced. During the Iron Age, the spring-fed river Bacchiglione reoccupied this abandoning course of the Brenta river, sustaining water delivery to the city. The river Brenta since that time flowed north of the city (Mozzi et al., 2004; Bondesan and Furlanetto, 2012). As in the Utrecht case, a constant baseflow from a subordinate source (Bacchiglione) continued to supply water through the residual channels and canals long after the river abandoned, sustaining the population in this expanding delta city.

Aquileia is a major site located closer to the Adriatic Sea, along the river Isonzo. It was one of the most important fluvial harbours during Roman times (Fig. 11c). Human settlement of the Aquileia deltaic plain already occurred since the 6th century BC. Aquileia city was built on the outer natural levee of a meander (Arnaud-Fassetta et al., 2003, 2010). Upstream from Aquileia-site, this palaeochannel is divided into two branches. Roman communities are known to have responded to ongoing flooding events and channel silting up, amongst others by canalizing rivers to ensure good navigability conditions. Also, flood protection measures were taken that reduced hazards in these hydromorphous environments. Finally, at the end of the Antique Period, the role of the city in Adriatic trade exchange decreased considerably, most likely due to problems arising from the military situation, and probably also because of difficulties in navigation resulting from the increased infill of the river channel (Arnaud-Fassetta et al., 2003, 2010).

The city of Pisa is located in the coastal plain of Tuscany, Western Italy (Fig. 11c; Thyrrenian Sea). During the Etruscan and Roman Periods periods in this region (resp. 7th-5th century BC and 1st century BC -2nd century AD), Pisa saw a fast urban expansion within a dense and unstable fluvial network (Sarti et al., 2010; Amorosi et al., 2013; Bini et al., 2015). Pisa was located at the confluence of two rivers: the palaeo-Arno and the *Auser*, which was an old branch of the river Serchio. The Romans used this urban centre as a river harbour (*Portus Pisanus*). Its rivers were essential for transport and communication, and continuous river-management using hydraulic works was necessary to protect the town from floods and to prevent expansion of wetlands. Occasional floods affected the shape of the harbour. Since Etruscan times, moderately raised topography hosted the historical city centre of Pisa. Parallels may be drawn with the stages of increased overbank deposition in the Utrecht case - separating Roman from Medieval stratigraphy levels). The confluence with the river *Auser* played a crucial role in the environmental and topographic evolution of the urban area. Major parts of Pisa were characterised by poor drainage conditions until the 1st century AD, when the alluvial plain became artificially drained. Pisa remained an important commercial and political centre during the Middle Ages until it definitively passed under the domination of Florence. As was the case with *Dorestad* until the middle of the 9th century and for Utrecht until the 12th century, easy access to the sea and harbour facilities greatly favoured the economic recovery of Pisa during the Middle Ages.

These reconstructions demonstrate that socio-political and socio-economic circumstances were important factors in the timing of the expansion of settlements into larger urban centres. However, keeping a multi-phased river-abandonment succession model in mind may help to separate these cultural drivers from the evolving suitability of the landscape to host such population centres owing to fluvial geomorphological processes.

6.2.2. *Rhône Delta (France)*

Archaeological research in the Rhône Delta has revealed the establishment of numerous settlements in the deltaic plain from the 6th century BC onwards (e.g. Arnaud-Fassetta et al., 2005, 2010; Arnaud-Fassetta and Landuré, 2003; Bruneton et al., 2001). Predominantly built along the distributaries of the palaeo-Rhône river, these settlements consisted of temporary and/or small rural (clusters of) dwellings located on the main exchange pathways which had developed between the sea and the continent in response to the influence of the ports of Marseilles and Arles (Fig. 11b). During the Roman Period the number of settlements decreased significantly, which was accompanied by a marked intensification of agricultural land use (Arnaud-Fassetta et al., 2010). In general, the occupation duration of settlements in this delta is considered to have depended on the functioning of a Rhône-paleochannel (Arnaud-Fassetta and Landuré, 2003).

Lyons and Vienna are two major urban sites dating to the Roman period, the first one (*Lugdunum*) being established in the Rhône-Saône confluence and the second one (*Colonia Julia Vienna*) situated on the levee of the upper Rhône river (Fig. 11b). The potential vulnerability of these urban centres to flooding was minimized by building the highest points of the floodplain, and by constructing building-boulder armouring for minimising the effects of fluvial erosion.

6.2.3. Nile Delta (Egypt)

The geological and archaeological data density in the Egyptian Nile Delta is restricted to individual archaeological sites, and in addition these data in many cases are hard to obtain (e.g. Macklin et al., 2015). Although several reconstructions of the delta development were assembled (e.g. Coutellier and Stanley, 1987; Stanley and Warne, 1993; Butzer, 2002), and even a general environmental space-time model (Pennington et al., 2016), the exact distribution and development of the various Nile distributaries over time remains challenging. Numerous individual, isolated landscape studies have been carried out recently (e.g. Stanley et al., 2004; Wilson, 2007; Trampier et al., 2013; Graham et al., 2013, 2014; 2015; Schiestl and Herbich, 2013). Yet, these investigations show that the observed changes in human behaviour and settlement patterns in the Nile Delta also need to be considered in terms of the dynamic and evolving landscape, such as avulsions, frequency of overbank floods and navigability of the river branches. As the landscape evolved, the availability and distribution of water changed, as well as the associated natural resources and transport options.

Stanley and Warne (1993) mentioned decelerating sea-level rise around 6500–5500 BC as the primary control of the initiation of farming settlements in the Nile delta, since this led to increased overbank accumulation and channel meandering. Classic historians Herodotus (2.179; 484–425/420 BCE), Strabo (17.1.4; ~64 BCE– AD 19) and Ptolemy (100–2; AD 87–150) mentioned the presence of up to seven major distributaries of the Nile active at the same time during the Ptolemaic and Roman Periods (resp. 332-30 BC and 30 BC–AD 395; Cooper, 2014, p. 30). During these periods the western Canopic and the eastern Pelusiac Nile-delta branches were main arteries for communication, trade and transport between the Egyptian Nile Valley and the Mediterranean. However the exact timing of channel activity and distribution of settlements during these periods is only roughly known. At many locations a linear distribution of ancient settlements suggests the course of ancient branches of the Nile, but detailed data on channel-belt geometry and period of activity are lacking (e.g. Trampier et al., 2013; Schiestl et al., 2016).

6.2.4. Water availability

In the Utrecht-Rhine case, we have mainly considered the role of the river in providing a transport and trade route, and a military border. Because in the Rhine Delta access to fresh water throughout the year is not problematic, availability of water has not been considered explicitly. During the times intervals in-between river floods, there is a difference in the source and purity of water between an active river receiving base flow from the hinterland and an open palaeo-channel with base flow from regional groundwater systems. In the temperate setting of the Rhine Delta and for Utrechts population densities during the 1st millennium AD, this difference hardly mattered (Renes, 2005). However, this difference may well have been relevant in the Mediterranean climate (especially for urban centres), and its influence probably was even larger in the semi-arid and monsoonal climate of Egypt.

7. Conclusion

Combined study of fluvial archives and geoarchaeology substantially improves the reconstruction of the timing and phasing of river development, and the understanding of past human settling along rivers, especially when dealing with avulsive river systems of delta plain lowlands. This is particularly the case for younger archaeological periods (classic civilisations, Medieval times, Renaissance), because of the higher find density, the accuracy of the geochronological age estimations, and limited post-depositional reworking. Late Holocene lower river reaches provide spatially extensive fluvial archives that allow studying river processes by making use of archaeological dating control. In turn, detailed reconstructions of fluvial dynamics in terms of channel belt activity and abandonment provide a better understanding of the phasing of former human occupation. The Utrecht case study of the abandonment of the river Rhine during the Roman Period and Middle Ages exemplifies how high-resolution morphological, chronological and archaeological information obtained in recent years enables to study channel morphodynamics and human settlement along a major former delta distributary branch. The work reveals the occurrence of distinct phases of geomorphological development and human settlement, and how the former influenced the latter, over a 1000-yr period of river abandonment.

The avulsion of the Oude Rijn and Kromme Rijn occurred in three steps: 1) a ~650-yr period of slowly decreasing river discharge and limited lateral channel movement, which facilitated human settlement on the alluvial ridge; 2) a 350-yr period in which the river carried very little water, due to additional avulsions further upstream in the delta; 3) the final silting up: a 300-yr period during which the transport capacity of the river strongly decreased, causing shallowing and narrowing of the river channel, the formation of very sharp meanders and a temporarily increase of flooding frequency. Finally, after AD 1000, the residual channel of the Oude Rijn started to collect muddy and peaty fill. Thereafter, the river became so small that it could be restrained and dammed at the avulsion node near Wijk bij Duurstede in AD 1122.

During the successive abandonment stages, people lived on the highest parts of the alluvial ridges in the study area, but they did not influence the avulsion process. The settlement history largely followed the river activity, although it was further directed by socio-economic and political factors. Only during the third phase (~AD 800–1122), the alluvial ridges were temporarily abandoned as intensified floodings most likely had a severe negative impact on agricultural activities as well an on river-based long-distance connections.

This long duration of the process of abandonment of former main branches appears to have been a common phenomenon in many deltas. During recent centuries, societies have controlled avulsions, but earlier on the abandonment aspect of avulsion appears particularly important in explaining which locations settlements became abandoned and on which locations their presence was continuous. Furthermore, as many deltas in the Late Holocene became civilisation centres and during this period only have been subjected to only one or a few avulsions, parallels can be drawn between the archaeological developments of larger sites located on top of channel belts of former rivers in different deltas.

Acknowledgments

We thank the editors of the 20-yr FLAG special issue for their advice regarding the submission of this manuscript. This research is part of Utrecht University's Domplein 2013 project *Treasures of the Dom square*. We thank the Archaeological department of the municipality of Utrecht for good cooperation and providing data access. We also thank colleagues in the department of Physical Geography for their input in discussions during the production of the manuscript. Furthermore, we would like to acknowledge the anonymous reviewers for their valuable comments and suggestions to improve the manuscript.

The digital repository holding the Appendix, also holds digital map data (GIS files) and is available through http://dx.doi.org/10.17026/dans-zrz-qm5n.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quascirev.2016.12.003.

References

Aarts, A.C. (Ed.), 2012. Scherven, schepen en schoeiingen; archeologisch onderzoek in een fossiele rivierbedding bij het castellum van De Meern. Basisrapportage Archeologie 43. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht. 349.

Aguzzi, M., Alessandro, A., Colalongo, M.L., Lucchi, M.R., Rossi, V., Sarti, G., Vaiani, S.C., 2007. Late Quaternary climatic evolution of the Arno coastal plain (Western Tuscany, Italy) from subsurface data. Sediment. Geol. 202, 211–229.

Amorosi, A., Stefani, M., Fontana, A., 2009. Late quaternary depositional evolution of the Po delta and Venice Lagoon areas. In: Pascucci, V., Andreucci, S. (Eds.), Field Trip Guide Book, Pre-conference Trip FT8, 27th IAS Meeting of Sedimentology, Alghero (Italy), September 20-23, 2009, pp. 159–184.

Amorosi, A., Bini, M., Giacomelli, S., Pappalardo, M., Ribecai, C., Rossi, V., Sammartino, I., Sarti, G., 2013. Middle to late Holocene environmental evolution of the Pisa coastal plain (Tuscany, Italy) and early human settlements. Quat. Int. 303, 93–106.

Arnaud-Fassetta, G., Landuré, C., 2003. Hydroclimatic hazards, vulnerability of societies and fluvial risk in the Rhône delta (Mediterranean France) from the Greek period to the early middle ages. In: Fouache, E. (Ed.), The Mediterranean World Environment and History. Proceedings of the International Conference “environmental Dynamics and History in Mediterranean Areas” Held in Paris, 24-26 April 2002. Elsevier, Paris, pp. 51–76.

Arnaud-Fassetta, G., Carre, M.B., Marocco, R., Maselli Scotti, F., Pugliese, N., Zaccaria, C., Bandelli, A., Bresson, V., Manzoni, G., Montenegro, M.E., Morhange, C., Pipan, M., Prizzon, A., Siché, I., 2003. The site of Aquileia (Northeastern Italy): example of fluvial geoarchaeology in a Mediterranean deltaic plain. Géomorphologie 4, 227–246.

Arnaud-Fassetta, G., Bruneton, H., Berger, J.F., Beaudouin, C., Boès, X., Provansal, M., 2005. A 8000-yr record of palaeohydrology and environmental change in fluviatile-influenced sediments from the urban Arles-Piton core, upper Rhône Delta, France. Geomorphology 49, 455–484.

Arnaud-Fassetta, G., Carcaud, N., Castanet, C., Salvador, P.G., 2010. Fluviatile palaeoenvironments in archaeological context: geographical position, methodological approach and global change - hydrological risk. Quat. Int. 216, 93–117.

Bechert, T., Willems, W.J.H. (Eds.), 1995. Die römische Reichsgrenze zwischen Mosel und Nordseeküste, p. 119. Theiss, Stuttgart, Germany.

Berendsen, H.J.A., 1982. De genese van het landschap in het zuiden van de provincie Utrecht - een fysisch-geografische studie. In: Utrechtse Geografische Studies 25. Geografisch Instituut Rijksuniversiteit Utrecht, Utrecht, p. 256.

Berendsen, H.J.A., 1990. Roman River Courses in the Central Netherlands. Berichten Rijksdienst Voor Het Oudheidkundig Bodemonderzoek, vol. 40, pp. 243–249. Amersfoort.

Berendsen, H.J.A., Stouthamer, E., 2001. Palaeogeographic Development of the Rhine-meuse Delta. Koninklijke Van Gorcum, The Netherlands. Assen. 268p. and Appendums 1–4.

Berendsen, H.J.A., Volleberg, K.P., 2007. New prospects in geomorphological and geological mappings of the Rhine-Meuse delta; applications of detailed digital elevation maps based on laser altimetry. Netherl. J. Geosci. 86–1, 15–22.

Berendsen, H.J.A., Wynia, S., 1993. Oude rivierlopen rond het Fort te Vechten. Rijn Lek 27–3, 17–23.

Berendsen, H.J.A., Cohen, K.M., Stouthamer, E., 2007. The use of GIS in reconstructing the Holocene palaeogeography of the Rhine-Meuse delta, The Netherlands. Int. J. Geogr. Inf. Sci. 21–5, 589–602.

Bettis, E.A., Benn, D.W., Hajic, E.R., 2008. Landscape evolution, alluvial architecture, environmental history, and the archaeological record of the Upper Mississippi River Valley. Geomorphology 101, 362–377.

Bianchini, G., Cremonini, S., Di Giuseppe, D., Vianello, G., Vittori Antisari, L., 2014. Multiproxy investigation of a Holocene sedimentary sequence near Ferrara (Italy): clues on the physiographic evolution of the eastern Padanian Plain. J. Soils Sediments 14, 230–242. http://dx.doi.org/10.1007/s11368-013-0791-2.

Bini, M., Rossi, V., Amorosi, A., Pappalardo, M., Sarti, G., Noti, V., Capitani, M., Fabiani, F., Gualandi, M.L., 2015. Palaeoenvironments and palaeotopography of a multilayered city during the Etruscan and Roman periods: early interaction of fluvial processes and urban growth at Pisa (Tuscany, Italy). J. Archaeol. Sci. 59, 197–210.

Blom, E., Vos, W.K. (Eds.), 2008. Woerden-Hoochwoert. De opgravingen 2002–2004 in het Romeinse Castellum Laurium, de vicus en van het schip de ‘Woerden 7’. ADC Monografie 2. ADC Archeoprojecten, Amersfoort. 462 p.

Bondesan, A., Meneghel, M., Rosselli, R., Vitturi, A. (Eds.), 2004. Geomorphological Map of the Province of Venice, Scale 1:50,000. LAC, Firenze (4 sheets).

Bondesan, A., Furlanetto, P., 2012. Artificial fluvial diversions in the mainland of the lagoon of Venice during the 16th and 17th centuries inferred by historical cartography analysis. Géomorphologie 2, 175–200.

Bonsall, C., Macklin, M., Payton, R., Boroneanţ, A., 2002. Climate, floods and river gods: environmental change and the Meso-Neolithic transition in southeast Europe. Before Farming 3–4, 1–15.

Borger, G.J., Ligtendag, W.A., 1998. The role of water in the development of the Netherland; a historical perspective. J. Coast. Conserv. 4–2, 109–114.

Bos, I.J., 2010. Architecture and facies distribution of organic-clastic lake fills in the fluvio-deltaic Rhine-Meuse system, The Netherlands. J. Sediment. Res. 1, 339–356.

Bos, I.J., Feiken, H., Bunnik, F.P.M., Schokker, J., 2009. Influence of organics and clastic lake fills on distributary channels in the distal Rhine-Meuse delta (The Netherlands). Palaeogeogr. Palaeoclimatol. Palaeoecol. 284, 355–374.

Bridgland, D.R., White, M.J., 2015. Chronological variations in handaxes: patterns detected from fluvial archives in north-west Europe. J. Quat. Sci. 30, 623–638.

Broer, C.J.C., de Bruijn, M.W.J., 1995. De eerste kerken in Utrecht: Sint-Thomas, Sint.-Salvator, Sint-maarten. Nederlands Centrum voor Volkscultuur, Utrecht, p. 76.

Broer, C.J.C., de Bruijn, M.W.J., 1997. Antonia, Wiltenburg, traiectum; de kennis van het romeinse verleden van Utrecht door de eeuwen hen. In: Van der Eerden, R., Van ’t Hart, P.D., Hoekstra, T.J., Jordans, A.L., Leeuwenberg, H.L.Ph., Pietersma, A. (Eds.), 150 jaar Romeinen in Utrecht. Jaarboek Oud-utrecht 1997, Vereniging Oud-utrecht, Utrecht, pp. 97–124.

Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. Radiocarbon 51, 337–360.

Brouwers, W., Jansma, E., Manders, M., 2013. Romeinse scheepsresten in Nederland. ARCHEObrief 17–4, 13–27.

Brouwers, W., Jansma, E., Manders, M., 2015. Middeleeuwse scheepsresten in Nederland: de Vroege Middeleeuwen (500-1050). ArcheoBrief 19–3, 6–24.

Brown, A.G., 1997. Alluvial Geoarchaeology: Floodplain Archaeology and Environmental Change. Cambridge University Press, Cambridge, p. 377.

Bruneton, H., Arnaud-Fassetta, G., Provansal, M., Sistach, D., 2001. Geomorphological evidence for fluvial change during the Roman period in the lower Rhone valley (southern France). Catena 45, 287–312.

Bruno, L., Amorosi, A., Curina, R., Severi, P., Bitelli, R., 2013. Human–landscape interactions in the Bologna area (northern Italy) during the mid–late Holocene, with focus on the Roman period. The Holocene 23-11, 1560–1571. http://dx.doi.org/10.1177/0959683613499054.

Bruno, L., Amorosi, A., Severi, P., Costagli, B., 2016. Late Quaternary aggradation rates and stratigraphic architecture of the southern Po Plain, Italy. Basin Res. http://dx.doi.org/10.1111/bre.12174.

Bruynel, G.J.A., 2001. De derde meander; de geografische situering van de rivierlopen in en rond de stad Utrecht. Jaarboek Oud-Utrecht 2001. Vereniging Oud-Utrecht, Utrecht, pp. 6–24.

Buitelaar, A.L.P., 1993. De Stichtse ministerialiteit en de ontginningen in de Utrechtse Vechtstreek. Verloren, Hilversum, p. 439.

Busschers, F.S., Kasse, C., van Balen, R.T., Vandenberghe, J., Cohen, K.M., Weerts, H.J.T., Wallinga, J., Johns, C., Cleveringa, P., Bunnik, F.P.M., 2007. Late Pleistocene evolution of the Rhine-Meuse system in the southern North Sea basin: imprints of climate change, sea-level oscillation and glacio-isostacy. Quat. Sci. Rev. 26 (25–28), 3216–3248.

Butzer, K.W., 1970. Physical Conditions in Eastern Europe, Western Asia and Egypt before the Period of Agricultural and Urban Settlement (No. 33). Cambridge Ancient History, third ed., vol. 1. Cambridge University Press, Cambridge, pp. 62–69.

Butzer, K.W., 2002. Geoarchaeological implications of recent research in the Nile delta. In: Van Den Brink, E.C.M., Levy, T.E. (Eds.), Egypt and the Levant, Interrelations from the 4th through the Early 3rd Millennium BC Leicester. University Press, London/New York, p. 8.

Carton, A., Bondesan, A., Fontana, A., Meneghel, M., Miola, A., Mozzi, P., Primon, S., Surian, N., 2009. Geomorphological evolution and sediment transfer in the Piave river system (northeastern Italy) since the last glacial maximum. Géomorphol. relief, Process. Environ. 3 (2009), 55–174.

Cohen, K.M., 2005. 3D geostatistical interpolation and geological interpretation of paleo-groundwater rise in the Holocene Coastal Prism in The Netherlands. In: Giosan, L., Bhattacharya, J.P. (Eds.), River Deltas: Concepts, Models and Examples. SEPM Special Publication 83. Society for Sedimentary Geology (SEPM), pp. 341–364.

Cohen, K.M., Stouthamer, E., Hoek, W.Z., Berendsen, H.J.A., Kempen, H.F.J., 2009. Zand in banen; Zanddieptekaarten van het rivierengebied en het IJsseldal in de provincies Gelderland en Overijssel. Provincie Gelderland, Arnhem, p. 130.

Cohen, K.M., MacDonald, K., Joordens, J.C.A., Roebroeks, W., Gibbard, P.L., 2012a. The earliest occupation of north-west Europe: a coastal perspective. Quat. Int. 271, 70–83.

Cohen, K.M., Stouthamer, E., Pierik, H.J., Geurts, A.H., 2012b. Rhine-Meuse Delta Studies' Digital Basemap For Delta Evolution And Palaeogeography/Digitaal Basisbestand Paleogeografie van de Rijn-Maas Delta. Utrecht University, Utrecht. http://dx.doi.org/10.17026/dans-x7g-sjtw.

Cohen, K.M., Toonen, W.H.J., Weerts, H.J.T., 2016. Overstromingen van de Rijn gedurende het Holoceen; relevantie van de grootste overstromingen voor de archeologie van het Nederlandse rivierengebied. Deltares report 1209091–000.

Deltares, Utrecht, p. 36.
Cooper, J.P., 2014. The Medieval Nile: Route, Navigation, and Landscape in Islamic Egypt. The American University in Cairo Press, Cairo, p. 432.
Constantine, J.A., Dunne, T., Piégay, H., Kondolf, G.M., 2010. Controls on the alluviation of oxbow lakes by bed-material load along the Sacramento River, California. Sedimentology 57, 389–407.
Corrò, E., Mozzi, P., 2016. Water matters; geoarchaeology of the city of Adria and palaeohydrographic variations (Po Delta, Northern Italy). J. Archaeol. Sci. Rep. http://dx.doi.org/10.1016/j.jasrep.2016.08.001.
Coutellier, V., Stanley, D.J., 1987. Late quaternary stratigraphy and paleogeography of the eastern Nile delta. Egypt. Mar. Geol. 77, 257–275.
De Boer, A.G., Laan, W.N.H., Waldus, W., Van Zijverden, W.K., 2008. LiDAR-based surface height measurements: applications in archaeology. In: Fischer, B., Dakouri, A. (Eds.), Beyond Illustration: 2d and 3d Digital Technologies as Tools for Discovery in Archaeology. British Archaeological Reports International Series 1805, pp. 69–77.
De Bruijn, M.W.J., 1994. Husinghe ende hofstede; een institutioneel-geografische studie van de rechtspraak over onroerend goed in de stad Utrecht in de middeleeuwen. Ph.D. thesis Amsterdam. University, The Netherlands/Spectrum, Utrecht, p. 464.
De Bruijn, M.W.J., 1995. De burcht Trecht. In: Olde Meierink, B., Van Baaren, G., Bosch van Drakestein, R.G. (Eds.), Kastelen en ridderhofsteden in Utrecht. Stichting Matrijs, Utrecht, pp. 429–432.
De Bruijn, M.W.J., 2008. Buurschap en gerecht. De ontwikkeling van twee samenhangende instellingen in middeleeuws Utrecht. Jaarboek Oud-Utrecht 2008. Vereniging Oud-Utrecht, Utrecht, pp. 128–154.
De Bruin, R.E., 't Hart, P.D., Van den Hoven van Genderen, A.J., Struick, J.E.A.L., Pietersma, A. (Eds.), 2000. Een paradijs vol weelde; Geschiedenis van de stad Utrecht. Stichting Matrijs, Utrecht, p. 592.
De Groot, H.L., 1991. Een levensteken uit de vijfde eeuw; het grafveld aan het Pieterskerkhof. Archeologisch Bouwhistorisch Centrum, Utrecht, p. 16.
De Groot, H.L., 1997. De haven die verdween. In: Bakker, G., Hoekstra, T.J. (Eds.), Het Stenen Geheugen. Centraal Museum Utrecht, Utrecht, pp. 12–39.
De Groot, H.L., 2000. Van strijdhamer tot bisschopsstaf (de vroegste geschiedenis tot circa 925). In: De Bruin, R.E., 't Hart, P.D., Van Hoven, A.J., Pietersma, A., Struick, J.E.A.L. (Eds.), Paradijs van Weelde; geschiedenis van de stad Utrecht. Stichting Matrijs, Utrecht, pp. 11–44.
De Groot, T., Morel, J.-M.A.W. (Eds.), 2007. Het schip uit de Romeinse tijd De Meern 4 nabij boerderij de Balije, Leidsche Rijn, gemeente Utrecht. Rapporten Archeologische Monumentenzorg 147, p. 173.
De Haan, M.J.A., 2004. Fort Vechten, gemeente Bunnik; onderzoek in het kader van de Actualisering van het Monumenten Register (AMR-project) uitgevoerd door RAAP i.s.m. de ROB (RCE). Internal report Monumentdossier. Rijksdienst voor het Cultureel Erfgoed, Amersfoort, p. 16.
De Jager, D.H., 2000. De Hoge Woerd, gemeente Vleuten-De Meern: aanvullend boor- en weerstandsonderzoek bij het Romeinse castellum van De Meern. RAAP-Rapport 531. RAAP Archeologisch Adviesbureau, Amsterdam, p. 34.
De Kam, R., Kipp, A.F.E., Claessen, D., 2014. De Utrechtse Domtoren; trots van de stad. Stichting Matrijs, Utrecht, p. 544.
De Min, M., Gamba, M., Gambacurta, G., Ruta Serafini, A. (Eds.), 2005. La città invisibile. Padova preromana. Trent'anni di scavi e ricerche. Edizioni Tipoarte, Bologna, p. 181.
Dekker, C., 1980. De dam bij Wijk. Nederl. Arch. 84, 248–266.
Dekker, C., 1983. Het Kromme Rijngebied in de middeleeuwen; een institutioneel-geografische studie. Stichting Historische Reeks 9, Walburg Pers, Zutphen, p. 762.
Dekker, C., 1990. Afwatering en scheepvaart ten westen van de stad Utrec tot in de 14e euw. In: Van de Kieft, C., Van der Gouw, J.L. (Eds.), Scrinium et scriptura. Opstellen betreffende de Nederlandse geschiedenis aangeboden aan Prof. Dr. J.L. van der Gouw, bij zijn afscheid als buitengewoon hoogleraar in de archiefwetenschap en in de paleografie van de veertiende tot de zeventiende eeuw aan de Universiteit van Amsterdam. Erven van de Kamp, Groningen, pp. 60–75.
Den Hartog, C.M.W., 2009a. Sportpark Terweide 2; LR41–42 Archeologisch onderzoek Sportpark Terweide. Basisrapportage Archeologie 18. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, p. 152.
Den Hartog, C.M.W. (Ed.), 2009b. Wonen aan het Zwarte Water; Inventariserend Veldonderzoek Merelstraat aan het Zwarte Water, gemeente Utrecht. Basisrapportage Archeologie 54. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, 40.
Den Hartog, C.M.W. (Ed.), 2010. Appellaantje; Een vroegmiddeleeuwse nederzetting aan de Wilhelminalaan bij Vleuten. Basisrapportage Archeologie 30. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, 222.
Den Hartog, C.M.W. (Ed.), 2013a. Zes IVO's in de bestaande stad; Inventariserend veldonderzoek aan de Johan Wagenaarkade, Weg naar Rhijnauwen, Rotsoord, Eykmanlaan, Groeneweg en de Kanonstraat in Utrecht. Basisrapportage archeologie 56. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, 54.
Den Hartog, C.M.W. (Ed.), 2013b. Het Huis Loenersloot; Archeologische begeleiding aan de Nieuwegracht 20 in Utrecht. Basisrapportage archeologie 61. Gemeente Utrecht DienstStadsontwikkeling, Utrecht. 38 p.
Den Hartog, C.M.W. (Ed.), 2013c. Nieuw licht op de Marnixlaan: een archeologisch onderzoek naar het kartuizerklooster Nieuw Licht. Basisrapportage Archeologie 66. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, 102.
Dielemans, L. (Ed.), 2010. LR64: Archeologisch onderzoek naar een laatmiddeleeuws erf aan de Strijlandweg, gemeente Utrecht. Basisrapportage Archeologie 45. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, p. 102.
Dijkstra, J. (Ed.), 2012. Het domein van de boer en de ambachtsman; het domein van de boer en de ambachtsman. ADC monografie 12, ADC Archeoprojecten, Amersfoort, p. 690.
Dijkstra, J., van Benthem, A., 2004. Definitief Archeologisch onderzoek op terrein 9 in Houten. ADC rapport 264, ADC Archeoprojecten, Amersfoort, p. 155.
Dijkstra, M.F.P. (Ed.), 2004. Gulle gaven, greppels en waterputten. De opgraving Wijk bij Duurstede – David van Bourgondiëweg. AAC-publicaties 26. Amsterdam Archeologisch Centrum, Amsterdam, p. 74.
Dijkstra, M.F.P. (Ed.), 2011. Rondom de mondingen van Rijn en Maas; landschap en bewoning tussen de 3e en de 9e eeuw in Zuid-Holland, in het bijzonder in de Rijnstreek. Ph.D. thesis Amsterdam University, The Netherlands, p. 539.
Dominicus, D., Van den Berg, J.R., 1971. Een fluviatiele afzetting van de Rijn in de stad Utrecht; verslag veldwerk sedimentologie. Master thesis. Utrecht Universiteit, The Netherlands, p. 39.
Duurland, M. (Ed.), Een Romeins grafveld in Utrecht; een archeologisch onderzoek bij het Duitse Huis/Hotel Karel V. Basisrapportage Archeologie 37, in press., Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht.
Edelman, C.H., 1950. Soils of the Netherlands. Soil Science 70/North-Holland Publishing Company, Amsterdam, p. 177.
Ferring, C.R., 1986. Rates of fluvial sedimentation: implications for archaeological variability. Geoarchaeology 1, 259–274.
Ferring, C.R., 1992. Alluvial pedology and geoarchaeological research. Soils Archaeol. 1–39.
Fogolari, G., Chieco Bianchi, A.M. (Eds.), 1981. Padova Preromana. Antoniana SpA Industria, Grafica, Padova, p. 307.
Fontana, A., 2006. Evoluzione geomorfologica della bassa pianura friulana, e sue relazioni con le dinamiche insediative antiche. Pubblicazione 47, Edizioni del Museo Friulano di Storia Naturale. Udine, p. 287.
Fontana, A., Mozzi, P., Bondesan, A., 2008. Alluvial megafans in the Venetian-Friulian Plain (north-east Italy): evidence of sedimentary and erosive phases during Late Pleistocene and Holocene. Quat. Int. 189, 71–90.
Fontana, A., Mozzi, P., Marchetti, M., 2014. Alluvial fans and megafans along the southern side of the Alps. Sediment. Geol. 301, 150–171.
Gates, C., 2011. Ancient Cities: the Archaeology of Urban Life in the Ancient Near East and Egypt, Greece and Rome. Taylor and Francis Group, Inc., p. 474
Giosan, L., Clift, P.D., Macklin, M.G., Fuller, D.Q., Constantinescu, S., Durcan, J.A., Stevens, T., Duller, G.A., Tabrez, A.R., Gangal, K., Adhikari, R., 2012. Fluvial landscapes of the Harappan civilization. Proc. Natl. Acad. Sci. 109, 1688–1694.
Gouw, M.J.P., Erkens, G., 2007. Architecture of the Holocene Rhine-Meuse delta (The Netherlands): a result of external control. Neth. J. Geosci. 86, 23–54.
Graafstal, E.P., 2002. Logistiek, communicatie en watermanagement; over de uitrusting van de romeinse rijksgrens in Nederland. Westerheem 51, 2–27.
Graham, A., Strutt, K.D., Emery, V.L., Jones, S., Barker, D.S., 2013. Theban harbours and waterscapes survey, 2013. J. Egypt. Archaeol. 99, 35–52.
Graham, A., Strutt, K.D., Hunter, D.A., Pennington, B.T., Toonen, W.H.J., Barker, D.S., 2014. Theban harbours and waterscapes survey, 2014. J. Egypt. Archaeol. 100, 41–53.
Graham, A., Strutt, K.D., Hunter, Toonen, W.H.J., Pennington, B.T., Lowenborg, D., Massonberghoff, A., Emery, V.L., Barker, D.S., Hunter, M.A., Lindholm, K.-J., Johansson, C., 2015. Theban harbours and waterscapes survey, 2014. J. Egypt. Archaeol. 100, 37–49.
Groenewoudt, B., de Groot, T., Theunissen, L., Eerden, M., 2016. Programma Kenniskaart Archeologie; Verantwoording NOaA 2.0.Rijksdienst voor het Cultureel Erfgoed, Amersfoort. http://archeologieinnederland.nl/bronnen-en-kaarten/nationale-onderzoeksagenda-archeologie-20.
Groot, M., 2008. Animals in Ritual and economy in a Roman Frontier Community. Excavations in Tiel-passewaaij. Ph.D. thesis. Amsterdam Free University, The Netherlands, p. 284.
Groot, M., Kooistra, L.I., 2009. Land use and agrarian economy in the Roman Dutch river area. Internet Archaeol. 27. http://intarch.ac.uk/journal/issue27/5/1.html.
Groot, M., Heeren, S., Kooistra, L.I., Vos, W.K., 2009. Surplus production for the market? The agrarian economy in the non-villa landscapes of Lower Germany. J. Roman Archaeol. 20, 231–252.
Groothedde, G., 2010. De 'nieuwe' IJssel; wat vertellen de geschreven bronnen en archeologische vondsten? Bijdragen en mededelingen historisch jaarboek voor Gelderland, deel ci. Vereniging Gelre, Arnhem, pp. 7–26.
Groothedde, G., 2013. Een vorstelijke palts te Zutphen? Macht en prestige op en rond het plein 's Gravenhof van de Karolingische tijd tot aan de stadsverlening. Ph.D. thesis, Leiden University, The Netherlands/Zutphense archeologische publicaties 77. Bureau Archeologie Gemeente Zutphen, Zutphen, p. 473.
Gunn, J.D., Folan, W.J., 2000. Three rivers: subregional variations in earth system impacts in the southwestern Maya lowlands (Candelaria, Usumacinta, and Champoton Watersheds). In: McIntosh, R.J., Tainter, J.A., McIntosh, S.K. (Eds.), The Way the Wind Blows: Climate, History, and Human Action. Columbia Univ. Press, pp. 263–270.
Haalebos, J.K., 1977. Zwammerdam Nigrum Pullum; ein Auxiliarkastell am Niedergermanische Limes. Cingula 3/Amsterdam University, Amsterdam, p. 319.
Haalebos, J.K., 1997. Van Nijmegen naar Utrecht; de Limes in Nederland. Jaarboek Oud Utrecht. Vereniging Oud-Utrecht, pp. 35–66.
Haarhuis, H.F.A., 1999a. Bestemmingsplan Veldhuizen, gemeente Vleuten-De Meern; kartering Romeinse weg bij de C.H. Letschertweg en waardering vindplaats 'De Balije'. RAAP-rapport 510. RAAP Archeologisch Adviesbureau, Amsterdam, p. 18.
Haarhuis, H.F.A., 1999b. Bestemmingsplan Veldhuizen, gemeente Vleuten-De Meern; kartering Romeinse weg, fase 2. RAAP-rapport 334. RAAP Archeologisch

Adviesbureau, Amsterdam, p. 31.
Haarhuis, H.F.A., 1999c. Bestemmingsplan Veldhuizen, gemeente Vleuten-De Meern: kartering Romeinse weg, fase 3. RAAP-rapport 372. RAAP Archeologisch Adviesbureau, Amsterdam, p. 23.
Haarhuis, H.F.A., Graafstal, E.P., 1993. Vleuten-Harmelen, een archeologische kartering, inventarisatie en waardering. RAAP-rapport 80. RAAP Archeologisch Adviesbureau, Amsterdam, p. 124.
Jones, H.L., Hajek, E.A., 2007. Characterizing avulsion stratigraphy in ancient alluvial deposits. Sediment. Geol. 202, 124–137.
Hemminga, M., Hamburg, T., Dijkstra, M., Cavallo, C., Knippenberg, S., van Lith, S.M.E., Bakels, C.C., Vermeeren, C., 2006. Vroeg Middeleeuwse nederzettingssporen te Oegstgeest; een inventariserend veldonderzoek en opgraving langs de Oude Rijn. Archol-rapport 102. Archol, Leiden, p. 122.
Hendrikx, P.A., 1987. De benedendelta van Rijn en Maas: landschap en bewoning van de Romeinse tijd tot ca. 1000. Hollandse studiën 19. Verloren, Hilversum, 174 p. and 9 maps.
Hesselink, A.W., Weerts, H.J.T., Berendsen, H.J.A., 2003. Alluvial architecture of the human-influenced river Rhine, The Netherlands. Sediment. Geol. 161, 229–248.
Hesselink, A.W., Kleinhans, M.G., Boreel, G.L., 2006. Historic discharge measurements in three Rhine branches. J. Hydraul. Eng. 132–2, 140–145. http://dx.doi.org/10.1061/(ASCE)0733-9429 (2006132:2(140).
Hessing, W.A.M., Steenbeek, R., 1990. Landscape and habitation history of 'De Horden' at Wijk bij Duurstede, an overview. Berichten van de Rijksdienst voor het Oudheidkundig Bodemonderzoek 40. Amersfoort, pp. 9–28.
Hijma, M.P., Cohen, K.M., 2011. Holocene transgression of the Rhine river mouth area, The Netherlands/Southern North Sea: palaeogeography and sequence stratigraphy. Sedimentology 58, 1453–1485.
Hill, C.L., 2014. Rivers: environmental archaeology. In: Encyclopedia of Global Archaeology. Springer, New York, pp. 6343–6351.
Hoegen, R.D., 2013. Plangebied Hamlaan; Middeleeuwse bewoning naast de Hamtoren te Vleuten. Basisrapportage Archeologie 46. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, p. 134.
Hoekstra, T.J., 1989. De vroege topgrafie van Utrecht. In: Dolfin, M.J., Kylstra, E.M., Penders, J. (Eds.), Utrecht, de huizen binnen de singels, part IIIA. gemeente Utrecht, 's-Gravenhage, Provincie Utrecht, pp. 1–20.
Hoffmann, T., Erkens, G., Cohen, K.M., Houben, P., Seidel, J., Dikau, R., 2007. Holocene floodplain sediment storage and hillslope erosion within the Rhine catchment. Holocene 17, 105–118.
Howard, A.J., Macklin, M.G., 1999. A generic geomorphological approach to archaeological interpretation and prospection in British river valleys: a guide for archaeologists investigating Holocene landscapes. Antiquity 73, 527–541.
Hudson, P.F., Middelkoop, H., Stouthamer, E., 2008. Flood management along the lower Mississippi (USA) and Rhine rivers (The Netherlands) and the Continuum of geomorphic adjustment. Geomorphology 101 (1–2), 209–236.
Jansen, B., Briels, I., Tol, A.J., 2014. *Castellum*-terrein Fectio, gemeente Bunnik: een archeologisch onderzoek in het kader van de publieks openstelling. RAAP rapport 1778. RAAP Archeologisch Adviesbureau, Amsterdam, p. 154.
Jansma, E., Morel, J.-M.A.W. (Eds.), 2007. Een Romeinse Rijnaak, gevonden in Utrecht-De Meern. Resultaten van het onderzoek naar de platbodem 'De Meern 1'. Rapportage Archeologische Monumentenzorg 144. Amersfoort, 144.
Jansma, E., 2013. Dendrochronologisch onderzoek van het scheepje 'Utrecht 6'. DCCD Rapportnummer 2013502. Rijksdienst voor het Cultureel Erfgoed, Amersfoort, p. 7.
Jansma, E., Haneca, K., Kosian, M., 2014. A dendrochronological reassessment of three Roman boats from Utrecht (The Netherlands). J. Archaeol. Sci. 50, 484–496.
Jansma, E., Van Lanen, R.J., 2016. The dendrochronology of Dorestad: placing early-Medieval structural timbers in a wider geographical context. In: Willemsen, A., Kik, H. (Eds.), Golden Middle Ages in Europe. New Research into Early-medieval Communities and Identities. Brepols Publishers, Turnhout, Belgium, pp. 105–144.
Jacobsen, T., 1995. Searching for sumer and Akkad. In: Sasson, J. (Ed.), Civilizations of the Ancient Near East. C. Scribners, New York, pp. 2743–2752.
Jezeer, W. (Ed.), 2011. Een Merovingische nederzetting aan de monding van de Rijn, ADC Rapport 2054. ADC Archeoprojecten, Amersfoort, p. 174.
Jones, L.S., Schumm, S.A., 1999. Causes of avulsion: an overview. In: Smith, N.D., Rogers, J. (Eds.), Fluvial Sedimentology VI. Special Publication of International Association of Sedimentologists 28, pp. 171–178.
Jongkees, J.H., Isings, C., 1963. Opgravingen op de Hoge Woerd bij De Meern (1957, 1960). Archaeologica Traiectina V, Wolters, Groningen, p. 100.
Kalee, C.A., 1982. Opgravingen op de Hoge Woerd in De Meern, 1830–1973, pp. 59–80. Historische Vereniging Vieuten-De Meern-Haarzuilens 2, Vleuten.
Kalee, C.A., Isings, C., 1980. Beknopt verslag van een opgraving in De Meern. Jaarboek Oud Utrecht 1980. Vereniging Oud-Utrecht, Utrecht, pp. 5–25.
Kalee, C.A., Isings, C. (Eds.), 1984. 150 jaar Graven Naar Het Romeins *Castellum* in De Meern. Historische Vereniging Vleuten- De Meern-Haarzuilens, Utrecht, p. 36.
Kaplan, J.O., Krumhardt, K.M., Zimmermann, N., 2009. The prehistoric and preindustrial deforestation of Europe. Quat. Sci. Rev. 28, 3016–3034.
Kelly, R.L., 1983. Hunter-Gatherer mobility strategies. J. Anthropol. Res. 39, 277–306.
Kemmers, F., 2008. Interaction or indifference? The Roman coin finds from the Lower Rhine delta. In: Bursche, A., Ciolek, R., Wolters, R. (Eds.), Roman Coins outside the Empire; Ways and Phases, Contexts and Functions, Nieborów. Collection Moneta 82, Wetteren, pp. 93–103.
Kleinhans, M.G., Jagers, H.R.A., Mosselman, E., Sloff, C.J., 2008. Bifurcation dynamics and avulsion duration in meandering rivers by one-dimensional and three-dimensional models. Water Resour. Res. 44 (W08454), 31. http://dx.doi.org/10.1029/2007WR005912.
Kleinhans, M.G., Cohen, K.M., Hoekstra, P., IJmker, J.M., 2011. Evolution of a bifurcation in a meandering river with adjustable channel widths, Rhine delta apex, The Netherlands. Earth Surf. Process. Landforms 36, 2011–2027. http://dx.doi.org/10.1002/esp.2222.
Kleinhans, M.G., Ferguson, R., Lane, S.N., Hardy, R.J., 2013. Splitting rivers at their seams: bifurcations and avulsion. Earth Surf. Process Landforms 38, 47–61. http://dx.doi.org/10.1002/esp.3268.
Kooistra, L.I., 1996. Borderland Farming. Possibilities and Limitations of Farming in the Roman Period and Early Middle Ages between the Rhine and Meuse. Ph.D. thesis Leiden University, The Netherlands/Van Gorcum, Assen., p. 401.
Kooistra, L.I., 2012. Die pfanzlichen Grundnahrungsmittel der Rheinarmee vor und nach der Gründung der Germania inferior. In: Stobbe, A., Tegtmeijer, U. (Eds.), Verzweigungen, Eine Würdigung für A.J. Kalis und J. Meurers-Balke, Bonn. Frankfurter Archäologische Schriften 18, pp. 171–188.
Kooistra, L.I., Van Dinter, M., Dütting, M.K., Van Rijn, P., Cavallo, C., 2013. Could the local population of the Lower Rhine delta supply the Roman army? Part 1: the archaeological and historical framework. J. Archaeol. Low Ctries. 4–2, 5–23.
Kosian, M., Weerts, H.J.T., Van Lanen, R., Abrahamse, J.E., 2013. The city and the river; the early Medieval Emporium (trade centre) of Dorestad; integrating physical geography with archaeological data in changing environments. In: Proceedings of the 17th International Conference on Cultural Heritage and New Technologies 2012 (CHNT 17, 2012). Stadtarchäologie 1–17, Museen der Stadt Wien, Vienna, Austria. In: http://www.chnt.at/proceedings-chnt-17.
Kosian, M., Van Lanen, R., Weerst, H., 2016. Dorestad's rise and fall: how the local landscape influenced the growth, prosperity and disappearance of an early-medieval emporium. In: Willemsen, A., Kik, H. (Eds.), Golden Middle Ages in Europe; New Research into Early-medieval Communities and Identities. Brepols Publishers, Turnhout, Belgium, pp. 99–104.
Langeveld, M. (Ed.), 2016. De vorming van een vicus; LR58 Vicuslaan: definitief archeologisch onderzoek naar een romeins kampdorp in de Meern (gem. Utrecht). Basisrapportage Archeologie 32. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht (in press).
Langeveld, M.C.M., Luksen-IJtsma, A. (Eds.), 2010. Wegens Wateroverlast. LR39 De Balije II: rivierdynamiek, wachttorens en infrastructuur in de romeinse tijd in een rivierbocht. Basisrapportage Archeologie Gemeente Utrecht 11. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, p. 266.
Langeveld, M., Luksen-IJtsma, A., Weterings, P. (Eds.), 2010. Een goede buur? LR46 en LR49: definitief archeologisch onderzoek naar de vicus, grafvelden, infrastructuur en een inheemse nederzetting in de omgeving van het Romeinse *castellum* in De Meern, deelgebied 'De Woerd' (Gemeente Utrecht). Basisrapportage Archeologie 19. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, p. 364.
Leijnse, K., Van Mousch, R. (Eds.), Utrecht, Diepriool Catharijnesingel, deeltraject Stationsstraat-Moreelsepark; definitief onderzoek. BAAC rapport A-12.0287, in press, BAAC bv Archeologie en Bouwhistorie, 's-Hertogenbosch.
Lidt de Jeude, W.F., 1973. Traiectum na 270, een studie naar laat-romeinse bewoning van het *castellum* in Utrecht, deel 1 en 2. Master thesis. Amsterdam University, The Netherlands.
Liendo, R., Solleiro-Rebolledo, E., Solis-Castillo, B., Sedov, S., Ortiz-Péréz, A., 2014. Population dynamics and its relation to ancient landscapes in the Northwestern Maya lowlands: evaluating Resilience and vulnerability. Archeol. Pap. Am. Anthropol. Assoc. 24, 84–100.
Louwe Kooijmans, L.P., Van der Broeke, P.W., Fokkens, H., Van Gijn, A.L. (Eds.), 2005. Prehistory of the Netherlands. Amsterdam University Press, Amsterdam, p. 842.
Luksen-IJtsma, A. (Ed.), 2010. De limesweg in West-Nederland. Inventarisatie, analyse en synthese van archeologisch onderzoek naar de Romeinse weg tussen Vechten en Katwijk. Basisrapportage Archeologie 40. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, p. 266.
Mackey, S.D., Bridge, J.S., 1995. Three-dimensional model of alluvial stratigraphy: theory and application. J. Sedimentol. Res. B 65–1, 7–31.
Macklin, M.G., Toonen, W.H.J., Woodward, J.C., Williams, M.A.J., Flaux, C., Marriner, N., Nicoll, K., Verstraeten, G., Spencer, N., Welsby, D., 2015. A new model of river dynamics, hydroclimatic change and human settlement in the Nile Valley derived from meta-analysis of the Holocene fluvial archive. Quat. Sci. Rev. 130, 109–123.
Makaske, B., Berendsen, H.J.A., Van Ree, M.H.M., 2007. Middle Holocene avulsion-belt deposits in the central Rhine-Meuse delta, The Netherlands. J. Sediment. Res. 77, 110–123.
Makaske, B., Maas, G.J., Van Smeerdijk, D.G., 2008. The age and origin of the Gelderse IJssel. Neth. J. Geosci. 87–4, 323–337.
Makaske, B., Smith, D.G., Berendsen, H.J.A., 2002. Avulsions, channel evolution and floodplain sedimentation rates of the upper Columbia River, British Columbia, Canada. Sedimentology 49, 1049–1071.
Manders, M., 2011. Waardestelling Vleuten 2; een 10e-eeuwse aak ontdekt bij het graven van de Vikingrijn op de Vinex-locatie Leidsche Rijn, Utrecht. Rapport Archeologische Monumentenzorg 198. Rijksdienst voor het Cultureel Erfgoed, Amersfoort, p. 48.
Manders, M., Hoegen, R., 2011. Waardestelling Vleuten 1; het onderzoek naar de resten van de opgeboeide boomstamboot uit de 8e eeuw na Christus. Rapport Archeologische Monumentenzorg 198. Rijksdienst voor het Cultureel Erfgoed, Amersfoort, p. 55.
Marchetti, M., 2002. Environmental changes in the central Po Plain (northern Italy)

due to fluvial modifications and anthropogenic activities. Geomorphology 44, 361–373.
McIntosh, J., 2008. The Ancient Indus Valley: New Perspectives. ABC-CLIO, p. 441.
McNabb, J., 2007. The British Lower Palaeolithic: Stones in Contention. Routledge, London, p. 420.
Middelkoop, H., 1997. Embanked Floodplains in The Netherlands; geomorphological evolution over Various Time Scales. Ph.D. thesis Utrecht University, The Netherlands/Netherlands Geographical Studies 224, Utrecht, p. 341. plus map.
RIZA rapport 99.003. In: Middelkoop, H., Van Haselen, C.O.G. (Eds.), 1999. Twice a River - Rhine and Meuse in The Netherlands. RIZA, Arnhem, p. 127.
Montforts, M.J.G.Th, 1991. De topografie van Utrecht in de Romeinstijd. Jaarboek Oud-Utrecht 1991. Vereniging Oud-Utrecht, Utrecht, pp. 7–38.
Montforts, M.J.G.Th, 1995. Romeins Utrecht. Historische Reek Utrecht 20. Stichting Matrijs, Utrecht, p. 72.
Mozzi, P., Furlanetto, P., Primon, S., 2004. La geomorfologia tra naviglio brenta e bacchiglione. In: Bondesan, A., Meneghel, M. (Eds.), Geomorfologia della provincia di Venezia. Esedra, Padova, pp. 269–283.
Mozzi, P., Piovan, S., Rossato, S., Cucato, M., Abbà, T., Fontana, A., 2010. Palaeohydrography and early settlements in Padua (Italy). Il Quat. 2, 409–422.
Nales, T., Vis, G.J., 2003. De paleogeografie van de Oude Rijn. MSc thesis. Universiteit Utrecht, The Netherlands, p. 93.
Ninfo, A.N., Ferrarese, F.R., Mozzi, P.A., Fontana, A., 2011. High resolution DEMs for the analysis of fluvial and ancient anthropogenic landforms in the alluvial plain of Padua (Italy). Geogr. Fis. Dimanica Quaternaria 94, 95–104.
Nokkert, M., Aarts, A.C., Wynia, H.L., 2009. Vroegmiddeleeuwse bewoning langs de A2 (LR51–54); Een nederzetting uit de zevende en achtste eeuw in Leidsche Rijn. In: Basisrapportage Archeologie 26. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, 372.
Nooren, C.A.M., Hoek, W.Z., Middelkoop, H., 2014. The Late Holocene Evolution of the Maya Delta in Southern Mexico. Abstracts NAC 12 Congress. Veldhoven, The Netherlands, p. 1.
Ozinga, L.R.P., Hoekstra, T.J., Weerd, M.D., Wynia, S.L., 1989. Het Romeinse castellum te Utrecht: de opgravingen uit 1936, 1938, 1943/44 en 1949 uitgevoerd onder leiding van A.E. Giffen met medewerking van H.Brunsting, aangevuld met latere waarnemingen. Broese Kemink, Utrecht, p. 191.
Parlevliet, D., 2001. De Rijnmond verstopt. Holland 22, 1–16.
Pennington, B.T., Thomas, R.I., 2016. Paleoenvironmental surveys at Naukratis and the Canopic branch of the Nile. J. Archaeol. Sci. Rep. 7, 180–188.
Pennington, B.T., Bunbury, J., Hovius, N., 2016. Emergence of civilization, changes in fluvio-deltaic style, and nutrient Redistribution forced by Holocene sea-level rise. Geoarchaeology 31, 194–210.
Piovan, S., Mozzi, P., Zecchin, M., 2012. The interplay between adjacent Adige and Po alluvial systems and deltas in the late Holocene (Northern Italy). Géomorphologie 427–440.
Polak, M., 1997. Romeinen aan de Kromme Rijn. In: Hessing, W.A.M., Polak, M., Vos, W.K., Wynia, S.L. (Eds.), Romeinen langs de snelweg: Bouwstenen voor Vechtens verleden. Uniepers, Abcoude/ ROB, Amersfoort, pp. 14–29.
Polak, M., 2009. The Roman military presence in the Rhine delta in the period c. AD 40-140. In: Morillo, A., Hanel, N., Martín, E. (Eds.), Limes XX, XXth Int. Congress of Roman Frontiers studies, Leon (España), Septiembre 2006. Anejos de Gladius 13-2 (Madrid), pp. 945–953.
Polak, M., 2014. An early-Roman naval base at Vechten; facts and fiction. In: Römisch-Germanisches, Zentralmuseum (Ed.), Honesta Missione - Festschrift für Barbara Pferdehirt. Römisch-Germanisches Zentralmuseum Monographie 100, Römisch-Germanisches Zentralmuseum, Mainz, Germany, pp. 69–98.
Polak, M., Wynia, S.L., 1991. The Roman Forts at Vechten, a Survey of the excavations 1829-1989. Oudheidkundige mededelingen uit het Rijksmuseum van Oudheden 71, Leiden, pp. 125–156.
Polak, M., Kloosterman, R.P.J., Niemeijer, R.A.J. (Eds.), 2004. Alphen aan den Rijn – Albaniana 2001–2002, Opgravingen tussen de Castellumstraat, het Omloopkanaal en de Oude Rijn. Libelli Noviomagenses 7, Nijmegen, p. 327.
Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.H.B., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0-50,000 years cal BP. Radiocarbon 55, 1869–1887.
Renes, H., 2005. Historische atlas van de stad Utrecht; Twintig eeuwen ontwikkeling in kaart gebracht. Uitgeverij SUN, Amsterdam, p. 80.
Roebroeks, W., 2001. Hominid behaviour and the earliest occupation of Europe: an exploration. J. Hum. Evol. 41, 437–461.
Rossato, S., Fontana, A., Mozzi, P., 2015. Meta-analysis of a Holocene ^{14}C database for the detection of paleohydrological crisis in the Venetian-Friulian Plain (NE Italy). Catena 13, 34–45.
Rossi, V., Amorosi, A., Sarti, G., Potenza, M., 2011. Influence of inherited topography on the Holocene sedimentary evolution of coastal systems: an example from Arno coastal plain (Tuscany, Italy). Geomorphology 135, 117–128.
Rijkswaterstaat-AGI, 2005. Actueel Hoogtebestand van Nederland. Rijkswaterstaat - Adviesdienst Geo-informatie en ICT, Delft.
Sarti, G., Bini, M., Giacomelli, S., 2010. The growth and decline of Pisa (Tuscany, Italy) up to the Middle ages: correlations with landscape and geology. Volume Speciale Il Quat. Ital. J. Quat. Sci. 23(2Bis) 311–322.
Sarti, G., Rossi, V., Amorosi, A., 2012. Influence of Holocene stratigraphic architecture on ground surface settlements: a case study from the City of Pisa (Tuscany, Italy). Sediment. Geol. 28, 75–87.
Schiestl, R., Herbich, T., 2013. Kom el-Gir in the western Delta. Egypt. Archaeol. 28–29.
Schiestl, R., Ginau, A., Wunderlich, J., 2016. Settling amongst shifting branches: fluvial and settlement dynamics in the northwestern Nile delta of Egypt. In: 4th International Landscape Archaeology Conference (LAC) 2016, Uppsala, 2nd-25th August 2016, p. 66.
Schoute, J.F.Th, 1984. Vegetation Horizons and Related Phenomena; a Paleoecological-micromorphological Study in the Younger Coastal Holocene of the Northern Netherlands (Schildmeer Area). Dissertationes Botanicae 81, Ph.D. thesis. Amsterdam Free University, the Netherlands, p. 269.
Sier, M.M., Van Doesburg, J., Verwers, W.J.H., 2004. Wijk bij Duurstede, Frankenweg/ Zandweg. ADC Rapport 282. ADC Archeoprojecten, Amersfoort, p. 51.
Slingerland, R., Smith, N.D., 2004. River avulsions and their deposits. Annu. Rev. Earth Planet. Sci. 32, 257–285.
Smith, N.D., Perez-Arlucea, M., 1994. Fine-grained splay deposition in the avulsion belt of the lower Saskatchewan River, Canada. J. Sediment. Res. 64–2, 159–168.
Smith, N.D., Cross, T.A., Dufficy, J.P., Clough, R., 1989. Anatomy of an avulsion. Sedimentology 36, 1–23.
Spaliviero, M., 2003. Historic fluvial development of the Alpine-foreland Tagliamento River, Italy, and consequences for floodplain management. Geomorphology 52, 317–333.
Sommer, S., 2009. Why there? The positioning along riverine frontiers of the Roman Empire. In: Hanson, W.S. (Ed.), The Army and Frontiers of Rome. Papers Offered to David J. Breeze on the Occasion of His Sixty-fifth Birthday and His Retirement from Historic Scotland. Journal of Roman Archaeology Supplementary Series 74, Portsmouth, U.S.A, pp. 103–114.
Stanley, J.-D., Warne, A.G., 1993. Nile delta: recent geological evolution and human impact. Science 260, 628–634.
Stanley, D.J., Warne, A.G., Schnepp, G., 2004. Geoarchaeological interpretation of the Canopic, largest of the relict Nile Delta distributaries. Egypt. J. Coast. Res. 20, 920–930.
Steenbeek, R., 1990. On the balance between Wet and Dry: Vegetation Horizon Development and Prehistoric Occupation: a Palaeoecological-micromorphological Study in the Dutch River Area. Ph.D. Thesis. Amsterdam Free University, The Netherlands, p. 267.
Stefani, M., Vincenzi, S., 2005. The interplay of eustasy, climate and human activity in the late Quaternary depositional evolution and sedimentary architecture of the Po Delta system. Mar. Geol. 222, 19–48.
Stefani, M., Zuppiroli, M., 2010. The interaction of geological and anthropic processes shaping the urban growth of Ferrara and the evolution of the surrounding plain. Il Quat. - Ital. J. Quat. Sci. 23 (2Bis), 355–372.
Stouthamer, E., Berendsen, H.J.A., 2000. Factors controlling the Holocene avulsion history of the Rhine-Meuse delta (The Netherlands). J. Sediment. Res. 70 (5), 1051–1064.
Stouthamer, E., 2001. Sedimentary product of avulsions in the Holocene Rhine-Meuse delta, The Netherlands. Sediment. Geol. 145 (1/2), 73–92.
Stouthamer, E., 2005. Reoccupation of channel belts and its influence on alluvial architecture in the Holocene Rhine-Meuse delta, The Netherlands. In: Giosan, L., Bhattacharya, J.P. (Eds.), River Deltas: Concepts, Models and Examples. SEPM Special Publication 83, SEPM, Tulsa, Oklahoma (USA), pp. 319–339.
Stouthamer, E., Cohen, K.M., Gouw, M.J.P., 2011. Avulsion and its implications for fluvial-deltaic architecture: insights from the Holocene Rhine-Meuse delta. SEPM Special Publication 97. In: Davidson, S.K., Leleu, S., North, C.P. (Eds.), From River to Rock Record: the Preservation of Fluvial Sediments and Their Subsequent Interpretation. SEPM, Society for Sedimentary Geology, pp. 215–232.
Stöver, R.J., 1997. De Salvator- of Oudmunsterkerk Te Utrecht: Stichtingsmonument van het Bisdom Utrecht. Clavis Kunsthistorische Monografieën 16. Clavis, Utrecht, p. 200.
Syvitski, J.P.M., Vörösmarty, C.J., Kettner, A.J., Green, P., 2005. Impact of humans on the flux of terrestrial sediment to the global coastal ocean. Science 308, 376–380.
Syvitski, J.P., Kettner, A.J., Overeem, I., Hutton, E.W., Hannon, M.T., Brakenridge, G.R., Day, J., Vörösmarty, C., Saito, Y., Giosan, L., Nicholls, R.J., 2009. Sinking deltas due to human activities. Nat. Geosci. 2, 681–686.
Syvitski, J.P., Kettner, A.J., Overeem, I., Giosan, L., Brakenridge, G.R., Hannon, M., Bilham, R., 2013. Anthropocene metamorphosis of the Indus Delta and lower floodplain. Anthropocene 3, 24–35.
Teunissen, D., 1986. Palynological investigation of some residual gullies in the Upper Betuwe (The Netherlands). Ber. Rijksd. het Oudheidkd. Bodemonderz. 36A, 7–24.
Trampier, J., Toonen, W., Simony, A., Starbird, J., 2013. Missing Koms and abandoned channels: the potential of regional survey in the western Nile delta landscape. J. Egypt. Archaeol. 99, 217–240.
Toonen, W.H.J., Kleinhans, M.G., Cohen, K.M., 2012. Sedimentary architecture of abandoned channel fills. Earth Surf. Process. Landforms 37, 459–472.
Toonen, W.H.J., Donders, T.H., Van der Meulen, B., Cohen, K.M., Prins, M.A., 2013. A composite Holocene palaeoflood chronology of the Lower Rhine. In: Toonen, W.H.J. (Ed.), A Holocene Flood Record of the Lower Rhine, pp. 137–150. Ph.D. thesis Utrecht University, The Netherlands/Utrecht Studies in Earth Sciences 41.
Törnqvist, T.E., 1993. Fluvial sedimentary geology and chronology of the Holocene Rhine-Meuse delta, The Netherlands. Neth. Geogr. Stud. 166, 169.
Törnqvist, T.E., 1994. Middle and late Holocene avulsion history of the river Rhine (Rhine-Meuse delta, The Netherlands). Geology 22–8, 711–714.
Turney, C.S.M., Brown, H., 2007. Catastrophic early Holocene sea level rise, human migration and the Neolithic transition in Europe. Quat. Sci. Rev. 26, 2036–2041.
Van Andel, T., Runnels, C.N., 1995. The earliest farmers in Europe. Antiquity 69,

481–500.
Van Asch van Wijck, H.M.A.J., 1838. Geschiedkundige beschouwing van het oude handelsverkeer der stad Utrecht van de vroegste tijden af tot aan de 14e eeuw, part I. L.E. Bosch, Utrecht, p. 171.
Van Asselen, S., 2011. The contribution of peat compaction to total basin subsidence: implications for the provision of accommodation space in organic-rich deltas. Basin Res. 23, 239–255.
Van de Moortel, A., 2009. The Utrecht type; adaptation of an inland boatbuilding tradition to urbanization and growing maritime contacts in medieval northern Europe. In: Bockius, R. (Ed.), Between the Sea; Transfer and Exchange in Nautical Technology Proceedings of the Eleventh International Symposium on Boat and Ship Archaeology, Mainz 2006. Museum of Ancient Shipping of the Roman-germanic Central Museum, Mainz, pp. 321–327.
Van den Bos, V., Brinkkemper, O., Bull, I.D., Engels, S., Hakbijl, T., Schepers, M., Van Dinter, M., Van Reenen, G., Van Geel, B., 2014. Roman impact on the landscape near *castellum* Fectio, The Netherlands. Veg. Hist. Archaeobotany 23, 277–298.
Van den Berg, J.J.H., Polak, M., Alders, P.G., 2012. Oppervlaktevondsten van Vechten-fectio: De veldkartering van 2009-2010. Auxiliaria 12. Radbout Universiteit, Nijmegen, p. 111.
Van der Gaauw, P.G., Van Londen, H., 1992. De Hoge Woerd; een boor- en weerstandsonderzoek naar het Romeinse castellum van De Meern. RAAP-rapport 65. RAAP Archeologisch Adviesbureau, Amsterdam, p. 74.
Van der Kamp, J.S., 2005a. Laatmiddeleeuwse bewoning langs de Hogeweide; Archeologisch proefonderzoek. Basisrapportage Archeologie 7. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, p. 30.
Van der Kamp, J.S., 2005b. Laatmiddeleeuwse bewoning langs de Hogeweide; Archeologisch onderzoek van een laat- en postmiddeleeuws bewoningslint. Basisrapportage Archeologie 8. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, p. 50.
Van der Kamp, J.S. (Ed.), 2006. Wonen aan het water (deel 1); Archeologisch onderzoek van een twaalfde-eeuwse nederzetting langs de Oude Rijn. Basisrapportage Archeologie 14. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, 82.
Van der Kamp, J.S. (Ed.), 2011. Boeren langs de Hogeweide; Een (post)middeleeuws boerderijlint op kapittelgrondgebied in Leidsche Rijn. Basisrapportage Archeologie 20. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, 439.
Van der Kamp, J.S. (Ed.), 2013. Veranderend landschap en schuivende erven; VTN '98–2: middeleeuwse bewoning in Veldhuizen (De Meern). Basisrapportage Archeologie 38. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, 56.
Van der Kamp, J.S., (Ed.), Langs de oever van een nieuwe rivier. Een vroeg-middeleeuwse nederzetting in Leidsche Rijn (gem. Utrecht), Basisrapportage Archeologie 44, in press, Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht.
Van der Linden, H., 1990. Oorsprong en oudste ontwikkeling van het hoogheemraadschap van Rijnland. Holland 22, 129–140.
Van der Tuuk, L., 1996. De theorieën over de rivierlopen in de stad Utrecht. Oud-Utrecht 1996-2. Vereniging Oud-Utrecht, Utrecht, pp. 36–44.
Van der Tuuk, L., 2001. De vroege topografie van de Utrechtse buitengerechten Oudwijk en Abstede. Oud-Utrecht 2001-7. Vereniging Oud-Utrecht, Utrecht, pp. 173–183.
Van der Tuuk, L., 2003. Gingen de Utrechtse bisschoppen Hunger, Odilbald en Radbod vanwege de Noormannen in ballingschap? Jaarboek Oud-Utrecht 2003. Vereniging Oud-Utrecht, Utrecht, pp. 33–66.
Van Dinter, M., 2013. The Roman Limes in The Netherlands: how a delta landscape determined the location of the military structures. Neth. J. Geosci. 92–1, 11–32.
Van Dinter, M., Kooistra, L.I., Dütting, M.K., Van Rijn, P., Cavallo, C., 2013. Could the local population of the Lower Rhine delta supply the Roman army? Part 2: Modelling the carrying capacity of the delta using archaeological, palaeo-ecological and geomorphological data. J. Archaeol. Low Ctries. 5–1, 5–50.
Van Es, W.A., 1981. De Romeinen in Nederland. Fibula-van Dishoeck, Bussum, p. 300.
Van Es, W.A., 1990. Dorestad centred. In: Besteman, J.C., Bos, J.M., Heidinga, H.A. (Eds.), Medieval archaeology in The Netherlands; studies presented to H.H. van Regteren Altena. Studies in prae- en protohistorie 4. Van Gorcum and Comp. N.V., Assen, pp. 151–182.
Van Es, W.A., 1984. Romeinse helmen uit de Rijn bij Rijswijk. In: Kouwenhoven, A.O., De Bruijne, G.A., Hoekveld, G.A. (Eds.), Geplaatst in de tijd, *liber amicorum* aangeboden aan Prof. Dr. M.W. Heslinga. Rijksdienst voor Oudheidkundig Bodemondezoek, Amersfoort, pp. 255–291.
Van Es, W.A., 1994. Volksverhuizingen en continuïteit. In: Van Es, W.A., Hessing, W.A.M. (Eds.), Romeinen, Friezen en Franken in het hart van Nederland; Van Traiectum tot Dorestad 50 v C. - 90 n. C. Stichting Matrijs, Utrecht, pp. 64–81.
Van Es, W.A., Verwers, W.J.H. (Eds.), 1980. Excavations at Dorestad 1; the Harbour: Hoogstraat 1, Amersfoort. Nederlandse Oudheden 9, Rijksdienst Voor Oudheidkundig Bodemonderzoek, Amersfoort, p. 319.
Van Es, W.A., Verwers, W.J.H. (Eds.), 2009. Excavations at Dorestad 3; Hoogstraat 0, II–IV, Amersfoort. Nederlandse Oudheden 16, Rijksdienst voor Archeologie, Cultuurlandschap en Monumenten, Amersfoort, p. 383.
Van Es, W.A., Verwers, W.J.H., 2010. Early medieval settlements along the Rhine: precursors and contemporaries of Dorestad. J. Archaeol. Low Ctries. 2–1, 5–39.
Van Es, W.A., Verwers, W.J.H., 2015. Excavations at Dorestad 4; The settlement on the river bank area. Nederlandse Oudheden 18, Rijksdienst voor Archeologie, Cultuurlandschap en Monumenten, Amersfoort, p. 468.
Van Lanen, R.J., Jansma, E., van Doesburg, J., Groenewoudt, B.J., 2016. Roman and early-medieval long-distance transport routes in north-western Europe: Modelling frequent-travel zones using a dendroarchaeological approach. J. Archaeol. Sci. 73, 120–137.
Van Loon, A.H., Schot, P.P., Griffioen, J., Bierkens, M.F.P., Batelaan, O., Wassen, M.J., 2009. Throughflow as a determining factor for habitat contiguity in a near-natural fen. J. Hydrol. 379, 30–40.
Van Rooijen, C., 1997. Een stathe aan de Vecht : ofwel het gelijk van N. van der Monde. Maandblad Oud-Utrecht 70-5. Vereniging Oud-Utrecht, Utrecht, pp. 80–85.
Van Rooijen, C., 1999. Continue Discontinuïteit; het *Castellum* Traiectum in het vroeg-middeleeuwse krachtenveld. Jaarboek Oud-utrecht 1999. Vereniging Oud-Utrecht, Utrecht, pp. 6–34.
Van Rooijen, C., 2010. Utrecht in the Medieval period; an archaeological analysis of its topography and a discussion of the location of the Stathe vicus. Mediev. Mod. Matters 1, 1–36.
Van Rooijen, C.A.M., Wynia, H., 1998. Zuidelijke binnenstad. In: Kok, D.H., Van Dockum, S.G., Vogelzang, F. (Eds.), Archeologische Kroniek Provincie Utrecht 1994-1995. Stichting Publicaties Oud-Utrecht, Utrecht, pp. 103–124.
Van Vliet, K., 2000a. De stad en de bisschop (circa 925-1122). In: De Bruin, R.E., 't Hart, P.D., Van Hoven, A.J., Pietersma, A., Struick, J.E.A.L. (Eds.), Paradijs van Weelde; geschiedenis van de stad Utrecht. Stichting Matrijs, Utrecht, pp. 45–72.
Van Vliet, K., 2000b. De stad en de burgers (1122-1304). In: De Bruin, R.E., 't Hart, P.D., Van Hoven, A.J., Pietersma, A., Struick, J.E.A.L. (Eds.), Paradijs van Weelde; geschiedenis van de stad Utrecht. Stichting Matrijs, Utrecht, pp. 73–112.
Van Vliet, K., 2002. In kringen van kanunniken; munsters en kapittels in het bisdom Utrecht 695-1227. Ph.D. thesis. Amsterdam University, The Netherlands/Walburg Pers, Zutphen, p. 503.
Van Winter, J.M., 1975. Utrecht aan de Rijn; middeleeuwse Rijnloop en wordingsgeschiedenis van de stad Utrecht. Jaarboek Oud-Utrecht 1975. Vereniging Oud-Utrecht, Utrecht, pp. 44–72.
Verwers, W.J.H., 1994. Wijk bij Duurstede-Dorestad. In: Van Es, W.A., Hessing, W.A.M. (Eds.), Romeinen, Friezen en Franken in het hart van Nederland; Van Traiectum tot Dorestad 50 v C. - 90 n. C. Stichting Matrijs, Utrecht, pp. 234–238.
Von Nagy, C., 1997. The geoarchaeology of settlement in the Grijalva delta. In: Stark, B.L., Arnold, P.J. (Eds.), Olmec to Aztec: Settlement Patterns in the Ancient Gulf Lowlands. University of Arizona Press, Tucson, pp. 253–277.
Vos, W.K., 1997. Sporen zoeken in de vicus. In: Hessing, W.A.M., Polak, M., Vos, W.K., Wynia, S.L. (Eds.), Romeinen langs de snelweg: Bouwstenen voor Vechtens verleden. Uniepers, Abcoude/ROB, Amersfoort, pp. 35–51.
Vink, T., 1954. De Rivierstreek. Bosch and Keuning, Baarn, p. 840.
Wansleeben, M., 1982. Resultaten archiefonderzoek naar lithologie onder de stad Utrecht. Master thesis. Universiteit Utrecht.
Weerts, H.J.T., Cleveringa, M.J.P., Gouw, M., 2002. De Vecht/Angstel, een riviersysteem in het veen. Grondboor Hamer 3–4, 66–71.
Weterings, P., Meijer, Y. (Eds.), 2011. Op zoek naar de weg. LR60: onderzoek naar de Romeinse limesweg in De Meern, Utrecht. Basisrapportage Archeologie Gemeente Utrecht 33. Gemeente Utrecht Dienst Stadsontwikkeling, Utrecht, 197.
Wilkinson, T.J., 2000. Regional approaches to Mesopotamian archaeology: the contribution of archaeological surveys. J. Archaeol. Res. 8, 219–267.
Willems, W.J.H., 1986. Roman and Batavians; a Regional Study in the Dutch Eastern River Area II, Amersfoort. Ph.D. thesis. Amsterdam University, The Netherlands/Berichten ROB 34, ROB, Amersfoort, pp. 39–331.
Williams, G.L. (Ed.), 2010. Wijk bij Duurstede, De Geer II; Een Inventariserend Veldonderzoek door middel van proefsleuven. ADC Rapport 2004. ADC Archeoprojecten, Amersfoort. 85.
Williams, G.L. (Ed.), 2013. Een nieuw stukje Dorestad; Een archeologische opgraving op De Geer II in Wijk bij Duurstede. ADC Rapport 3467. ADC Archeoprojecten, Amersfoort, 107.
Wilson, P., 2007. The Western Delta Regional Survey. https://community.dur.ac.uk/penelope.wilson/Delta/Survey.html (last accessed June 2015).
Ypma, J., Jansma, E., van Lanen, R., Wynia, H., 2014. Placing the Jan Meijenstraat excavations (Utrecht, 1979-1981) in Aphysical-geographical Context: a Dendrochronological, Archive and Literature Analysis; Research Internship in the Context of NWO Humanities Research Project' the Dark Age of the Lowlands in an Interdisciplinary Light: People, Landscape and Climate in TheNetherlands between AD 300 and 1000' (2012-2017; UU with RCE and RUG). Utrecht University, The Netherlands.
Zandstra, M.J.M., Polak, M., 2012. De Romeinse versterkingen in Vechten-fectio: Het Archeologisch Onderzoek in 1946-1947. Auxiliaria 11. Radboud Universiteit, Nijmegen, p. 317.

Classic text references

Annales, Bertiniani, Waitz, G., 1883. Annales Bertiniani. Monumenta Germaniae Historica, Scriptores Rerum Germanicarum 5. Impensis Bibliopolii Hahniani, Hannover, Germany, p. 193. https://archive.org/details/annalesbertinia00waitgoog.
Annales, Fuldenses, Kurze, F., 1891. Annales Fuldenses sive Annales Regni Francorum Orientalis. Monumenta Germaniae Historica, Scriptores Rerum Germanicarum 7. Impensis Bibliopolii Hahniani, Hannover, Germany, p. 182. https://archive.org/details/annalesfuldenses00einhuoft.
Annales Xantenses, Vedastini, De Simson, B., 1909. Annales Xantenses et Annales

Vedastini., Monumenta Germaniae Historica, Scriptores Rerum Germanicarum 12, Hannover/Leipzig, Germany, pp. 1–39.
Alpertus van Metz, 1999. In: Van Rij, H. (Ed.), Gebeurtenissen van deze tijd; Een fragment over bisschop Diederik I van Metz; De mirakelen van de heilige Walburg in Tiel. Verloren, Hilversum, p. 95.
Briefe des Bonifatius, Willibalds Leben des Bonifatius, nr. 109. In: Rau, R. (Ed.), 1968. Freiherr-vom-Stein-Gedachtsnisausgabe IVb, Darmstad, Germany, pp. 338–342.
Commemoratio de rebus Sancti Martini Traiectensis ecclesie, que iam olim ibidem a fidelibus tradite sunt. In: Gysseling, M., Koch, A.C.F. (Eds.), 1950. After copy C in Diplomata Belgica ante annum millesimum centesimum scripta I, Brussel. Original Latin text and Dutch translation also In: Dijkstra, M.F.P., 2011: App. 5: Goederenlijst van de Utrechtse St. Maartenskerk, pp. 473–479.
Commentarii de Bello Gallico. Doesburg j.j., 1895. Amsterdam.
Diplomata Belgica ante annum millesimum centesimum scripta I. In: Gysseling, M., Koch, A.C.F. (Eds.), 1950. Belgisch Inter-universitair Centrum Voor Neerlandistiek, Brussel, Belgium, p. 464.
Oorkondenboek van Holland en Zeeland, Koch, A.C.F., Kruisheer, J.G., Burgers, J.W.J., Sparreboom, J., 1970. Oorkondenboek van Holland en Zeeland I, Eind van de 7e eeuw tot 1222. Nijhof, 's Gravenhage/Van Gorcum, Assen, pp. 297–301.
Oorkondenboek van het Sticht Utrecht tot 1301 I. Muller, Fz., S., Bouman, A.C., Heeringa, K., 1920. Staatsdrukkerij- en uitgeverijbedrijf, 's-Gravenhage, p. 471.
Vita Willibrodi archiepiscopi Traiectensis auctore Alcvino. In: Levison, W. (Ed.), 1920. Monumenta Germaniae Historica, Scriptores Rerum Merovingicorum 7. Hahn, Hannover-leipzig, Germany, pp. 81–141.
Vita sancti Liudgeri auctore Altfrido. In: Diekamp, W. (Ed.), 1881. Die Vitae Sancti Liudgeri, Geschichtsquellen des Bisthums Münsters 4, Theissing,Münster, Germany, p. 466. https://archive.org/details/dievitaesanctili00altfuoft.

Map references

Anonymous, 1873. Chromo-topografische kaart des Rijks (Bonnekaart), Zeist, blad 446, schaal 1:25,000. Bureau Militaire Verkenningen.
Anonymous, 1874. Chromo-topografische kaart des rijks (Bonnekaart), Utrecht, blad 445, schaal 1:25,000. Bureau Militaire Verkenningen.
Anonymous, 1875. Chromo-topografische kaart des rijks (Bonnekaart), Harmelen, blad 444, schaal 1:25,000. Bureau Militaire Verkenningen.
Blaeu, Willem Janz., 1633-1635. Wtrecht, map scale 1:16,000 (Amsterdam). GAR Bibliotheek 61 F 13. In: Donkersloot- de Vrij, M. (Ed.), 1989. Kaarten van Utrecht; topografische en thematische kartografie van de stad uit vijf eeuwen. HES, Utrecht, nr. 11, p. 43.
Berendsen, H.J.A., 1982. De genese van het landschap in het zuiden van de provincie Utrecht - een fysisch-geografische studie. Utrechtse Geografische Studies 25, Geografisch Instituut Rijksuniversiteit Utrecht, Utrecht. 256 p. plus Appendices: De geomorfogenetische kaart van Zuid-Utrecht, scale 1:25,000, map sheet, pp. 1–5.
Blaeu, Joan, 1649. Traiectum Wtrecht, map scale 1:5,500 (Amsterdam). GAU TA Ab 67, Ab 68, Ab 69; UBL BN 40-71 and 72; UBA 26-04-32. In: Donkersloot-de Vrij, M. (Ed.), 1989. Kaarten van Utrecht; topografische en thematische kartografie van de stad uit vijf eeuwen. HES, Utrecht, nr. 14, pp. 45–47.
Buringh, P., Van der Knaap, W., 1952. Bodemgesteldheid rond de stad Utrecht. deel I-IV. Stichting voor Bodemkartering, Wageningen.
Specht, C., 1695–1989. Urbis Traiecti ad rhenum novissima et accuratissima delineatio, map scale 1 ; 6,000 (Utrecht). GAU TA Ab 76, Ab 77 and Ab 79; UBL BN 40-88, 40–89; UBA kv 26-11-16, MFA AC 2-30-1. In: Donkersloot-de Vrij, M. (Ed.), Kaarten van Utrecht; topografische en thematische kartografie van de stad uit vijf eeuwen. HES, Utrecht, nr. 20, pp. 53–55.
Specht, C., 1696. Caerte vande Vrijheyd der Stadt Utrecht volgens desicie vanden jare 1539, map scale 1:20,000 (Utrecht). GAU TA Ab 03, Ab 83; UBL BN 40-45; LUW Ct Atlas 1-39. In: Donkersloot-de Vrij, M. (Ed.), 1989. Kaarten van Utrecht; topografische en thematische kartografie van de stad uit vijf eeuwen. HES, Utrecht, nr. 140, pp. 127–128.
Stichting voor Bodemkartering, 1976. Bodemkaart van Nederland, blad 31 Oost (Utrecht). Stichting voor Bodemkartering, Wageningen.
Van de Meene, E.A., Van Meerkerk, M., Van der Staay, J., 1988. Geologische kaart van Nederland, Scale 1: 50,000, Blad Utrecht Oost (31O). Rijks Geologische Dienst, Haarlem.
Van Deventer, J., 1569-1570. *Traiectum inferius*, map scale 1 : 8,000 (Mechelen). Madrid, Biblioteca Nacional, manuscritos CC 19 and 20. In: Donkersloot-de Vrij, M. (Ed.), 1989. Kaarten van Utrecht; topografische en thematische kartografie van de stad uit vijf eeuwen. HES, Utrecht, nr. 2 and 29-30, p. 64.
Verstraelen, Hendrick Jz., 1629. Kaart van het plan tot de uitbreiding vande stadsfortificaties op vier plaatsen. Map scale c. 1: 3,400. GAU TA Ab 62 and Ab 62 B. In: Donkersloot-de Vrij, M. (Ed.), 1989. Kaarten van Utrecht; topografische en thematische kartografie van de stad uit vijf eeuwen. HES, Utrecht, nr. 92, p. 103.