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Faculty of Geosciences

Cultural Heritage Agency
Ministry of Education, Culture and Science

Dark Ages Project

Development of new river channels and river maturation in the Rhine-Meuse delta, during the Late Roman Period and Early Middle Ages, AD 300-1000

MSc-thesis Earth Sciences

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Supervisors
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using a conceptual river phase model for integration of existing and new (multidisciplinary) datasets for river maturation in longitudinal and lateral direction on a centennial temporal resolution.

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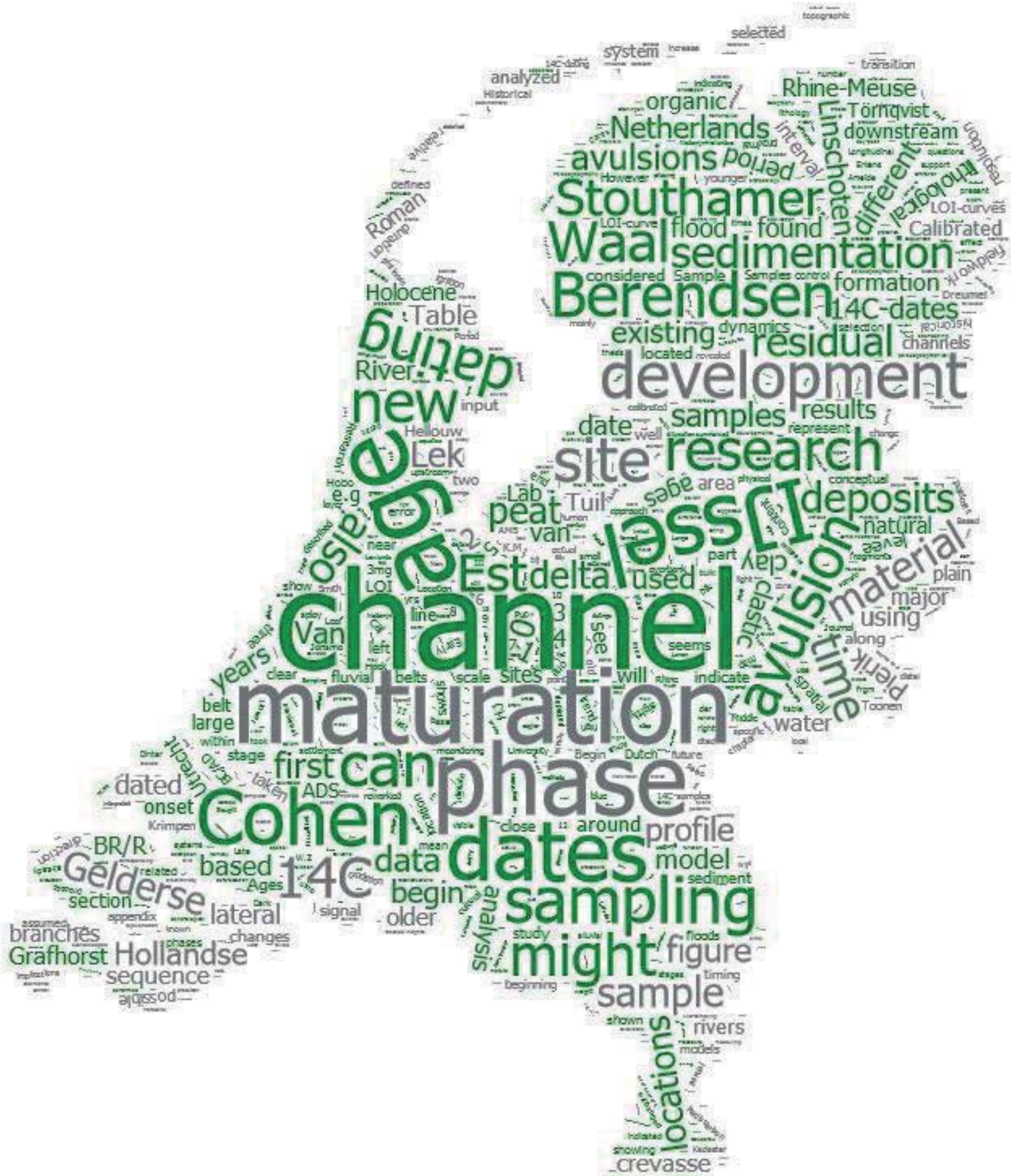
Front page image:
cut out of the artwork "Talking about Levees", based on the levee-reconstruction map of H.J. Pierik for the Rhine-Meuse delta AD 100 and the face contour of the author of this thesis.



Word cloud summary of this Msc-thesis made using the tool on wordclouds.com.

Summary

This study focuses on the spatial trends in new river course development of three major rivers in the Netherlands. The alluvial architecture and paleogeography of the Dutch river plain area have been studied over years. There are over 200,000 corings and 1700 relevant ^{14}C-dates, which made identification of different river generations possible. However, temporal resolution of most dates is too low to answer questions of longitudinal and lateral river channel development on a centennial time step resolution for a single river channel. Higher time step resolution of river channel maturation can improve conceptual models of alluvial architecture in general and can be used to validate computer models on river channel development and maturation.

This study aims to (1), avulsion history reconstruction on a centennial time step resolution, (2) evaluation of assembly of multidisciplinary datasets and (3) to give more insight in river channel maturation in longitudinal and lateral direction.

A conceptual river phase model (from non-existence to buried residual channel) is introduced to enable integration of both existing and new ^{14}C-dates to distinguish local sedimentary and hydrological footprints of individual dates from regional trends. For each phase, from non-existence to buried residual channel, related dating methods are combined originating from historical sources, archeology, lithology, dendrology and type of ^{14}C-dates.

New sampling sites have been selected based on existing cross-sections and new cross-sections, that were drawn using existing data. Loss-on-Ignition (LOI) of the sampled cores is used as ^{14}C sub-sample selection strategy as clay-on-peat transitions could be identified in more detail. For sequenced dates AMS ^{14}C-dates have been calibrated using Oxcal Sequence Dating.

Begin of sedimentation ages for the river channels were tightened with new ^{14}C-dates. Sedimentation started almost simultaneously over the river course, as no clear longitudinal and lateral trends in river channel development during maturation could be deduced from the data. Classification of ^{14}C-dates to different phases of the river phase model was useful, although still a large within phase heterogeneity of ^{14}C-dates was visible.

As no large actual time hiatus in lateral direction between levee and floodplain deposits is observed in this study, future clay-on-peat samples (for *type 1* dates, cf. Berendsen, 1982) should and could be taken not too close to the natural levee. ^{14}C-samples thereby always represent a local sedimentary and hydrological footprint and cannot be simply combined in analysis only based on their bare ages. And although lithological information is present in ^{14}C databases, lithological sequence information, as well as LOI-curves when used for ^{14}C-sampling, should be inserted in the ^{14}C databases, as this information is conditional for meaningful further analysis of ^{14}C-dates. Moreover LOI-curves can be used to identify possible oxidation of peat, and to visualize local river maturation (sudden or gradual) in more detail.

Further improvement of timing of river maturation also contributes to studies which attempt to combine environmental, cultural or archaeological data in a high time step resolution.

Keywords: river maturation| Dark Ages | radiocarbon dating | multidisciplinary datasets
Late Roman Period | Early Middle Ages | river maturation | sampling strategies

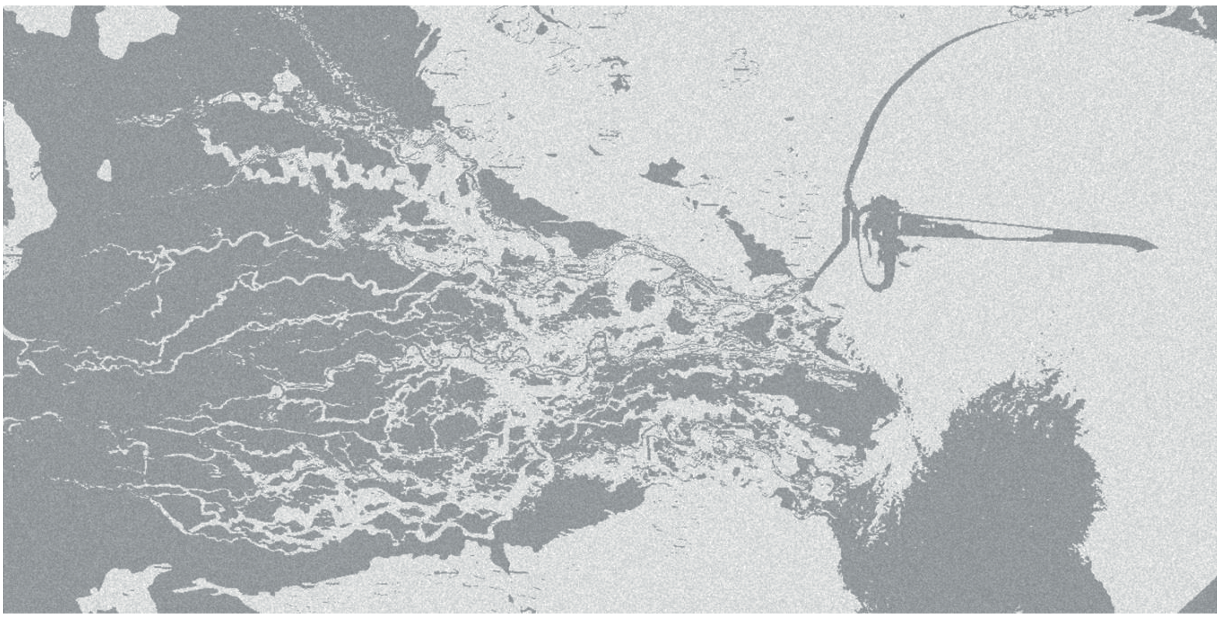
Preface

This master thesis is part of the MSc curriculum of Earth, Surface and Water at Utrecht University, Utrecht, the Netherlands. This research was performed within the NWO-research program entitled: The Dark Ages of the Lowlands in an interdisciplinary light: people, landscape and climate in the Netherlands between AD 300 and 1000. From an interregional and multidisciplinary perspective this NWO-research program focuses on landscape development, settlement dynamics, land use, demography and trade networks for successive time slices covering the first millennium AD (Jansma et al., 2014). The thesis was supervised by H.J. Pierik MSc (as daily supervisor on physical geography), R.J. van Lanen MA (as daily supervisor on archaeology) and dr. E. Stouthamer (overall MSc-thesis supervisor).

The process of research and MSc thesis writing was experienced as a meandering river itself. Starting with a somewhat meandering main thought, encountering several levee breakthroughs and related crevasse splay formation or even facing some failed bifurcations or partial avulsions to finally end up with this thesis as a delta made up of the '*sedimented'* results of months of fieldwork, lab analysis and literature reviews. Peer meetings and coffee corner discussions with Harm Jan Pierik, Rowin van Lanen, Marjolein Gouw-Bouman, Hessel Woolderink, Tim Winkels, Niels Mulder and Juul Beltman are greatly acknowledged and gave rise to proper improvements and kept up motivation. Harm Jan Pierik, Hessel Woolderink, Rowin van Lanen, Kim Cohen and Wim Hoek are acknowledged for their support during the field campaign, as well as all landowners for allowing us to conduct hand drillings on their land. I would like to thank Hessel Woolderink for his support with digitizing the cross-sections. Nelleke van Asch (ADC ArcheoProjecten) is acknowledged for identifying macrofossils for radiocarbon dating and feedback on possible exchanged samples. Suggestions and remarks of Vera van de Put improved the readability and are gratefully acknowledged.

I hope any reader will experience an educational journey in the world of river dynamics of the Dutch river plain area in the Late Roman Period and Early Middle Ages and I hope results of this thesis will support and inspire future research.

A report on the fieldwork campaign around the river Gelderse IJssel by the regional television station *RTV Oost* can be found using the following link http://www.rtvoost.nl/nieuws/default.aspx?nid=194000 (Dutch only). More information on the Dark Ages project can be found on darkagesproject.com.



Artwork "Talking about Levees", based on the levee-reconstruction map of H.J. Pierik for the Rhine-Meuse delta AD 100 and the face contour of the author of this thesis. Cut out as front image.

Content

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Bold figures represent key-figures of this MSc-thesis.

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1. Introduction

Alluvial architecture and paleogeography of the Rhine-Meuse delta plain have been studied for many years to understand delta forming processes (e.g. Berendsen and Stouthamer 2001). Avulsion is a key process of alluvial architecture (e.g. Leeder, 1978 and Stouthamer et al., 2011) and in the paleogeographic evolution of the Rhine-Meuse delta (Berendsen and Stouthamer, 2001, Stouthamer et al., 2011). Forcing factors are described by Jones and Schumm, (1999) and Stouthamer and Berendsen (2000). These paleogeographical reconstructions provide detailed information on development of new rivers on millennial timescales (Cohen and Stouthamer, 2012). So avulsions are known to be the driving process for formation of rivers and the formation process of breakthroughs and crevasse splay formation and maturation have been studied extensively (e.g. Smith et al., 1989). However, less studies have been focussing on longitudinal river channel development or maturation of the river channel after this moment of formation of a new channel, the lithological footprint of this river maturation phase and river channel maturation time. One-dimensional modelling approaches do exist (e.g. Kleinshans et al, 2011), but natural data to validate them is lacking.

Nowadays, there is a growing interest in more detailed information on former deltaic landscapes and their relation with settlement dynamics and vegetation patterns. There are over 200.000 corings and over 1700 related ^{14}C-datings from the Dutch river plain area (Cohen and Stouthamer, 2012), from which age maps of new river channels are derived and wherein successfully different generations of rivers systems are identified. However, temporal resolution and accuracy of most present day available ^{14}C-datings underlying these paleogeographical reconstructions cannot answer questions of longitudinal and lateral development of new river branches on a centennial time step resolution. Insights in river channel development on a high temporal and spatial resolution ultimately can support questions of spatial diachronicity or time lags between paleogeographical landscape evolution and settlement dynamics in the Netherlands.

Such research questions on the structure and genesis of former landscapes and the underlying determining factors can hardly be answered by following a mono-disciplinary approach, so more and more studies successfully show a multidisciplinary approach by combining methods and data of archaeological, landscape and vegetation studies (e.g. Kooistra et al. 2006; Van Beek, 2009; Van Dinter et al., 2013). First attempts for phasing of developing (Hobo, 2015) and degrading river systems (Van Dinter et al., 2016) have been made in the past year. Although the importance of a multidisciplinary approach is widely endorsed, a integrative conceptual model for integration of historical, archeological, lithological, hydrological, dendrochronological and ^{14}C-dates for dating different phases of river channel development and river maturation is not developed yet and will be presented in this study.

This research is focusing on development of new river channels and river maturation in the Rhine-Meuse delta during the Late Roman Period and Early Middle Ages, AD 300-1000. Because of the scarcity of historical sources from this period, interpretations mainly rely on archaeological finds, geological and palynological (pollen) data. This thesis will predominantly have a geomorphological or landscape evolutional approach. In de next paragraph, research aims and derivative research questions are elaborated in further detail.

1.1 Research aims and research questions

The objectives of this research are (1), *avulsion history reconstruction*, (2) *evaluation of assembly of multidisciplinary datasets* and (3*) river channel maturation*. To reconstruct (1) the timing of avulsion and channel development for the (**a**) river Gelderse IJssel (*Zutphen-Zwolle*), (**b**) Nederrijn-Hollandse IJssel/Lek (*Wijk bij Duurstede - Krimpen aan de Lek*) and (**c**) the river Waal-Nieuwe Merwede (downstream of *Tiel*) (Fig. 1). To assess this first objective existing (multidisciplinary) data and additional new fieldwork data have to be integrated. The second research aim (2) is juxtaposing possibilities and limitations of the assembly of these multidisciplinary datasets in the context of dating of different phases of river channel development. This MSc-research also pursues the derivative aim (3) to give more insight in the development of a new channel into a mature channel from proximal to distal deltaic fluvial environments and in a lateral direction and the maturation time of newborn rivers. Implications of spatial diachronicity of river branch development, leads and lags between paleogeographical landscape evolution and settlement dynamics (e.g. timing of occupation after landscape element formation) in the fluvial area of the Netherlands are only briefly assessed in the literature review (chapter 2) and discussion section (chapter 5). In line with (Zarina, 2010), which asserts that previous activities in the landscape will influence the subsequent sequence of events, the late-Roman paleo landscape will be the starting point. These three research objectives (*1), Avulsion history reconstruction, (2) evaluation of assembly of multidisciplinary datasets and (3) river channel maturation* lead to the following research questions:

- What is the timing of the development of three new river branches of the Krimpen river system (river IJssel, river Nederrijn-Hollanse IJssel-Lek and Waal-Nieuwe Merwede) between AD 300 and AD 1000 in a centennial time step resolution?

- How can multidisciplinary datasets be integrated to tight age control for timing of the existence period of channel belts and eventually date different phases of river channel development?

- How do the three river branches compare to each other in transition (or maturation) from proximal to distal fluvial environments?

Relevance of this research

Further detailed information on the development of natural rivers and insights in avulsion parameters as avulsion duration (period of avulsion formation), interavulsion period (period of activity of individual river channels) avulsion rates (duration of the complete shift from one active channel to another), can be used to improve models of alluvial architecture and river maturation in general (Stouthamer and Berendsen, 2001; Törnqvist, 1994). In a Rhine modeling-case Kleinhans et al. (2011) found width adjustment of the downstream branches to the changing discharge and the effect of meandering are necessary conditions for explanation of the avulsion duration. High temporal and spatial resolution data of avulsion maturation can improve validation of such modelling approaches, as already stated by Mackey and Bridge (1995, as cited by Stouthamer and Berendsen, 2001). Still a lot of these one-dimensional models work on a Holocene or millennia timescale, whereas this research contributes to the knowledge of avulsion parameters and river channel development on the timescale of centuries.

Improved timing of the ages of beginning of river sedimentation of the rivers *Gelderse Ijssel, Hollandse IJssel, Lek* and *Waal* will also contribute to knowledge of the paleogeography of the Rhine-Meuse delta, especially for the late-Roman and early medieval period. A higher chronological resolution of landscape reconstructions resulting from improved dating of the development of river channels can also contribute to models which attempt to combine environmental and cultural data, such as the network friction model of Van Lanen (2015) for that specific period. In an attempt to correlate dating methods from historical sources, archaeology, dendrochronology and physical geography (e.g. ^{14}C- and optically stimulated luminescence datings) to river channel development phases, this research also shows the tight age control that multidisciplinary dataset integration might facilitate.

1.2 Research Area

The Holocene Rhine-Meuse delta is a back-barrier fluvial plain (Berendsen and Stouthamer 2001). Which consists of numerous fossil channel belts which represent abandoned rivers (Stouthamer and Berendsen, 2000), flanked by natural levees, crevasse splays and peaty and clayey floodbasin deposits. For this research relative young channel belts are selected, all assumed to be formed around the late Roman or early medieval period and assumed to have good age-control opportunities and sufficient archaeological finds. The three river branches are: river Gelderse IJssel (*Zutphen-Zwolle,* Cohen et al., 2012 channel belt #50), Nederrijn-Hollandse IJssel/Lek (*Wijk bij Duurstede - Krimpen aan de Lek,* respectively channel belts #116, #68, #91) and the river Waal-Nieuwe Merwede (downstream of *Tiel;* channel belt #174). The studied rivers in this research are part of the Krimpen alluvial system (cf. Berendsen, 1982), although the residual channel of Est has to be considered as part of the Est river system in active times. Cohen et al. (2012) defined the separate Liemers river system for the eastern part of the Nederrijn and the river Gelderse IJssel.

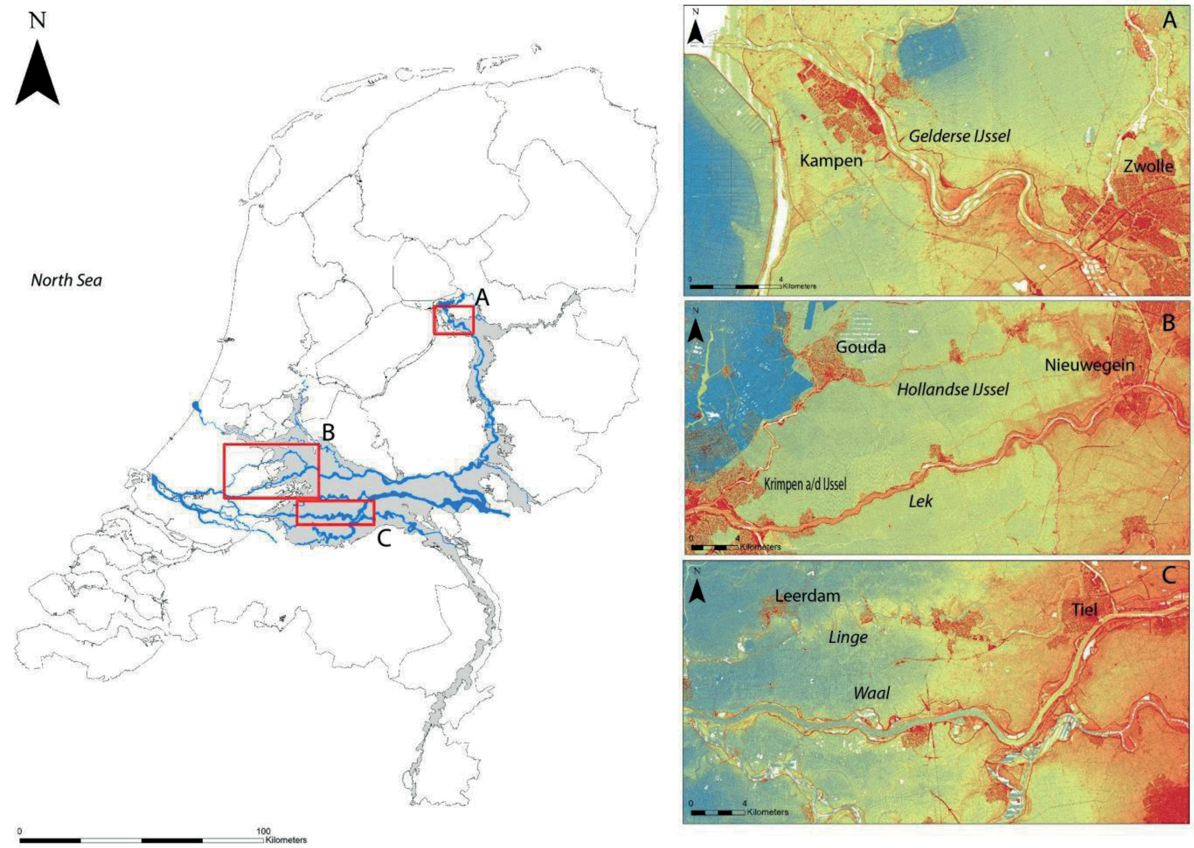


Figure 1 | Holocene Rhine-Meuse delta and focus research areas. In grey the Dutch river plain area in the central area of The Netherlands is depicted and in blue present day active rivers (source: Cohen et al., 2012). Digital elevation model maps (AHN) are shown for respectively subareas A (river Gelderse IJssel), B (rivers Nederrijn-Hollandse IJssel-Lek) and C (river Waal downstream of city of Tiel).

1.3 Thesis outline

In the next chapter literature and existing datings will be reviewed to illustrate the broader context and underline the complementary value of this research. In chapter 3 a new conceptual phase model for river channel development is introduced. In chapter 4 outlines the results of the fieldwork campaign, new datings as well as longitudinal and lateral analysis along the river branches. The discussion section (chapter 5) mainly focusses on the usability of the new conceptual phase model for river channel development, implications of longitudinal and lateral spatial diachronicity for future dating site selection and implications of higher temporal resolution of river channel development on archeology. Conclusions of this research can be found in chapter 6. In a separate chapter 7 suggestions for future research are summarized.

2. River channel formation and maturation in the late Roman period and Early Middle Ages

The avulsions studied in this research took place in a time period together with cultural and natural changes. To illustrate the wider context of this research, the present day insights on these cultural and physical causes of the collapse of the Western Roman Empire and the onset of the Dark Ages of the Lowlands are reviewed (paragraph 2.1). Thereafter focus is on the process of avulsion; the drivers, deposits and dating of avulsions are described (paragraph 2.2) and river maturation and existing river phase models are discussed (paragraph 2.3). The present day knowledge on the onset and development of the selected rivers in the Dutch river plain area during the studied period and the existing underlying ^{14}C-dates are reviewed in paragraph 2.4. Figure 2 shows an overview of relevant time periods and ages used in this thesis.

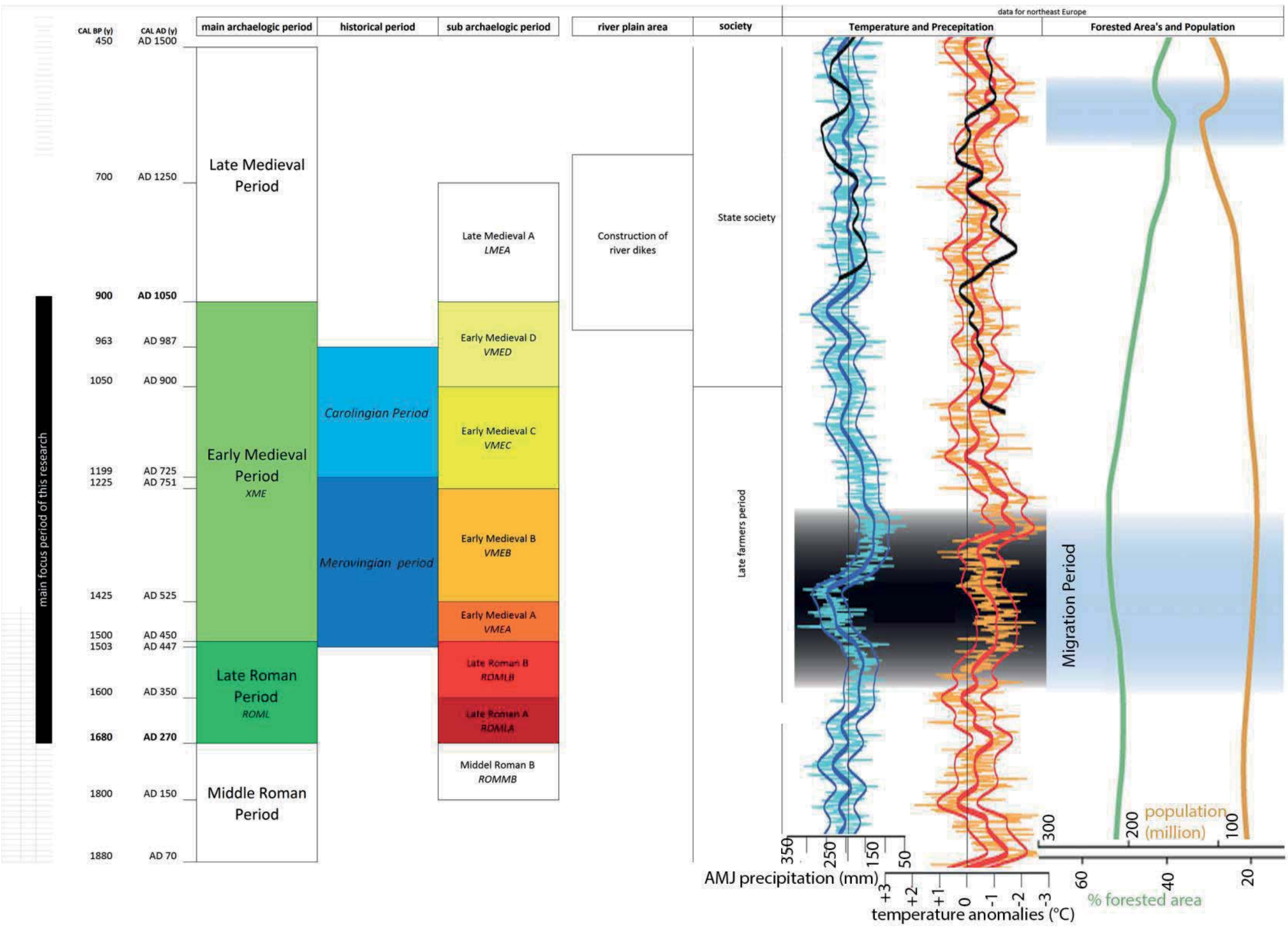


Figure 2 – Division of archeological time periods in the Netherlands. Associate ages in calibrated ^{14}C years before present (BP) and as calendar years anno Domini (AD). Showing main time periods in green, historical periods in blue and archeological sub periods in red to yellow. Abbreviations are indicated in italic. The period boundaries are according to ARCHIS and based on Stouthamer et al. (2015). AMJ (*April-May-June*) precipitation and JJA (*June-July-August*) temperature anomalies according to Büntingen et al. (2011), black lines showing independent precipitation and temperature reconstructions. Forested area and population of NW-Europe according to Kaplan et al. (2009) adapted by Stouthamer et al. (2015).

2.1 Collapse of the Western Roman Empire and onset of the Dark Ages of the Lowlands

During the studied period of frequent avulsions, also other environmental changes took place together with cultural changes, which were in several cases related. The collapse of the Western Roman Empire seems to coincide with dramatic land-use changes, changes in settlement patterns and severe demographic decline in many parts of post-Roman Europe (Cheyette, 2008). A regression of agriculture and large scale reforestation for this period and pollen diagrams show a supporting sudden decrease in grasses and cereals *(Cerealia, Secale)*, (Louwe Kooijmans, 1974, Kaplan et al., 2009, Van Beek et al., 2015).

Traditionally, the end of the Roman period in The Netherlands was often associated with mainly cultural factors as the strategic withdrawal of the Roman Empire or the societal turmoil of the Large Migration Period (Büntgen et al., 2011). The Migration Period (AD 250 to AD 400) is known as the biggest historical crisis marked by political turmoil, cultural change (later on: feudalism) and socio-economic instability (McCormick, 2001 as cited by Büntgen et al., 2011). Next to a severe depopulation, trade networks collapsed (Jansma et al., 2014).

Preindustrial deforestation and population trends over the last 2500 years seem to mirror each other, indicating human landscape interference (see figure 2, Kaplan et al., 2009). Even though, by a lack of high-resolution paleoclimatic evidence, discrimination between environmental and anthropogenic impacts on past societies is still difficult (Büntgen et al., 2011), recent research increasingly illuminates the possible influence of natural or physical causes for the end of the Roman period

Climatic variations and changes in river regime

The shifting climate towards more cool and moist conditions (Van Geel et al. 1998) and two different early medieval cold periods discernible with a clear warmer period between them (Medieval Warm Period) around AD 400 and AD 800 (Ljungqvist, 2010), might be such a physical cause. Based on tree ring reconstructions, Büntgen et al. (2011) also found increased climate variability from BC 250 to AD 600 for central Europe.

Human impact on the environment was already extensive during pre-Roman times when agricultural activities and deforestation upstream in the Rhine catchment caused increased sediment input in the delta (Kalis et al., 2003; Erkens, 2009). This rapid deforestation caused the rise of groundwater levels (Erkens, 2009). From 300 AD onwards the frequency of peak discharges increases significantly after a relative calm period (Figure 3; Toonen, 2013). The increased sediment input and increased flood frequency is likely to be related to the observed severe river-network reorganization and increased around AD 300-400 (Stouthamer and Berendsen, 2000; Cohen et al., 2016; see paragraph 2.2 for a further elaboration on the relation between sediment load and avulsions).

More detailed insight on the timing and development of the physical landscape, as proposed in this research, is conditional for determination of the relationship of the physical environment on cultural changes ('physical determinism' as suggested by e.g. McCormick, 2001; Büntgen et al., 2011, Van Lanen et al., 2015). In the next paragraph drivers and deposits of avulsions and their relation to river channel development are discussed in more detail.

2.2 Avulsions and river channel development: drivers, deposits and dating

The formation of new channels and associated abandonment of existing channels is a process known as avulsion. For the Rhine-Meuse delta avulsions were the dominant process for formation of new channels, as for the eastern part meander chute cutoffs initiate mostly new river channels (Törnqvist, 1993). As such avulsion also plays a primary control on deltaic architecture (Stouthamer et al., 2011). When the discharge of the old channel is fully taken over by the new channel the avulsion is called full avulsion. In case the avulsion takes only over a part of the discharge the avulsion is called a partial avulsion (Stouthamer and Berendsen, 2000). Makaske (1998) also identified a failed avulsion, when the crevasse splay did not develop into a new channel belt. Independent on whether an avulsion is full, partial or failed, different drivers and triggers for avulsions can be distinguished.

Drivers and triggers

River dynamics is controlled by the supply of water and sediment and the accommodation space in the delta (Hobo 2015). Stouthamer and Berendsen (2000) qualitatively assessed the factors that influenced the occurrence of Holocene avulsions in the Rhine-Meuse delta to be respectively: (1) relative sea-level rise, (2) neotectonics, (3) increased discharge and/or within channel sedimentation and (4) human influence on a timescale of millennia. As this research focusses on river channel development in the first millennium AD, increased discharge and/or within channel sedimentation and human influence will have the most determining role on river channel development. A higher sediment load will lead to higher natural levees, which are more sensible to avulsions. Also shift of the apex upstream and expanding sea intrusions downstream may drive avulsions (Stouthamer, 2001; Pierik et al, *unpublished*).

On a smaller time scale, fluctuations in discharge or even a single large flood might onset or trigger avulsions (Cohen et al., 2009; Toonen, 2013; Cohen et al., 2016). Next to major floods, vegetation enrichment, ice-jam induced floodings, active tectonics, animals trails may also trigger the formation of an avulsion (Jones and Schumm, 1999). The independent data of timing of major floods (figure 3, Toonen, 2013) can be combined with existing river branch dating (e.g. Cohen et al., 2012) and may reduce dating uncertainties of the individual river avulsions (Cohen et al., 2016). Dating of channel belts will be discussed in the next paragraph.

Deposits and alluvial architecture

Crevasse splays are precursors for avulsions. After a breakthrough in the original natural levee , water and sediment are transported through this overflow spot only with high discharges. With successive high waters the crevasse splay develops and eventually might evolve into a new river channel. Figure 4 shows the three different stages of a crevasse splay and associated lithological architecture, a process which was observed both in the Cumberland Marches (Saskatchewan, Canada) by Smith et al., (1989) and in the Rhine-Meuse delta e.g. Makaske (1998) and Berendsen and Stouthamer (2001). For the Rhine-Meuse crevasse-splay complexes are found near the base of overbank deposits and consist of sandy material in the channels and silty and sandy clay deposits in distal areas (Stouthamer, 2001). The process of crevasse-splay formation is often gradual (Smith et al., 1998; Toonen et al., 2016).

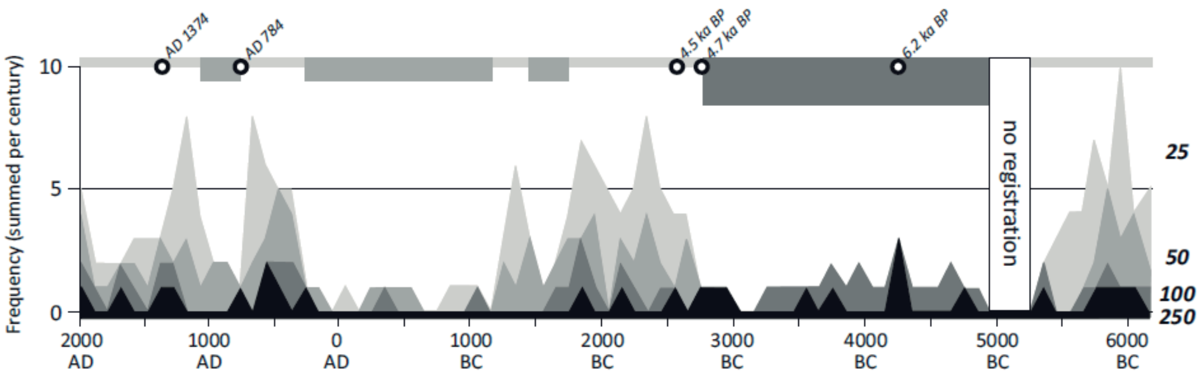


Figure 3 | **Flood frequency per century (Toonen, 2013).** Flood frequency per century illustrated by the frequency of various flood magnitudes, exceeding recurrence times of 250, 100, 50, and 25 years and respectively corresponding with black, dark grey, grey, and light grey. The figure shows relative more and relative larger floods for the period 300-800 AD. Increased flooding frequencies coincide with settlement abandonment and shifts in north-west Europe.

A
B
C

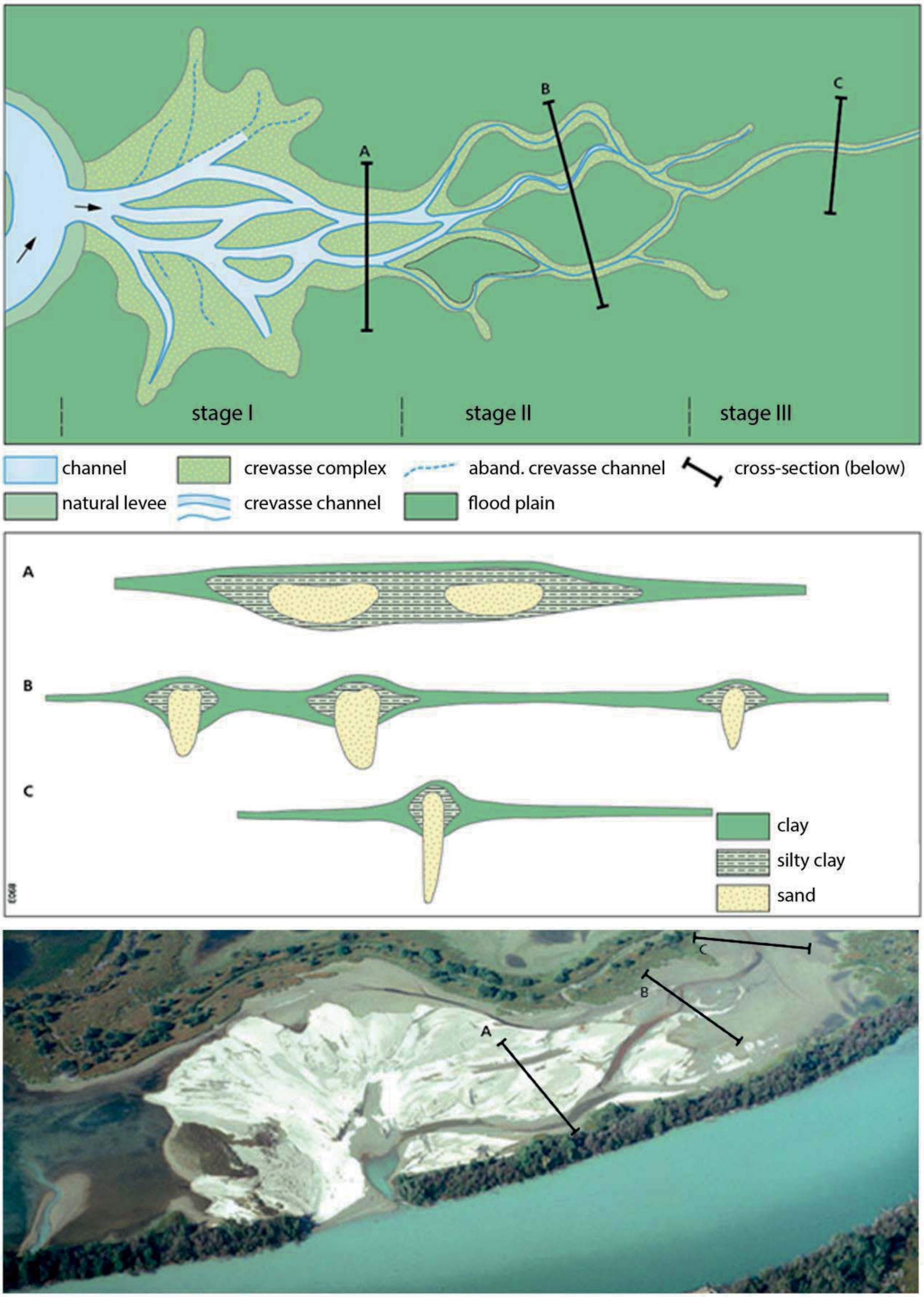


Figure 4 | **A crevasse splay (A) and its lithological architecture (B) (from Stouthamer et al., 2015).** Based on Smith et al., 1989. Below (4C): A natural crevasse splay in the Colombia River (foto: H.J.A. Berendsen).

For some situations avulsions are not related to crevasse splay deposits. Deposits might be eroded by the new channel , or deposits might have never been formed, as when an old channel has been reoccupied by the new channel Stouthamer (2001). Two types of reoccupations have been described by Stouthamer (2001): type-1, the new channel can reoccupied an existing, older channel, or type-2: the new channel reoccupies its own channel downstream.

Although much research has been done on the formation of crevasse splays, less research has been performed on the subsequent river channel development and its timing. In the next paragraph phasing of river channel development and maturation duration will be discussed in more detail. In the method section a new conceptual model of phasing of river channel development (river maturation) is introduced and linked to earlier river channel development phasing studies.

Dating of channel belts and avulsions

The relatively complete geological record, as a result of rapid aggradation during the Holocene, and the availability of a large and detailed database were underlying the avulsion-study of Stouthamer and Berendsen (2000). Most river avulsions (82 out of 91) were dated with an accuracy of ± 200 ^{14}C years. However, most avulsion dates are from one location per channel belt (near the avulsion point). To obtain insights on channel belt maturation after the avulsion in a high spatial and time resolution, more dates are required per channel belt.

Optimized sampling strategies for absolute dating of channel belts and avulsions have been described by Törnqvist and Van Dijk (1993; elaborating on Verbraeck, 1970; Berendsen, 1982), mainly focusing on obtaining relevant ^{14}C ages for beginning and end of activity of fluvial systems. This sampling strategy, still present-day practice, can be summarized in three idealized ^{14}C-sampling places (see figure 5A). Top of peat or organic beds underneath overbank deposits (*type-1* dating cf. Berendsen, 1982; number 1 in figure 5A) indicate the beginning of activity of fluvial systems. This type of dating can be considered as *terminus post quem* (TPQ, 'limit after which'). Because of the indirect dating of the underlying peat, the actual age of begin of sedimentation (or maturation) is somewhat after the TPQ-date (Cohen et al., 2016). Top-of-peat-datings yield longitudinal consistent ages, or a synchronous onset of overbank deposits, as over a distance of at least 20 km along channel belts dates are consistent (Törnqvist and Van Dijk, 1993).

Maturation of the river channel (Dutch: '*bloeifase*') is often indicated by a change in lithology (e.g. from heavy clay to sandy clay in the floodplain area), for which in a situation without organic material ^{14}C-dating is difficult. Cohen et al. (2012) proposed that distal clay sedimentation in the floodbasin could indicate the maturation of a channel. As dates close to the river could indicate first clastic inputs in the system and clay deposits at large lateral distance might indicate optimal clay transport towards the floodplains and hence indicates the presence of a mature river.

However, sampling close to the river channel might be prone to an erosion effect (and so result in relative older dates) or original clastic material might be reworked, especially for larger channel belts as the Nederijn and Waal for example. Törnqvist and Van Dijk (1993) presumed that the beginning of overbank sedimentation represents the start of significant activity of a river channel.

The end of fluvial activity can be dated by dating the base of residual channel fills (number 5, figure 5A; end-of-within-channel-sedimentation-date) or by dating the base of organic beds overlying overbank deposits (number 2, figure 5A; end-of-fluvial-sedimentation-date). Commonly, overlying-overbank ^{14}C-dates are younger than residual channels of the same fluvial system, indicating non-depositional unconformities (Törnqvist and Van Dijk, 1993).

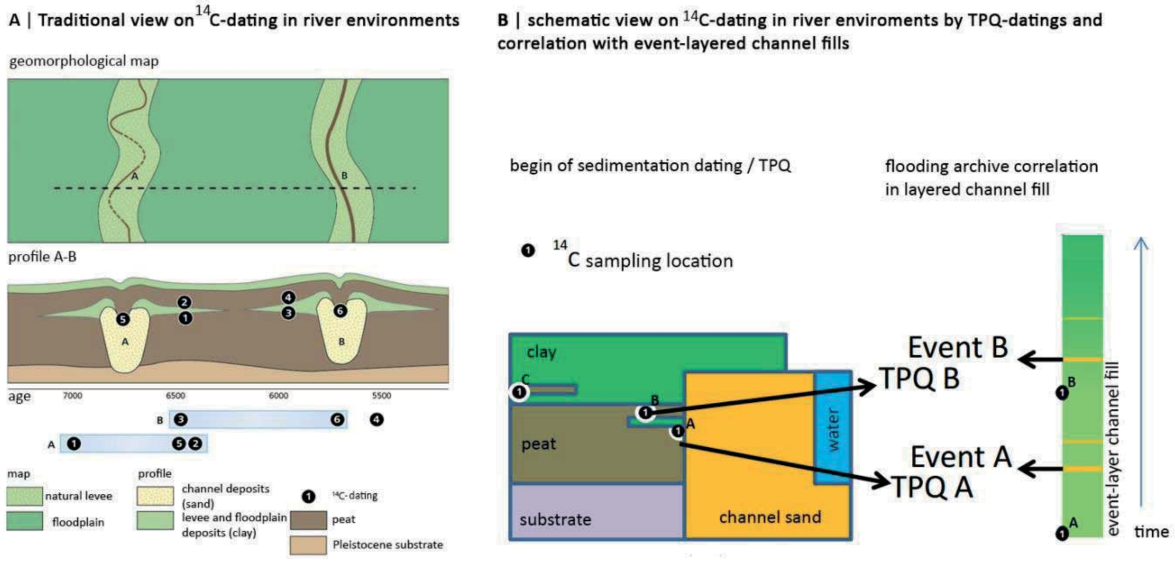


Figure 5 | **Views on ^{14}C-dating.** 5A showing the traditional view on ^{14}C dating in river environments (reworked from Stouthamer et al., 2015, after Berendsen 1982). And 5B as a schematic view on ^{14}C-dating in river environments by TPQ-datings and correlation with event-layered channel fills (after Cohen et al., 2016).

Uncertainties for ^{14}C-dating comprise not only laboratorial measurement uncertainties (displayed as 'visible uncertainty' ± behind a specific ^{14}C-date). The sampling, and in specific the subsampling might influence uncertainties into a greater extent than laboratory uncertainties, especially for old bulk samples, for which large sampling sizes of are not unusual. Also non-depositional unconformities, erosional contacts, deposition of reworked material, bioturbation, hard water effects and oxidation of peat might yield bigger uncertainties than laboratory uncertainty (Törnqvist et al., 1992). To be precise, problems with precision of the dating tend to overrule problems with accuracy (uncertainty).

Channel belts and associated avulsions might also be dated using relative dating methods such as cross-cutting relationships, relative depth of overbank deposits, elevation of calciumcarbonate-rich deposits and Gradient of Top channel Sand (GTS-) lines (reviewed by Berendsen, 1982; Berendsen and Stouthamer, 2000).

Cohen et al. (2016) indicated that begin of sedimentation dates presumably coincide with large floods. As large floods might be the onset for avulsions and river formations. Following the assumption of Cohen et al. (2016) 'active' residual channel, which are not filled up with peat already, might also contain flood signals (see figure 5B). These flood signals can be used as place independent, but event dependent dating. So large clastic peaks in a residual channel infill may represent the flood which caused the avulsion of the neighboring new channel.

2.3 Avulsions and river channel development: phasing and development duration

Phasing of river channel development

The cited river channel development phasing model is the one of Smith et al. (1989). The conceptual model consists of three phases in which a crevasse splay matures to a new river channel. The three phases are shown as plan view (figure 4A) and lithological cross-section (figure 4B). The model is scale independent, so it can apply to maturation of a crevasse splay on local scale as well as on the formation of a complete new river channel on delta scale.

To quantify the sedimentary dynamics for a mid-Holocene paleochannel with a modelling approach Hobo (2015) proposed a 4-stage life cycle of new channels initiated by avulsions (figure 6) The actual avulsion (Av), an initial meander stage (S1), a reworking meandering stage (S2) and a stage of abandonment (Ab). As this study focused on sedimentary dynamics each stage is defined by a specific sediment budget, amount of eroded older sediment and amount of sediment reworked by the channel.

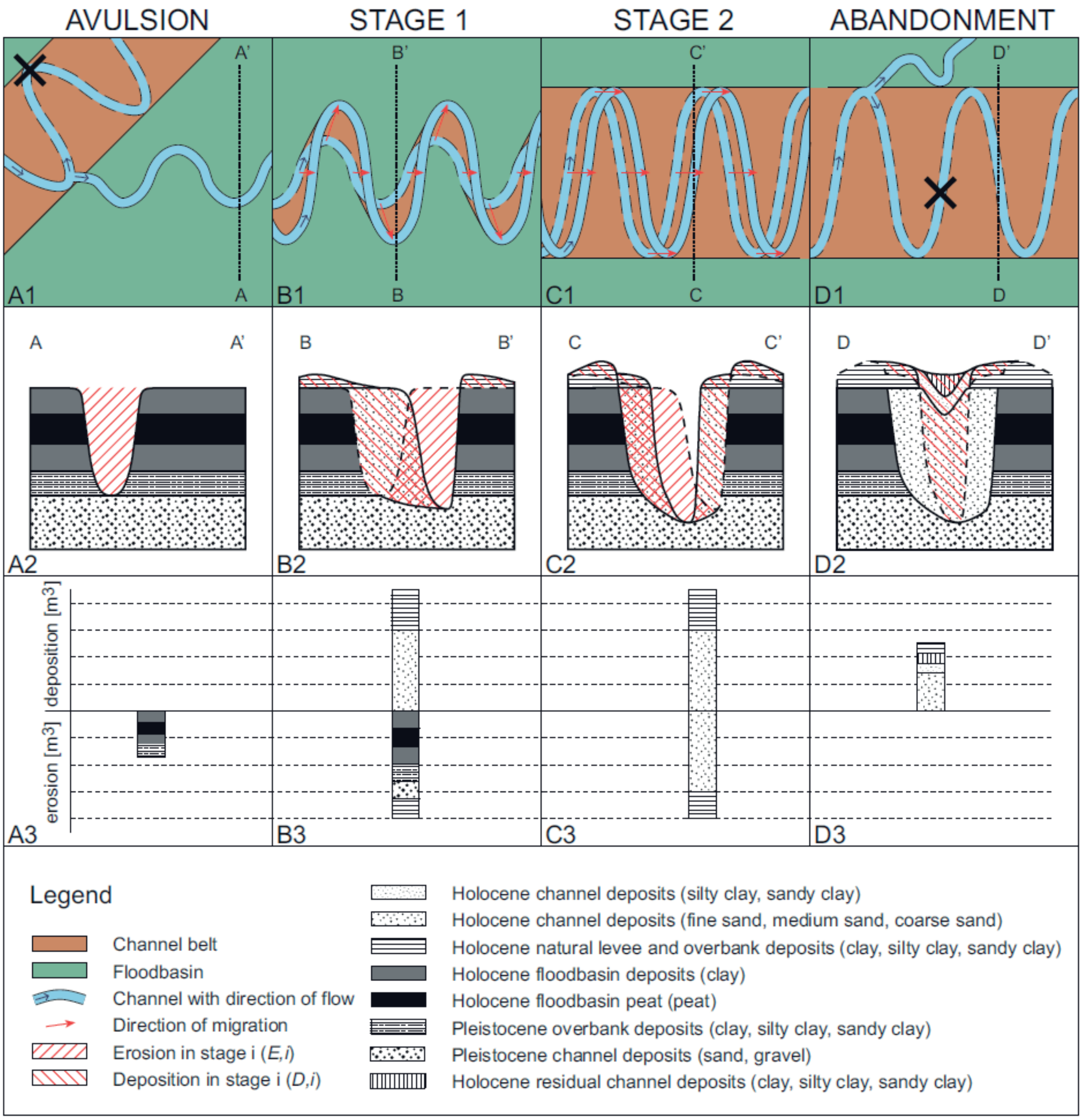


Figure 6 | **Development phases from a sedimentary dynamics view (Hobo, 2015).** The differences in direction, material and volume between the stages are schematized in a plan view (1), a cross-sectional view (2) and a budgetary view (3). Previous river courses are indicated by dotted lines. Time axis is indicative. Adopted from Hobo (2015).

Total avulsion pace and duration

For the Holocene Rhine-Meuse delta the period of activity or period of existence of all channel belts shows no significant trend and is highly variable. It averages 1280 ± 820 calibrated years (Stouthamer and Berendsen, 2001). The interavulsion period is defined as the time period between successive avulsions (Stouthamer and Berendsen, 2001). The interavulsion period averages 945 calibrated years and so is shorter than the period of existence (Stouthamer and Berendsen, 2001).

The time between the initiation of a new channel and complete abandonment of the previous channel is defined as the avulsion duration (Berendsen and Stouthamer, 2001). For the Rhine-Meuse delta, avulsion duration averages 335 calibrated years and fluctuates from less than 200 to 1250 calibrated years and remained constant till at least 1900 calibrated years before present. However, the majority of the newly formed channels in the Holocene Rhine-Meuse delta are considered to be partial avulsions and channels functioned simultaneously for a few hundred years (Stouthamer and Berendsen, 2001). As it takes several human generations for a new channel to form and to take fully over discharge of the parent river, an avulsion is a process that is rarely observed on a human time scale (Jones and Hajek, 2007 as cited by Van Dinter et al., 2016). When avulsion duration is more than 200 years the avulsion is defined gradual (Stouthamer and Berendsen, 2001). This number reflects methodological problems and the limited resolving power of ^{14}C-dating (Törnqvist and Van Dijk, 1993). Instantaneous and gradual avulsions do not necessarily coincide with full (complete shift of channel) and partial (new channel takes partially takes over discharge) avulsions .

In one of the first attempts to assess development duration of river maturation Hobo (2015) applied the Bank Stability and Toe Erosion Model (BSTEM) on the Hennisdijk system. Stage S1/phase II was modelled to have a duration of 827 years and stage S2/phase III to be 189 years. Hobo (2015) assumed that the period of activity, defined as the period between beginning and ending of sedimentation (Stouthamer and Berendsen, 2000), equals the total duration of stages S1 and S2 (phase II, III and if applicable IIIb). Still, the duration of the actual avulsion phase (Av/II) and abandoning phase (Ab) are assumed based on the maximum duration of a full instantaneous avulsion of 200 years given by Berendsen and Stouthamer (2001).

2.4 River channel development AD 300-1000 and underlying 14C-dates review

Paleogeography BC 500 and AD 300

Between AD 300 and AD 1000 the Dutch river plain area was characterized by major avulsions and severe river-network reorganization. The number of severe floods is known to be very low in the last century before Christ (see figure 3) and flood frequency shows a big increase from AD 300 onwards (Late Roman Period and Early Medieval Age). Rather than to an increase of discharge, the increase of avulsion is attributed to an increase in sediment supply and a related more efficient formation of natural levees (Cohen et al., 2016). The combination of major floods and a continued high sediment load (Erkens, 2009) is seen as driving mechanism to the large number of avulsions in the first millennium AD (Cohen et al., 2016).

Figure 7 is showing a paleogeographic reconstruction (Vos and De Vries, 2013) in which this collection of small precursor river branches is visible as well as a clear shift from the Utrecht river system to the Krimpen river system within the two time steps. Phasing of the end-phase of the Utrecht river system is carried out by Van Dinter et al. (2016).

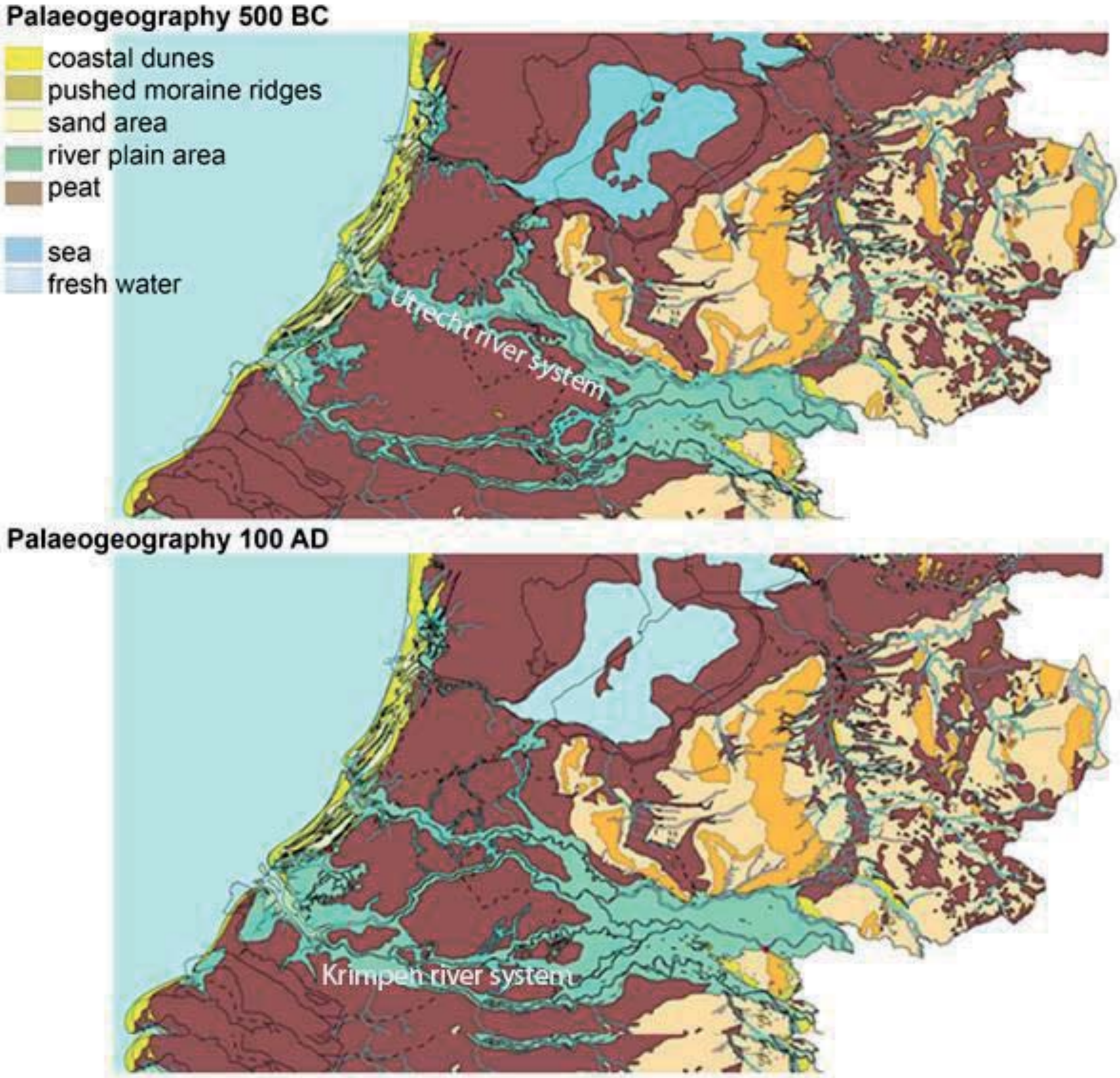


Figure 7 | **Paleogeography 500 BC and 100 AD of the river plain area** (Vos and De Vries, 2013). Showing the shift from the Utrecht river system to the Krimpen river system.

In an attempt to link river channel development further to large floods, Cohen et al. (2016) identified two clusters of major avulsions or begin-of-sedimentation-dates (*type-1 date*, cf. Berenden, 1982). The first one around 2200 ^{14}C years representing the onset of the Linge, proto-Waal (Bruchemse channel belt) and Ravenwaaij channel belts (Lek-Hollandse IJssel-system). The second cluster shows up around 2050 with TPQ-dates of 260 ±50 BC and 50 ±60 BC for major avulsions. It took some centuries before the Lek-Hollandse IJssel and Waal river systems reached the maturation phase (figure 8).

In the next section river channel development and underlying 14C-dates are reviewed for respectively de river Gelderse IJssel, river Nederrijn-Lek-Hollandse IJssel and river Waal. This reconstruction of river channel development AD 300-1000 is mainly based on the extended review of Cohen et al. (2012). Results of this review of underlying ^{14}C-dates for river channel development AD 300-1000 are summarized in table 1.

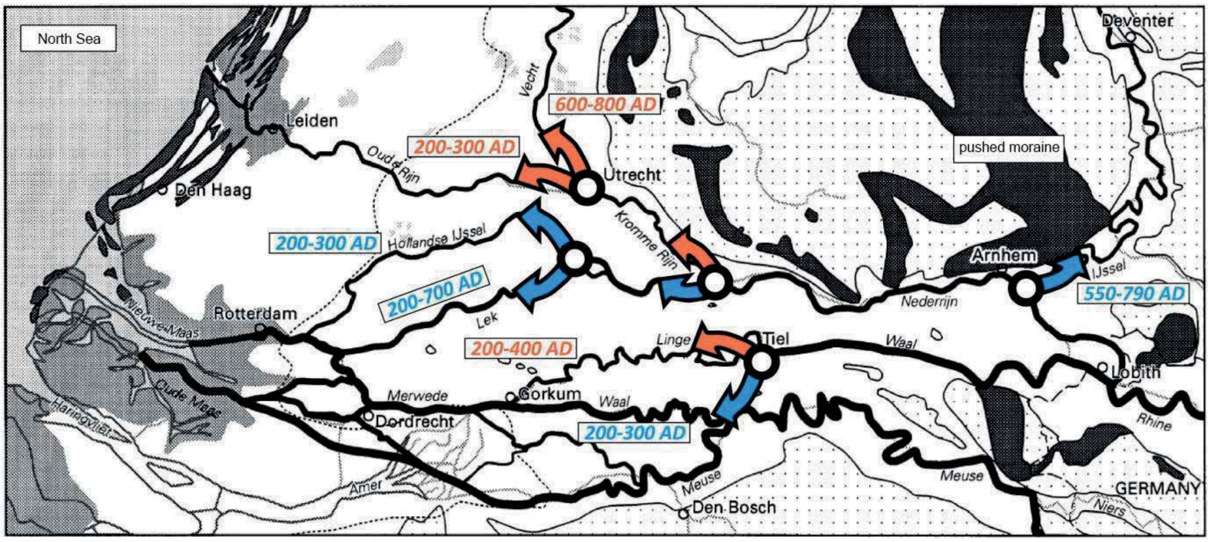


Figure 8 | **River dynamics and major river avulsions for the Rhine-Meuse delta for the first millennium AD.** Blue arrows indicate new river branches and corresponding period of beginning and blooming. Red arrows indicate older Rhine branches loosing discharge and abandoning stage. Cohen et al., 2016 after Berendsen and Stouthamer, 2000; 2001; Cohen et al., 2012).

River Gelderse IJssel

For the river Gelderse IJssel the studies of Makaske et al. (2008) and Cohen et al. (2009) both support an inferred early-medieval age and an (semi-natural; Cohen et al. 2009) avulsive genesis. However the studies differ with regard to the invoked avulsion mechanism and age determination: upstream deltaic levee breaching (Makaske et al., 2008) versus tributary reversion and drainage divide breaching (Cohen et al., 2009), mainly a derivative of different location of the watershed. Cohen et al. (2009) suggested further ^{14}C-dating of 'IJsselclay-on-peat'-locations at a closer distance to the river and locations closer to the crevasse-splay deposits to refine existing age determinations. The crevasse-splay deposits testify for a stage wise avulsion development (as described by Smith et al., 1989).

Table 1 | **Overview of begin age and maturation age of 5 major river branches of the Krimpen riversystem** (based on Cohen et al. (2012) and Cohen et al. (2016)).

River (#Cohen et al., 2012)	**Section**	**Begin age TPQ** *"beginfase"* oldest option	**Begin age TPQ** *"beginfase"* youngest option	**Mature river** *"bloeifase"*
Gelderse IJssel (#50)	*Arnhem-Zutphen* *Zutphen-Zwolle*	**314 ±48 AD** *1720 ± 25 yr BP GrN-7525* **509 ±50 AD** *1535 ± 30 yr BP GrA-38085*	**481 ±44 AD** *1575 ± 35 yr BP GrN-10293* **1260 ±23 AD** *780 ± 35 yr BP GrN-34961*	**700 AD to ± 950 AD** Cohen et al., 2012 **> 735 ± 62 AD** Cohen et al., 2016 >1295 ±35 yr BP
Nederrijn (#116)	*Wijk bij Duurstede - Nieuwegein*	**646 ±126 BC** *2540 ± 100 yr BP GrN-16819*	**477 ±55 AD** *1585 ± 50 yr BP GrN-7266*	-
Lek (#68)	*Nieuwegein - Krimpen a/d Lek*	**293 ±103 BC** *2220 ± 35 yr BP GrN-8708*	**50 ±35 AD** *1950 ± 30 yr BP GrN-8707*	**300 AD – 800 AD** Berendsen, 1982 **± 700 AD** Cohen et al., 2016
Hollandse IJssel (#91)	*Nieuwegein - Krimpen a/d IJssel*	**96 ±75 AD** *2070 ± 60 yr BP*	**217 ±73 AD** *1805 ± 50 yr BP GrN-7577*	**< 800 AD** Cohen et al., 2016
Waal (#174)	*Tiel - Gorinchem*	**206 ±67 AD** *1815 ± 50 yr BP GrN-6993*	**465 ±56 AD** *1600 ± 50 yr BP UtC-1899*	**> 450 AD** Cohen et al., 2016

It can be assumed that the IJssel avulsion contrasts to the majority of avulsions known from elsewhere in the Holocene river delta, since: (1) the position of crevasse-splay deposits is separated from the position of the channel bifurcation, (2) the channel belt architecture differs for the most upstream part compared to the more downstream reaches of the IJssel, as the upstream part is more incisive, (3) deviating direction in the upstream part (backwards to the east) and (4) the fact that it was an annexation of a new part of the Holocene delta area (Cohen et al., 2009). All having implications for the mechanisms that caused this particular avulsion to succeed and the river IJssel to mature from crevasse-splay to meandering channel belt (Cohen et al., 2009). The suggested avulsion triggering mechanism by Cohen et al. (2009), a single 'millennium-megaflood' of the river Rhine breaking though a Pleistocene sand ridge, was critically different. However, the processes of channel belt maturation that followed the initial stages is expected to be similar to the avulsions elsewhere in the Rhine-Meuse delta (Cohen et al., 2009). The time lag, indicated by the downstream decreasing age of fluvial sedimentation found by Makaske et al. (2008) as well as Cohen et al. (2009), is interesting in the scope of this research.

Dates of the upstream reach of the Gelderse IJssel (e.g. 2000 ±65 yr BP (GrN-5491); 1830 ±110 yr BP (GrN-11894); 1720 ±25 yr BP (GrN-7525); 1575 ±35 yr BP (GrN-10293)) can be considered as accumulating slack water clay of the Nederrijn in the old valley of Oude IJssel (Cohen et al., 2012). This clay is indicating the extension of the delta floodplain towards the Deventer-Zutphen watershed. Following the discussion before, for this research only the lower part of the river IJssel (*Deventer-Zwolle-Ketelmeer*) is taken into account. For the river Gelderse IJssel a lateral age trend has been suggested by Cohen et al. (2012) as dates show rejuvenation in dates from close (1930 ± 165 yr BP (GrA-42389); 1295 ±35 yr BP (GrA-44639)) to great distance (1026 ±43 yr BP (UtC-14774); 980 ±35 yr BP (GrA-34964); 780 ±35 yr BP (GrA-34961) proximal to the channel belt. However, for the latest date (GrA-34961) pollen data seems to suggest a late Subboreal age, as no indications of human activity were found in the pollen data (Brijker and Van Zijverden, 2009) and a medieval age of this sample seems unlikely. So, comparing dates just only on the age values without assessing the applied method and sequence will not give a reliable analysis of lateral development of the channel belt.

For the downstream reach (*Deventer-Zwolle-Ketelmeer*), dates of changes in peat type (1535 ±30 yr BP (GrA-38085) 1350 ±30 (Poz-20197)) seem to be in agreement with palynology of thin humic clays below Gelderse IJssel deposits and dendrochronological dating of a drowning oak forest at Zwolle (Kooistra et al., 2006 as cited by Cohen et al., 2012) and are interpreted to represent initial spills of Rhine water (Cohen et al., 2012). It took the river Gelderse IJssel up to ca 1295 yr BP (700 AD) to establish a permanent channel through the divide near Zutphen-Deventer and up to 1142 yr BP (900 AD) for entering the fully mature phase, according to Cohen et al. (2009). Difference between the later changes in peat type (1535±30 yr BP) and the establishment of the permanent channel (clay-on-peat dating of 1295 yr BP) indicated a hiatus between the first hydrological signal and the first sedimentological signal of de Gelderse IJssel. Cohen et al. (2012) proposed a shallow channelization of the drainage divide as a plausible explanation.

Rivers Nederrijn- Lek, Hollandse IJssel- and residual channel Linschoten

The river Nederrijn has some diffuse underlying dating evidence and so far has mainly been dated based on ^{14}C-dates related to the downstream river Lek and clay on peat dating near the IJssel-Nederrijn bifurcation (Cohen et al., 2012). Based on dating of a residual channel near Arnhem the beginning of sedimentation was dated at 2540 ±100 ^{14}C yr BP (GrN-16819). However, near the relatively close city of Elden 1585 ±50 ^{14}C yr BP (GrN-7266) was received as date for the beginning of sedimentation by conventional bulk ^{14}C-dating (of humic clay; Willems, 1986). Oldest archaeological traces are from Early and Late Middle Ages, although some Roman and Iron Age traces have been found on erosional remnants of former channel belts (Cohen et al., 2012). For the downstream part of the river Nederrijn (*Wijk bij Duurstede – Vianen/Montfoort*) TPQ-dates of 2220 ±35 ^{14}C yr BP (293 ±62 BC; GrN-8708; river Lek; Berendsen, 1982) and alternatively the slightly younger 2070 ±60 ^{14}C yr BP (96 ±75 BC) are listed by Cohen et al. (2012).

For the river Lek begin of sedimentation started at 1950 ±30 ^{14}C yr BP based on the clay-on-peat transition near Nieuwegein (peaty clay; Berendsen, 1982). Downstream near Willege Langerak Berendsen found an older age for the clay-on-peat transition of 2220 ±35 ^{14}C yr BP (clayey peat; Berendsen, 1982). Based on changes in lithology and assuming linear sedimentation rates, Berendsen (1982) proposed an increase of discharge between 300 AD and 700 AD. By 1774 BP precursor river Kromme Rijn has lost discharge to the developing of the river Lek (Van Dinter et al., 2016). Cohen et al. (2016) linked the older begin of sedimentation age to a large Late Roman age flood (transition from 3rd to 4th century) and the younger begin of sedimentation age to a series of floods in the Early Merovingian Period.

Begin of sedimentation for the river Hollandse IJssel has been dated at 1805 ±50 ^{14}C yr BP (GrN-7577, Berendsen, 1982) using a peat bulk sample. It is known from historical sources that the Hollandse IJssel was already existing before 800 AD (Cohen et al., 2012). As concluded from Roman archaeological founds, the river Linschoten was no longer draining water in the first and second century AD, which according to Cohen et al. (2012) implies a somewhat earlier onset then the age of 1805 ±50 ^{14}C yr BP found by Berendsen. This slightly earlier onset also seems to fit in the paleogeographic development of the Rotterdam estuary. Roman sherds and bones in the lower part of the channel fill of a crevasse channel known as 'Mare' were dated at 1845 ±50y ^{14}C yr BP (GrN-17542; Berendsen 1990). Although interpreted as a Roman canal by Berendsen (1982), a large excavation showed no traces of digging and the Mare is interpreted as a natural crevasse channel of the Hollandse IJssel. By being a crevasse channel of the Hollandse IJssel, the Hollandse IJssel should be formed before 1845 ±50y ^{14}C yr BP. For the Hollandse IJssel also the older TPQ-date of 2070 ±60 ^{14}C yr BP (96 ±75 BC) was listed by Cohen et al. (2016).

End of sedimentation of the river Lange Linschoten is not accurately known, but though to coincide with the formation of the river Hollandse IJssel. As it is estimated (Cohen et al., 2012) that the river became active between 1800 and 1250 during floods, sedimentary signals of these flood peaks in the residual channel might be used as indirect dating for the river Hollandse IJssel.

River Waal and residual channel of Est

Beginning of sedimentation of the river Waal downstream from Tiel has been dated by Verbraeck (1984), by dating a vegetation horizon below fresh Waal clays, revealed an age of 1815 ±50y ^{14}C yr BP (GrN-6993). Which can be considered the oldest possible beginning of sedimentation age for the river Waal. Berendsen (1986) dated a thin layer of humic clay in a clastic bed to a comparable age of 1795 ±50y ^{14}C yr BP (GrN-12456). At the same location a date of 1655 ±50y ^{14}C yr BP (GrN-13504) was received from the humic clay (as an alkali extract). More downstream near Dalem, Törnqvist (1993) found a beginning of sedimentation age of 1600 ±50y ^{14}C yr BP (UtC-1899) by an AMS-^{14}C-date on a fragment of *Salix* wood in top of a thin peat layer. As the first two dates had a low organic content, the last two dates are considered more reliable (Törnqvist, 1993). Early to Late Middle Ages archaeological finds west of Tiel (Cohen et al., 2012) might indicate a minimal mature age of 450 AD.

The end of sedimentation of the Est channel belt was dated by Törnqvist at 2310 ±60y ^{14}C yr BP (GrN-12466) and 2190 ±60y ^{14}C yr BP (GrN-12465). The residual channel of Est was rejuvenated (Törnqvist, 1990). For the end of this rejuvenation phase a date of 1860 ±60y ^{14}C yr BP (GrN-12464) was obtained from a gyttja. This rejuvenation phase coincides with the begin of sedimentation age for the river Waal. The residual channel of Est might also consist of sedimentary signals of these flood peaks in the residual channel which might be used as indirect dating for the river Waal (Cohen et al., 2016).

3. Approach and Methods

To answer questions on the timing of development of the three new river branches between AD 300 and AD 1000 in a centennial time step resolution and on river channel maturation, more ^{14}C-dates along (longitudinal) the channel belts are needed. For this study, complementary fieldwork, sampling and lab-analysis as well as a GIS analysis are performed. The obtained results were compared to existing dates and existing paleogeographical reconstructions on the selected river branches.

In the first paragraph (3.1) a new river phase model will be introduced. This river phase model will be used to classify different ^{14}C-dates and will be used as stepping stone to integrate existing and new ^{14}C dates. Paragraph 3.2 focusses on the selection procedure for individual sampling sites, fieldwork procedures and used coring equipment. The application of loss-on-ignition as a ^{14}C-sampling strategy is elaborated in further detail (3.3) where after sampling on coring scale and laboratory analysis are outlined (3.4). Finally, the database setup and GIS-analysis used for the analysis of levee gradient lines and height of archeology are described (3.5).

3.1 General approach: a conceptual phase-model

A conceptual phase-model of river channel development (figure 9A) is presented as an attempt to relate river channel development to multidisciplinary dating methods (originating from historical sources, archeology, lithology, dendrology and type of ^{14}C-dates) and to assemble existing phase models of river channel development. The model also supports integration of existing and new ^{14}C dates, as it can be considered to be a framework to assign significance to different dates in a uniform way. The river phase model builds on earlier river channel development models of Berendsen (1982), Smith et al. (1989), Hobo (2015) and Van Dinter (2016). The conceptual phase model is based on paleogeographical or lithological defined phases with distinctive processes marking the transition from one phase to another. Focus of this research is on phase 0-III. Phase IV-VI are more comprehensively described by e.g. Van Dinter et al. (2016).

0. *Non-existence*

The new river branch has not formed yet. Not yet reached areas might consist of large scale peat formation or floodplain clay deposits from older rivers in an aggrading deltaic setting. The river is not mentioned in historical sources and tree rings do not show any hydrological stress yet, characterized by broad tree rings. This phase coincides with the 'end-phase'-date (e.g. date of infill of residual channel) the future abandoned channel.

I. *Crevasse-splay phase*

The initial bifurcation or avulsion is the onset of this phase. This phase can be linked to a major flood, which might be the actual trigger for the bifurcation. When the new branch does not reach the following phase, the avulsion can be classified as 'failed avulsion' (Stouthamer and Berendsen, 2000). The phase corresponds to the Av-phase of Hobo (2015, figure 6). This phase can be seen as the onset of hydrological change. As the new crevasse or embryonal river might have a hydrological effect on the area, without leaving (a significant) sediment signal in the sediment record. From a dendrological point of view, tree rings might show a light stress as a response to hydrological changes. As the phase model of Smith et al. (1989) is independent of spatial scale, this phase can be seen as a combination of stage I-II-III together on local scale, or stage I and II on a larger scale (see also figure 4).

II. *Bifurcation or partial avulsion phase – 'groeifase'*

In this stage the crevasse splay develops to a major river. Flood basin peat, and clay deposited by older river systems, and older channel belts and eventually the underlying Pleistocene sand deposits are eroded. Stouthamer et al. (2011) reconstructed that it took a few hundred years for a new channel to reach stable dimensions. After an initial more erosional phase, the river starts meandering and starts to build its own channel belt (ST1-phase; Hobo, 2015). The new branch is taking over discharge of the old main channel. This phase is often dated with *type-1* (cf. Berendsen, 1982) dates, or by dating clay-on-peat contacts. The first clastic input will be visible in the loss-on-ignition curve (see paragraph 3.3). Phase II coincides with the transition (either gradual or abrupt) from high to low LOI-values. From historical data the new channel might be mapped or there might be references to river toponyms. At the end of the phase first human occupation (probably on the levee) might occur. Tree rings show stressed wood and dendrochronological dates ('end-wood') mark this phase. When the older channel does not completely lose discharge the river remains into phase II and can be considered a bifurcation or partial avulsion (Stouthamer and Berendsen, 2000).

III. Major river phase IIIa – 'bloeifase'

This phase coincides with the S2 stage of Hobo (2015) in which the channel starts to rework its own deposited material and so there is no longer erosion of flood basin material, but erosion of the river's own sandy deposits. As meander migrations rates are high in the eastern part, the rivers might develop fast from stage S1 to S2 (phase II to III in this model). In contrast to the western part of the delta, as cohesive floodplain deposits and erosion resistant levees might cause S1/II to take such a long time it might even not be reached before the next avulsion takes place (Hobo, 2015). The onset of the major river phase can be dated using a sequence of dates proximal (close to further away) from the river (Cohen et al., 2016). The onset of phase III is also clear in the LOI-curve as the stabilization of low LOI-curves. When the river reaches phase III it can be considered a full avulsion or 'major' avulsion (Stouthamer and Berendsen, 2000).

Major river phase IIIb – external driven phase

This external driven phase is optional. Extra discharge, increasing discharge or lower discharge due to upstream avulsions (and so partial loss of discharge/sediment) are the processes after which the river can reach this phase. This phase is visible as change in lithological signal, as an increase of clastic signal in the LOI-curve for example. It can also be defined by historical data as major floods or decreasing discharge also influences trade and major cities along the river. As so, decreasing discharge might also be the onset for phase IV; the abandoning phase of the river.

IV. Abandoning phase

This phase starts when the matured channel has become abandoned by a subsequent upstream avulsion. For the stage model of Hobo (2015) this stage (Ab) is defined by the end of reworking of channel deposits due to the decreasing flow. The river is still carrying water, but trade and trading cities are declining. This phase is referred to as shallowing-phase by Toonen et al. (2012) as the river is trapping sediment by reduced flow velocities.

V. Abandoned phase

In this phase the channel is not connected to the new formed channel anymore. The residual channel can be considered to be a stagnant water and gyttja and eventually peat might form in this water. In case of major floods, sand and clay might be deposited in the channels, as a result of a temporarily reactivation of the channel.

VI. Burried residual channel

The life cycle of the channel has come to an end and the residual channel is buried with clastic material from neighboring rivers or other sediments.

Figure 9B shows a plan view of each phase. As figure 9C shows, different phase of different river channels coincide, which can also be used to integrate different types of ^{14}C dates of different rivers.

Conceptual River Phase Model

Figure 9A | Description of each Phase

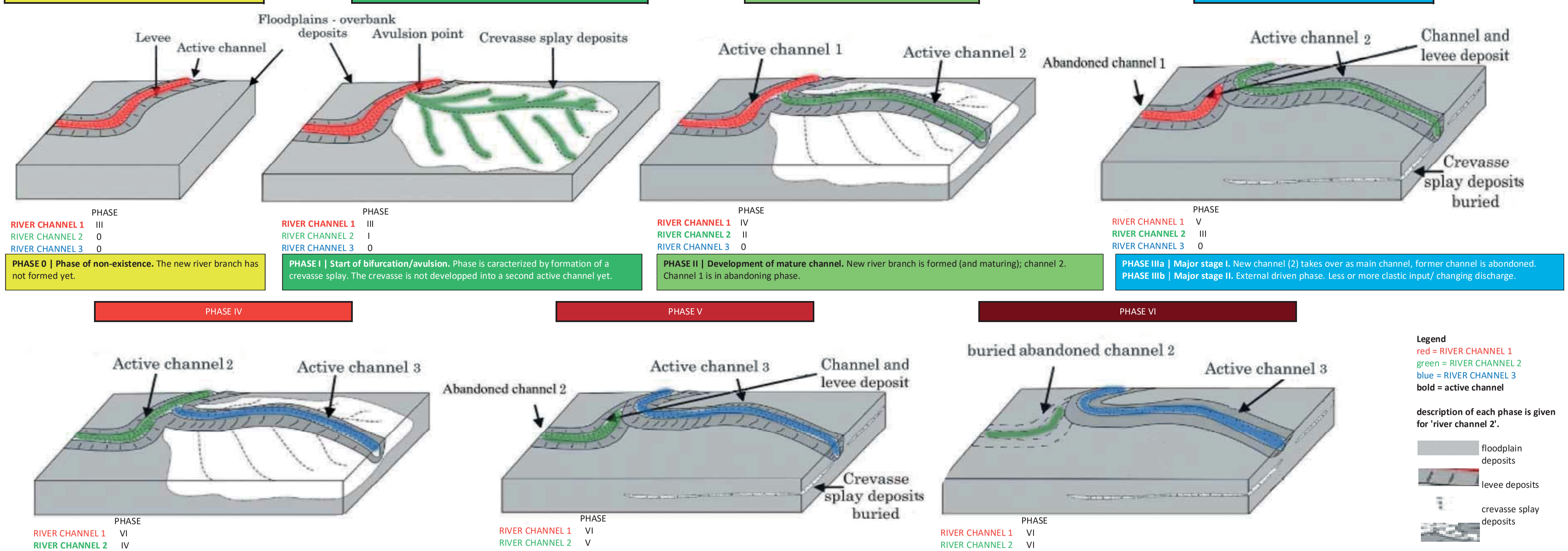
Scale	Phase	Description	Historic sources and toponyms	Archeology	Lithology / Sedimentary legacy	Dendrology	Type of (C14-)dating	Time Q = Qualitative, M = modelled	van Dinter et al. (2015)	Hobo et al. (2015)	Konijnendijk	Smith et al. 1989 see figure L3
-	0	**Non-existence.** The new river branch has not formed yet. Not yet colonized areas might consists of large peat formations or floodplain clay deposits from previous rivers.	not mentioned	lacking on specific stratigraphic level	large peatlands, local brook valley deposits	no stress signal in tree-rings	end-phase dating of 'parent'-river					
local	I	**Start of bifurcation, breakthrough moment, avulsion by formation of crevasse splays.** Maturation of the crevasse splay.	major flood which migh be on set		Only visible in local sediment record (crevasse splay deposits), No regional lithological signal.	ligth stress in direct surroundig	dating of top peat under crevasse deposits (mind erosive contact!), OSL on crevasse deposits					stage I-II-III
regional	II	**Bifurcation / partial avulsion phase.** New river branch is forming, characterised by erosion in the main channel, first clastic signal on 'flood plains'. New branch is taking over old main channel, increase of clastic signal (Dutch: "groeifase" river) .	mentioning of waterway, new channel is mapped, reference to river in toponyms	first occupation (on levees or river)	start formation of natural levees, clay deposits in more distal floodplains	stressed wood	dating clay-peat contact: *beginning-of-sedimatation*-date (first clay input in LOI-curve)	**Q** <200 hundred years instantenous (Stouthamer et al. 2011) **Q** >200 for gradual avulsion (Stouthamer et al. 2011) **M** 827 years (Hobo et al. 2015) **Q** 'relatively rapidly' (Jones and Schumm, 1999)		Av ST1 starts meandering and, netto sedimentation		
regional	III	**Major river stage I** (Dutch: "bloeifase" river), sedimentation in delta, old channel is abondoned. River is 'navigable' (subjective criterion),	toponyms of trading city, river ports	occupation, relicts trade city/harbour, trade routes	maximum extent of levees (lateral and vertical)	end wood, eventually dating of harbour wood	blooming-date (significant clay input in LOI-curve)	**M** 189 years (Hobo et al. 2015)	0	ST2, netto recast		
regional	IIIb	**Major river stage II, external driven phase (optional).** Extra discharge/floods by changes upstream or lower discharge by upstream avulsions (and so partial loss of discharge)		change in levee settlements by flood or droughts	extra (or less) clastic input (higher discharge)/ change in clastic signal		dating of change in LOI-curve (assuming LOI inversely propotional to clastic input)		0	(renewed ST1>ST2?)	A	
regional	IV	**Abandonment stage of the river.** Discharge is taken over by the new river, the river is still containing water and navigable.	decline of trade for trading cities	still occupation of levees, as levees are relict high grounds			*end-of-sedimentation* -date		1	Ab	B	
regional	V	**Abandoned stage of residual channel.**			gyttja-formation, eventually clastic flood signals, start peat formation		dating of material start infill of residual channel		2+3 (reactivation)	Ab	C	
regional	VI	**Buried residual channel**. The residual channel is completely filled, no more open water remains.			buried with clastic material from neighboring rivers		dating top infill or relative dating from other river system		-	-	D	

Stouthamer and Berendsen (2000): period of existence channel belt / avulsion rate; avulsion duration I; interavulsion period; avulsion duration II; failed avulsion; partial avulsion; full avulsion / 'major' avulsion

discharge (indicative); hydrological signal; channel maturation; abondoning / degrading

numbers and letters refer to specific phase of authors

Figure 9B | Plan view of each phase (based on Ferreira do Nascimento et al., 2013)



PHASE: RIVER CHANNEL 1 III; RIVER CHANNEL 2 0; RIVER CHANNEL 3 0

PHASE 0 | Phase of non-existence. The new river branch has not formed yet.

PHASE: RIVER CHANNEL 1 III; RIVER CHANNEL 2 I; RIVER CHANNEL 3 0

PHASE I | Start of bifurcation/avulsion. Phase is caracterized by formation of a crevasse splay. The crevasse is not developped into a second active channel yet.

PHASE: RIVER CHANNEL 1 IV; **RIVER CHANNEL 2 II**; RIVER CHANNEL 3 0

PHASE II | Development of mature channel. New river branch is formed (and maturing); channel 2. Channel 1 is in abandoning phase.

PHASE: RIVER CHANNEL 1 V; **RIVER CHANNEL 2 III**; RIVER CHANNEL 3 0

PHASE IIIa | Major stage I. New channel (2) takes over as main channel, former channel is abondoned.
PHASE IIIb | Major stage II. External driven phase. Less or more clastic input/ changing discharge.

PHASE: RIVER CHANNEL 1 VI; **RIVER CHANNEL 2 IV**; **RIVER CHANNEL 3 II**

PHASE IV | Abandonment of the former main active channel (channel 2). New river branch is formed (and maturing); channel 3. Channel 1 is a buried residual channel (may take some more generations of avulsions).

PHASE: RIVER CHANNEL 1 VI; RIVER CHANNEL 2 V; **RIVER CHANNEL 3 III**

PHASE V | Abandoned stage. River channel 2 still exists as water body. Processes: gyttja-formation, eventually clastic flood signals and start peat formation. River channel 3 is new major active river.

PHASE: RIVER CHANNEL 1 VI; RIVER CHANNEL 2 VI; RIVER CHANNEL 3 III

PHASE VI | Buried residual channel. Channel 2 is a buried residual channel (may take some more generations of avulsions).

3.2 Sampling site selection and field sampling

New data was gathered during fieldwork in July 2013 (river Gelderse Ijssel – Vreugderijkerwaard) and April 2014 (other sampling sites). Part of the data was received from fieldwork assessed and carried out by Harm Jan Pierik in 2013 (river Hollandse IJssel and river Lek) and results are incorporated in this study. We combined new and existing dates to obtain sites of at least three locations, ranging from distal to proximal environments relative to the avulsion point, possible sedimentation (maturation) patterns might be found in downstream direction. The sites for dating were mainly selected based on the abundance of a clay on peat transition representing the beginning of overbank sedimentation and the age of formation of the associated channel belt, as the formation of a new channel by avulsion is accompanied by widespread sedimentation which stops peat growth (Berendsen 1983; Törnqvist & Van Dijk 1993).

Suitable locations were found by examining existing cross-sections, maps and borehole descriptions. Existing cross-sections (e.g. Gouw & Erkens, 2007) and new cross-sections based on existing data (LLG-database Utrecht University, DINO-database TNO) and associated age analysis (e.g. Berendsen and Stouthamer, 2001) were evaluated on their (14C-) sampling locations to ultimately facilitate selection of optimal new sampling locations. Using the sand-depth maps of the central and upper Rhine-Meuse delta (Cohen et al., 2009) and high resolution digital elevation map (Actueel Hoogtebestand Nederland, AHN) the overbank sediment-on-peat sequences along the selected river branches were systematically examined on the absence of disturbing crevasse deposits. We additionally used borehole querying (a minimum of 40 cm levee deposits on a minimum of 20 cm peat) from the LLG-database (Utrecht University) for an automatic selection of this overbank sediment-on-peat sequences. When areas with suitable sites were identified, detailed individual core descriptions were inspected to exclude sites with a discrete stratigraphy or an erosional silt-on-peat or clay-on-peat contact.

Coring and field observations have been done using the LLG-UU-fieldwork protocol (Berendsen, 2010). For sampling the Boncke-modified Livingstone piston corer (diameter 6 cm) or a Dutch gauge with a diameter of 4 cm (inner diameter 3.5 cm) was used. Samples might be slightly compressed during sampling. For lithological description the texture classification of De Bakker and Schelling (1989) was used. We sampled intervals with a gradual stratigraphical clay-peat sequence to avoid sites with erosion. Samples were stored in sealed PVC-tubes and kept at 7°C to minimize after sampling oxidation.

3.3 The application of Loss on Ignition (LOI) as a C-14 sampling strategy

Loss-on-ignition is a method for estimating the organic and inorganic content of sediments, mainly based on the fact that ignition of the sediment at 500-550°C results in the chemical conversion of organic matter in CO_2 and ash. So organic rich sediments result in high LOI-values. The lab procedures are extensively described by Heiri et al. (2001) and can be found in appendix A1.

LOI has been used in previous studies to identify flood events (Toonen, 2013), for core-to-core validation (Konijnendijk, 2010) or to improve age-depth models of fluvio-lacustrine deposits (Nesje et al., 2001; Minderhoud et al., 2016). Figure 10 shows the application of LOI for the identification of different stages of infilling of a residual channel. In the case of identifying flood events, the input of clastic material will be indicated by a decline or drop in LOI-values. The presence of more clastic material during flood events will reduce the relative contribution of organic material in a sample. LOI is a helpful tool for identifying gradual sedimentary variations as selection based on the eye easily become selections based on color over actual changes in lithology. LOI-based subsampling is more accurate and verifiable.

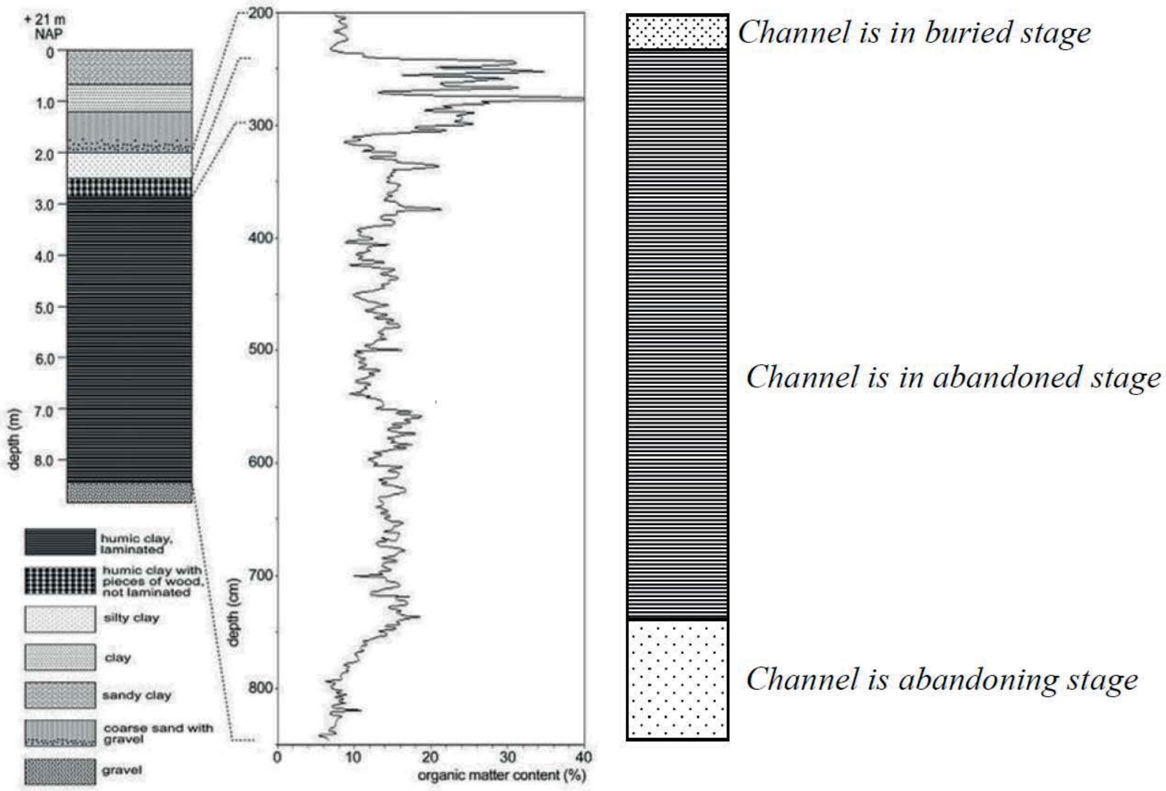


Figure 10 | Stages of infilling of a residual channel based on organic matter content obtained by loss on ignition. The figure is showing lithology, organic matter content (%) and stages of infilling. The transitions between stages are defined by changes in organic matter content. Around 550 cm below surface a shift in background sedimentation rate, which is interpreted as indicating a channel in abandoning stage (Minderhoud, 2008), can be observed.

Besides the use of LOI for ^{14}C sampling as it can be used to identify different phases (figure 11), and possible oxidation. In case of oxidation of peat, the LOI-graph will become relatively steep. Figure 11 shows the received profile and a hypothetical original LOI-curve, showing the effect of oxidation. LOI-curves themselves might also be used to correlate phases of different river branches. However, as LOI-curves always show a local lithological footprint, generalization on river scale based on LOI-curves must be taken careful. For each LOI-curve also moist percentage and predicted LOI (empirical formula drawn by W.Z. Hoek, see next paragraph) are depicted.

Although not directly related to river channel maturation, small peaks in LOI-curves of residual channels might support the hypothesis of Cohen et al. (2009) of a 'millennium-mega flood' forcing the IJssel-avulsion or any new avulsion in general.

3.4 Coring scale sampling and laboratory analysis

In the laboratory the cored samples were split in half along the long side. The cores were photographed and again described, on the lithological texture, color and particularities (e.g. presence of concretions, freshwater shells, or disturbance by fresh root fragments) in a centimeter resolution. Continuous samples with a 1 cm interval were taken for determination of organic content by *loss on ignition* (LOI) of the peat-clay intervals.

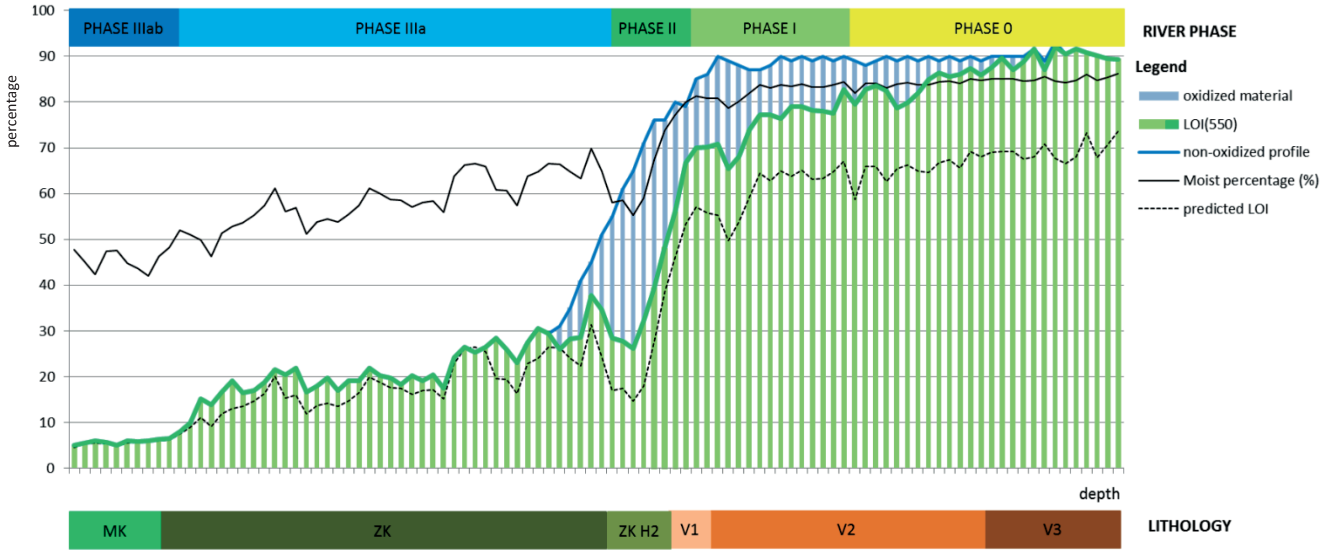


Figure 11 | **The use of Loss-on-ignition for ^{14}C-sampling.** A hypothetical LOI-curve showing relation between LOI-curve and river phases. Sampling based on lithology would have resulted in a different sub-sampling selection, as the actual transition is on the edge of V1 and ZK H2. Also showing moist-percentage of the sample and predicted LOI based on work of W.Z. Hoek (unpublished).

The samples were prepared for AMS ^{14}C dating by removing clastic and calcareous matter and so selecting organic material (see Appendix A1 for the exact procedure). Samples have been examined on macrofossils by Nelleke van Asch of ADC ArcheoProjecten before sending them to Centre of Isotope Research for Radiocarbon Dating in Groningen. More information on sample treatment and measuring ^{14}C using an Accelerator Mass Spectrometer (AMS) can for example be found in Bayliss et al. (2004). For calibrating the ^{14}C dates the OXCAL calibration curve (Reimer et al., 2013) was used. For successive dating in single cores the calibration was refined using sequences dating. Dates are given as cal. BP (calendar years Before Present = 1950), and as historical dates (yr BC/AD), in order to compare with other geological, and archaeological/dendrochronological studies.

3.5 Spatial analysis and data base set-up

As the amount of available ^{14}C-dates has increased over the past years, a first attempt is made to asses timing of the onset of floodplain sedimentation in a longitudinal and lateral direction. For the spatial analysis, using ArcGIS (Esri; version 10.3.1), only ^{14}C-dates were taken into account for which the corresponding lithological cross section or lithological sequence was available. Using the before proposed conceptual river phase model (paragraph 3.1), different dating-phases were appointed to the ^{14}C-dates. Line axis through the river channel belts were drawn based on the AD 900 levee reconstruction map (Pierik, *unpublished*).

Using ArcGIS function *locate features along route,* the longitudinal distance (*MEAS*) was calculated to the upstream avulsion node (or designated downstream point as for the river Gelderse IJssel). Using ArcGIS function *point to line* lateral distance was calculated. Figure 12 is showing the used ArCGIS-functions.

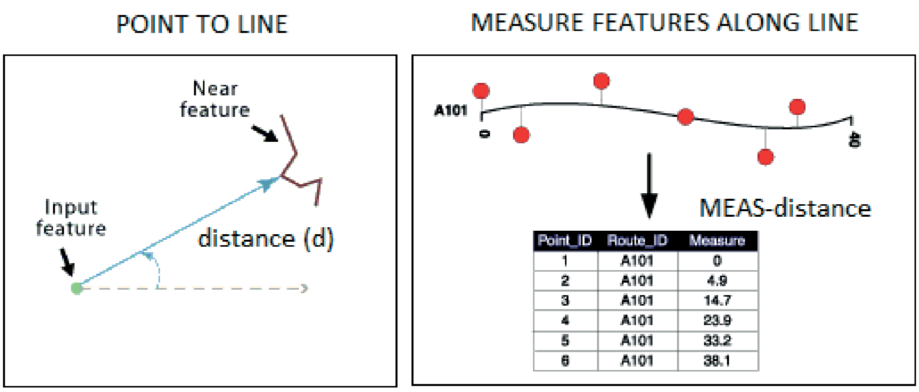


Figure 12 | **ArcGIS function point to line and locate features along route.**

4. Results

In this results section first, corings, corresponding lithological profiles, LOI-curves and ^{14}C-results are shown for the river *Gelderse IJssel* (section 4.1), river *Waal* and residual channel of *Est* (section 4.2) and river *Nederrijn-Hollandse IJssel/Lek* (section 4.3). Each section ends with a synthetic interpretation on regional river channel development setting and interpretation of LOI-curves. Then results of the longitudinal and lateral spatial analysis are given in section 4.4. Existing and new ^{14}C-dates are assembled in this analysis based on the river phase model (figure 9). Information on the classification of all ^{14}C-dates for this analysis can be found in appendix A6. Location of sites relative to each other are depicted in figure 12. Light green spots indicate fieldwork locations conducted for this research and dark green sites are of the consonant fieldwork by H.J. Pierik, of which the results are also included in this research. Lithological core descriptions of corings conducted for this research can are outlined in appendix A3. Factsheets, on which results are combined for each coring location can be found in appendix A4-I to A4-IX. All ^{14}C-results (meta information, dated material, raw data and calibrated ages) can be found in appendix A5.

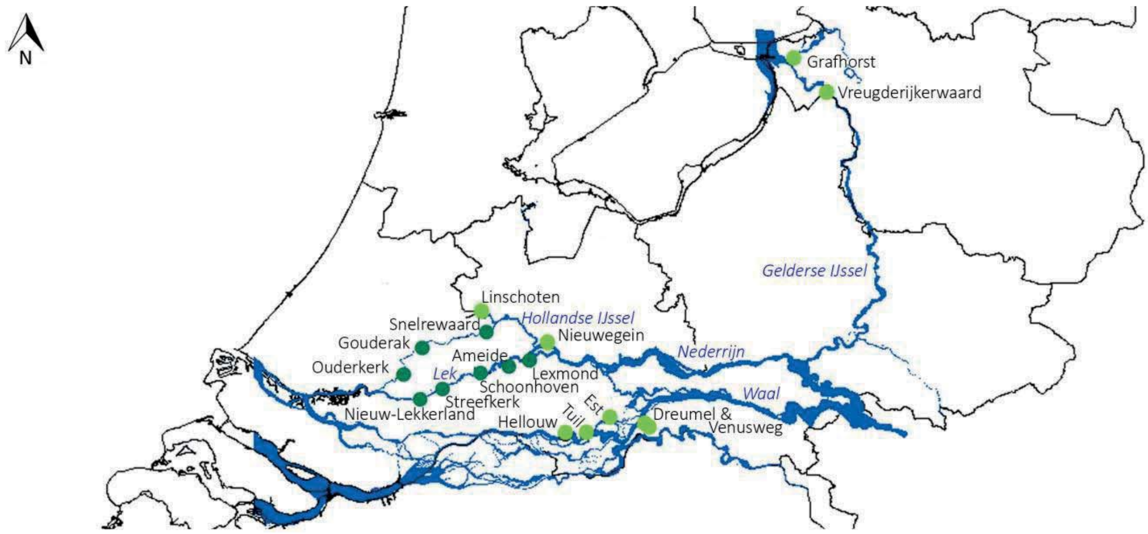


Figure 13 | Sampling locations. Locations of this research depicted in light green. Locations of consonant fieldwork by H.J. Pierik in dark green.

4.1 River Gelderse IJssel

4.1.1 site Vreugderijkerwaard

The site Vreugderijkerwaard (Dutch Ordnance System; RD-coordinates 198.839-502.877) is located at the northern levee of the river Gelderse IJssel, near the city of Zwolle. A cross-section (figure 14) was cored from the lower embankment near the river towards the flood basin in distal lateral direction, supplemented with existing corings. Samples are taken at the clay-on-peat transition around -1m NAP. The IJssel natural levee is recognizable as silty clay. The heavy clay in the top of the profile was also showing a lateral gradient, with heavier clays further away from the river.

Samples Vreugderijkerwaard 1 and 2 were taken in the field. Sample Vreugderijkerwaard 1 (2665 ±30 ^{14}C yr BP) presumably consisted of reworked older material, even though in the field no signs of reworking or erosional contact was visible (see coring 2013.07027 in appendix A2). The charcoal directly on top of the sample Vreugderijkerwaard 1, labeled as sample Vreugderijkerwaard 2, was

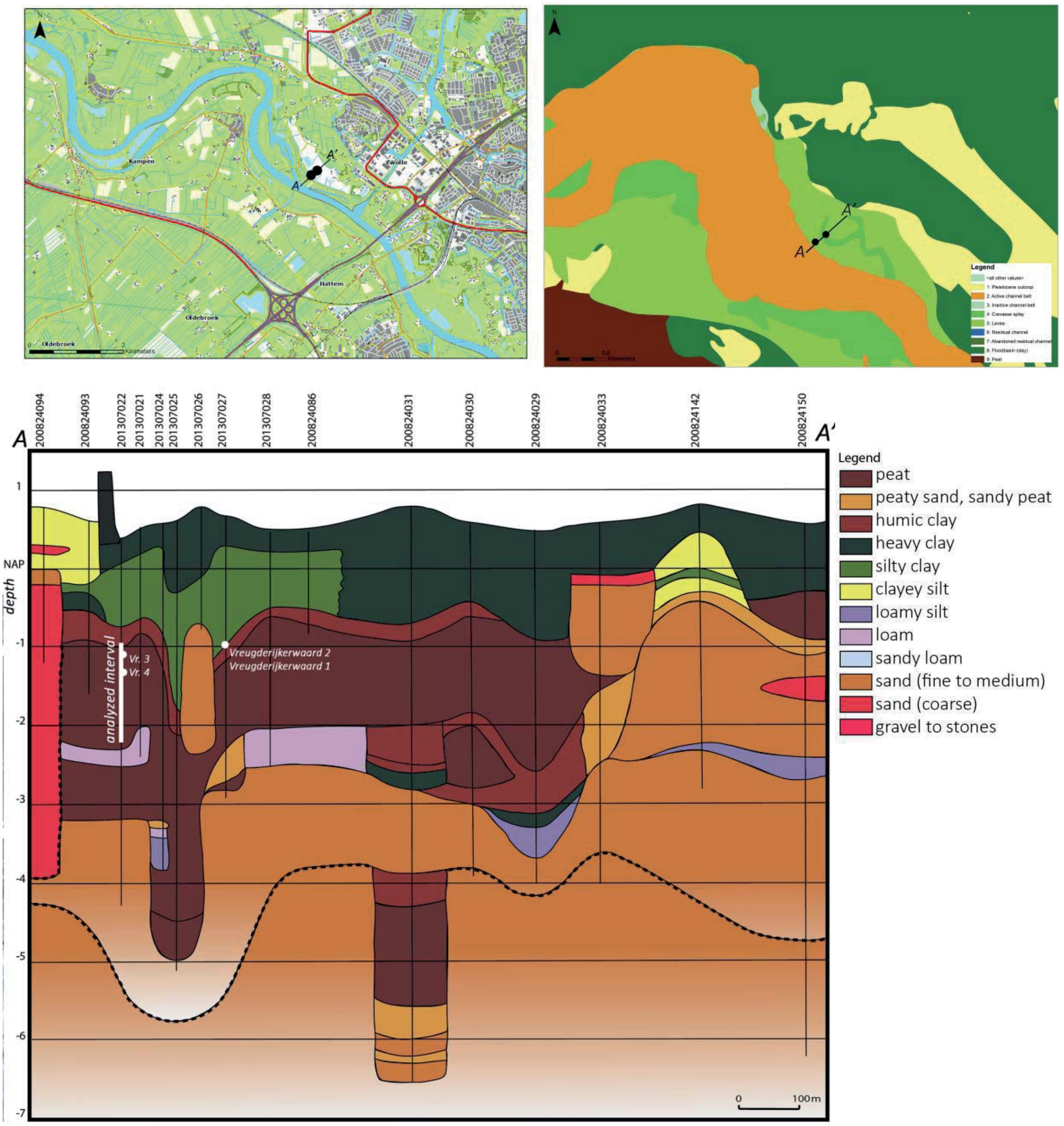


Figure 14 | **Lithological cross-section, analyzed interval and sampling locations for site Vreugderijkerwaard.** River IJssel is located left in the profile. Location of ^{14}C-samples shown on the topographic map (left: Kadaster) and AD 900 paleo levee-map (right: Pierik, unpublished).

Table 2 | **^{14}C dates for the site Vreugderijkerwaard.** Calibrated ages using sequence dating in blue.

Sample	River Phase	**Lab nr.**	**Lab age ± error**	Calibrated age mean ±σ [cal yrs BP] BR/R	**Historical age [yr BC/AD] BR/R**	
Vreugderijkerwaard 1*	N.A.	GrA62950	2665 ±30	2779 ±26	836 BC – 801 BC 830 BC ±26	
Vreugderijkerwaard 2*	III	GrA63107	960 ±30	862 ±42	1024 AD – 1150 AD 1088 AD ±42	
Vreugderijkerwaard 3	III	GrA64249	1105 ±30	1009 ±37 1014 ±35[S]	897 AD – 981 AD 938 AD ±37	895 AD – 976 AD[S] 936 AD ±35
Vreugderijkerwaard 4	II	GrA64341	1210 ±35	1135 ±55 1133 ±52[S]	770 AD – 878 AD 811 AD ±55	790 AD – 880 AD[S] 817 AD ±53

dated 862 ±42 yr BP (1088 AD ±42) which is in line with results of Vreugderijkerwaard 3 and 4.

Vreugderijkerwaard 3 and 4 were sub-sampled based on LOI-analysis. Vreugderijkerwaard 4 was sampled to represent begin of sedimentation (phase II-date) and was dated 1133 ±52^{S} (817 AD ±53^{S}). Vreugderijkerwaard 3 was sampled to represent the maturation phase (phase III-date) and was selected on the relative low organic content (see LOI-curve in appendix A4-I). Vreugderijkerwaard 3 was dated at 1014 ±35^{S} (936 AD ±35^{S}), indicating a maturation time of 119 ±88 years for the river IJssel. Comparing the first hydrological signal (phase I, Veeneiken II) with the mature river phase (phase III) yields a maturation time of 614 years for the river *Gelderse IJssel*.

4.1.2 site Grafhorst

The site Grafhorst (RD 191512, 510417) is located near the village of Grafhorst (close to Kampen) and is located on the western natural levee of the present day Ganzendiep. The Ganzendiep is thought to be the first branch of the river IJssel in the IJssel delta (Cohen et al., 2009). The lithological cross-section (Figure 15) is showing deltaic deposits in the northeast of the transect, which are in line with cross-section D of the IJssel delta by Van der Hop (2010).

Table 3 summarizes the results for the site of Grafhorst. Sample Grafhorst 1 was sampled to receive a begin of sedimentation age (phase II-date). Grafhorst 1 was dated at 1301 ±18^{S} yr BP (649 AD ±18^{S}). Based on the LOI-curve (see appendix A4-II), Grafhorst 2 was sampled to date the start of the maturation phase (phase III-date) and received an age of 1271 ±28^{S} yr BP (679 AD ±28^{S}. The transition from phase II to phase III here comprises a period of only 30 ±36 year.

4.1.3 integration of results: regional river channel development of the river IJssel

For the lower section of the river Gelderse IJssel, results of this research seem to be in line with earlier dates (see table 1). Especially the dates obtained from Vreugderijkerwaard fit within results upstream of Zwolle. Results of dendrological research at the same site showed a stress period from 27 AD to 223 AD (Veeneiken groep A; Jansma, 2015) which might reflect a first hydrological signal and a second drowning phase from 278 AD to 505 AD (Veeneiken groep B; Jansma, 2015) with a somewhat delayed sediment signal.

Dates of Grafhorst are slightly older than the ages from Vreugderijkerwaard, but also fit within the dendrological data. For the site of Grafhorst possible some erosion of peat at the delta front might have cause this slightly older ages. Maturation dates for the river IJssel obtained from Vreugderijkerwaard and Grafhorst show the same pattern in light of existing data (see appendix A6) with maturation in Vreugderijkerwaard somewhat later and Grafhorst somewhat earlier. Clay deposits might also be of lacustrine origin, but at the end the river IJssel should be regarded as the source of clay in the area whether or not it has been reworked later on.

The small difference in time between the samples of Grafhorst 1 and Grafhorst 2 might illuminate a small effect between LOI-based sampling and bulk sampling as well. However, considering uncertainties, difference can be up to 76 years for this specific case.

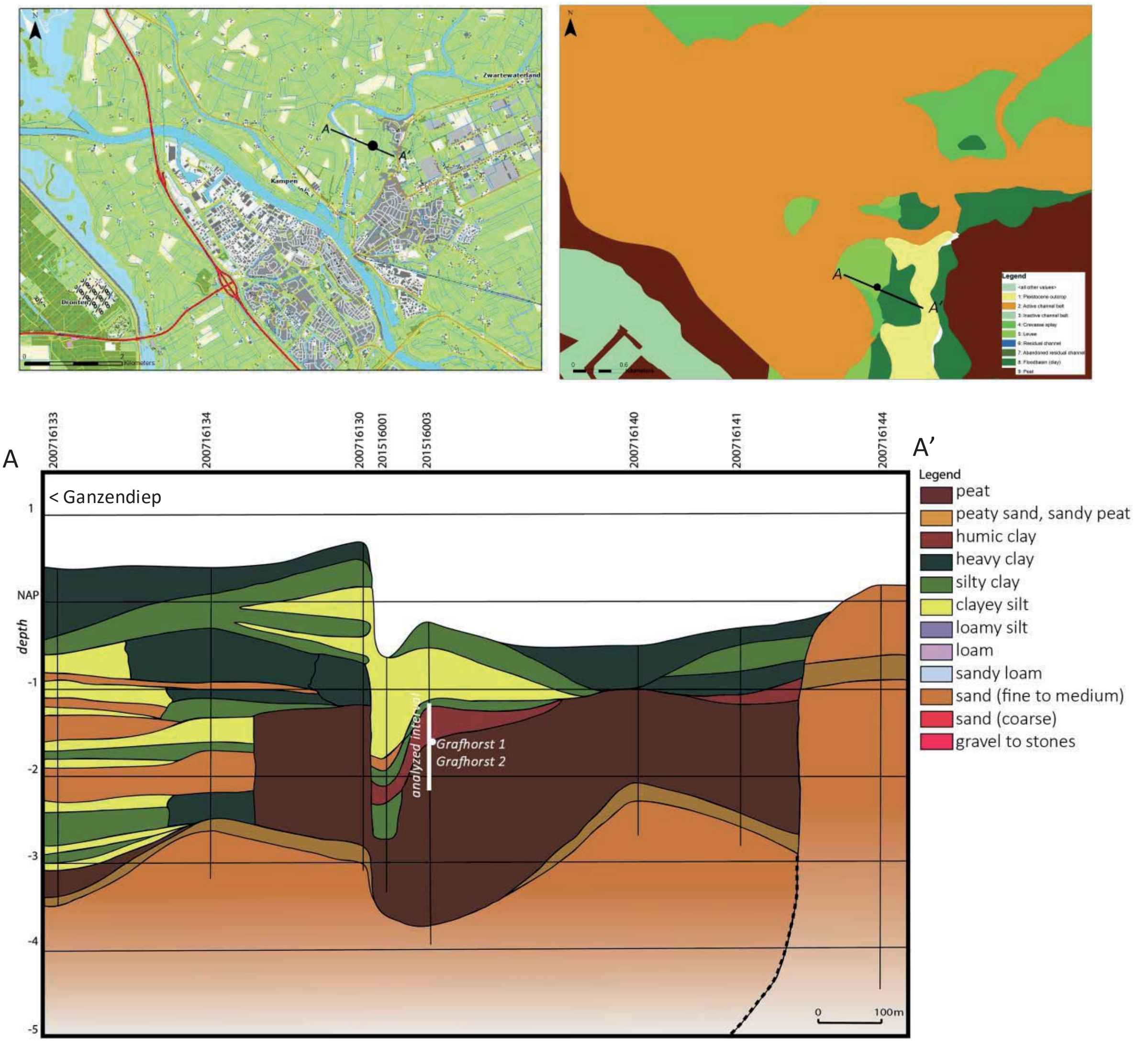


Figure 15 **| Lithological cross-section, analyzed interval and sampling locations for site Grafhorst.** River IJssel precursor Ganzendiep is located left to the profile. Location of ^{14}C-samples shown on the topographic map (left: Kadaster) and AD 900 paleo levee-map (right: Pierik, unpublished).

Table 3 **| ^{14}C dates for the site Grafhorst.** Calibrated ages using sequence dating in blue.

Sample	River Phase	Lab nr.	Lab age ± error	Calibrated age mean ±σ [cal yrs BP] $^{BR/R}$	Historical age [yr BC/AD] BR/R
Grafhorst 1	III	GrA64248	1345 ±35	1280 ±35 1271 ±28^{S}	647 AD – 758 AD 681 AD ±35 651 AD – 686 AD^{S} 679 AD ±28^{S}
Grafhorst 2	II	GrA64338	1375 ±45	1297 ±38 1301 ±18^{S}	618 AD – 677 AD 655 AD ±38 638 AD – 669 AD^{S} 649 AD ±18^{S}

4.2 River Waal and residual channel of Est

4.2.1 sites Dreumel en Venusweg

At the eastern natural levee of the river Waal near Tiel two sampling sites were selected. As the Waal is flowing generally in westward direction, this is a section of the Waal flowing north-south and is close to the avulsion point of the river Waal and the river Linge. The site was selected to investigate a possible age (younging) effect of sampling lateral from the river channel in distal direction. The lithological cross-sections (figure 16) clearly shows a floodplain with distinctive small peat and organic rich clayey vegetation horizons. Unfortunately, the layers were not as proximal traceable as was thought based on the cross-sections of Verbraeck (1984).

Table 4 is summarizing the results for the site of Dreumel and Venusweg. The sampling location of Dreumel (RD 157764, 428471) was located just below the natural level of the river Waal. The sampled layer was thought to represent begin of clastic sedimentation of the river Waal. Unfortunately an older layer was dated (2289 ±58 yr BP; 340 ±58 BC) within the analysed interval. The date is in line with the second layer (Dreumel II) found by Verbraeck (1984), who revealed a date of 2560 ±60 ^{14}C yr BP. Sampling site Venusweg (RD was located more into the flood plain area, but still had some deposits on top, which can be interpreted as natural levee deposits of the river Waal. Based on the LOI-curve two possible sub sampling locations for representing the clastic signal of the river Waal are identified. The deepest sample Venusweg 2 revealed an age of 3086 ±64 yr BP (1137 BC ±64). This date is considered too old to represent begin of Waal sedimentation. Venusweg 1 (+2.62 NAP), located 31 centimeter above Venusweg 2 (+2.31 NAP), was dated on 2317 ±68 yr BP (369 BC ±68). The sample was the first organic enriched layer (LOI-values ~30%) found from the surface. Compared to dates retrieved downstream, this date also can be considered too old. However, it might also reflect deposits from the river Linge or pre-Waal.

4.2.2 sites Tuil en Hellouw

The sampling site of Tuil (RD 144798, 426257) is located at the northern natural levee of the river Waal. The sampling location was just below silty natural levee deposits (+0.5m NAP, figure 17). Although general levels of LOI were low, they showed a distinctive pattern from -240 to -200 below surface (appendix A4-V). As the LOI-curve of Tuil looked more promising than the LOI-curve of Hellouw, Tuil was selected for three datings: a begin of sedimentation date (phase II-date; Tuil 2, +0.45 NAP), a maturation date (phase III-date, Tuil 1, +0.66 NAP) and a sample at the base of peat as internal time control (Tuil 3, +0.17 NAP). Table 5 is summarizing the results for the site Tuil. All samples revealed far too old ages. Tuil 1 (3285 ±49 yr BP, 1333±49 BC) and Tuil 2 (3529 ±70 yr BP, 1583 BC ±70) presumably represent reworked peaty material, as dates are not internally consistent. As sample Tuil 3 (3397 ±40 yr BP, 1447 ±40 BC) is relatively old compared to downstream dates (site Dalem; Törnqvist, 1993), the complete peat layer can be considered to be reworked peaty material. As well as because reinterpretation of coring photos (see appendix A4-V) is showing characteristic layering.

The sampling site of Hellouw (RD 140238, 425906) is located downstream of the sampling site Tuil, also at the northern natural levee of the river Waal. The sampling location was very close to the channel belt sand body (figure 18) and due to seepage water the organic material appeared well preserved. No clear erosional contact was observed in the field. Table 6 is summarizing the results for the site of Hellouw. Hellouw 2 (-0.28 NAP) was considered to represent begin of sedimentation for the river Waal and Hellouw 1 (-0.18 NAP) the onset of the maturation phase. In line with Tuil 1 the dated material of Hellouw 1 was too old (3081 ±178 yr BP, 1137 BC ±178) and presumably also represents reworked material. The dates of Tuil and Hellouw seem mutually accurate but not precise, as they date the wrong event. Redefinition of the age of the river Waal (see table 1), seems unlikely considering the reworked (layered) material which was dated (see appendix A4-V and A4-VI).

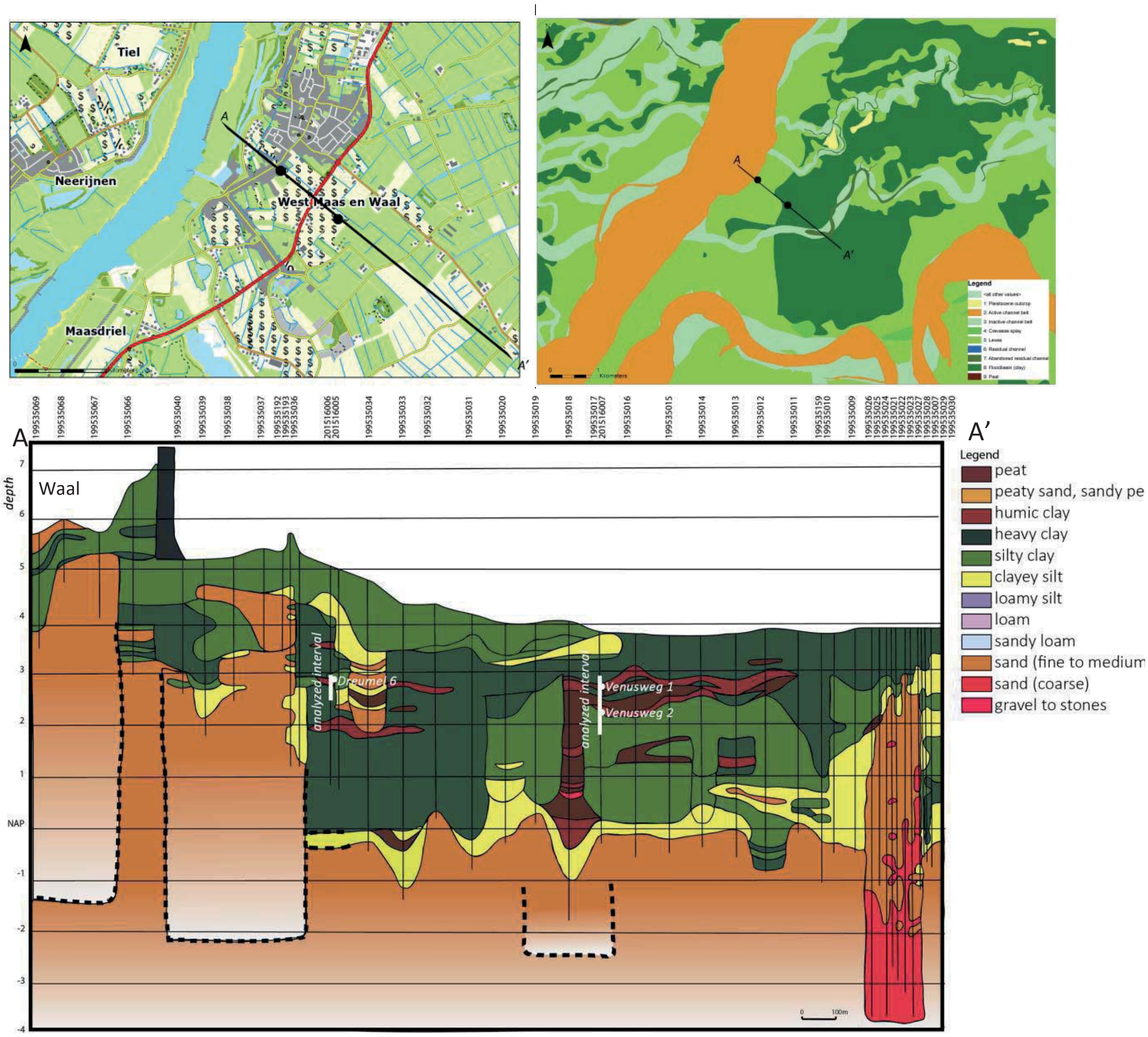


Figure 16 | **Lithological cross-section, analyzed interval and sampling locations for site Dreumel and Venusweg.** River Waal is located left in the profile. Location of ^{14}C-samples shown on the topographic map (left: Kadaster) and AD 900 paleo levee-map (right: Pierik, unpublished).

Table 4 | **^{14}C dates for the site Dreumel and Venusweg.** Calibrated ages using sequence dating in blue.

Sample	River phase	**Lab nr.**	**Lab age ± error**	Calibrated age mean ±σ [cal yrs BP] BR/R	**Historical age [yr BC/AD] BR/R**
Dreumel 6	II	GrA64246	2285 ±30	2289 ±58	399 BC – 262 BC 340 BC ±58
Venusweg 1	II	GrA64340	2310 ±40	2331 ±65 2317±68^{S}	408 BC – 262 BC 362 BC ±65 410 BC – 262 BC^{S} 369 BC ±68
Venusweg 2	II	GrA64337	2940 ±40	3095 ±64 3086±64^{S}	1215 BC – 1059 BC 1143 BC ±64 1210 BC – 1057 BC^{S} 1137 BC ±64

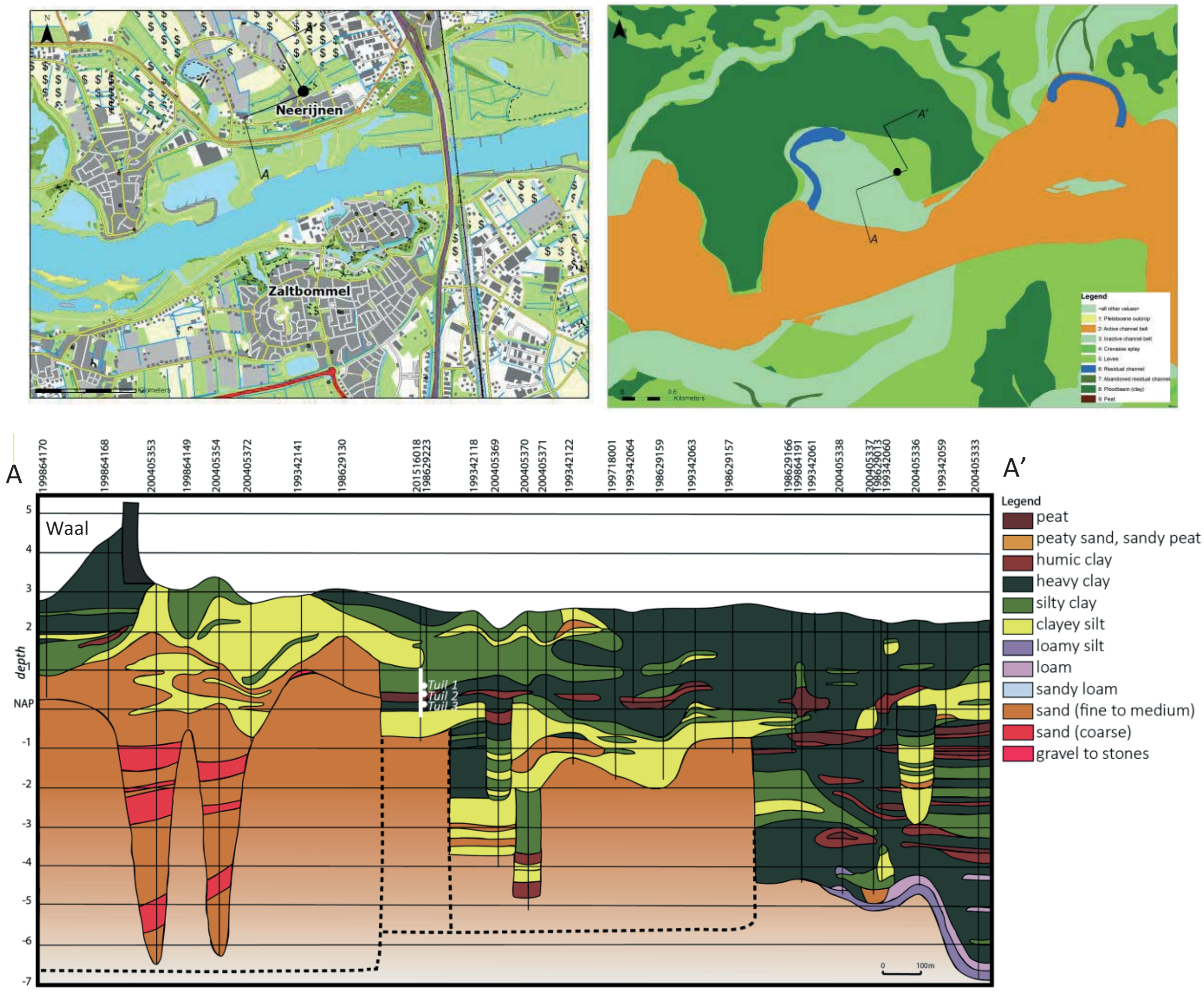


Figure 17 **| Lithological cross-section, analyzed interval and sampling locations for site Tuil.** River Waal is located left in the profile. Location of ^{14}C-samples shown on the topographic map (left: Kadaster) and AD 900 paleo levee-map (right: Pierik, unpublished).

Table 5 **| ^{14}C dates for the site Tuil.** Calibrated ages using sequence dating in blue. As dates were not in sequence, regular calibration dates were used.

Sample	River phase	**Lab nr.**	**Lab age ± error**	Calibrated age mean ±σ [cal yrs BP] [BR/R]	**Historical age [yr BC/AD] BR/R**
Tuil 1	III	GrA64242	3070 ±35	3285 ±49 3336 ±37[S]	1394 BC – 1282 BC 1333 BC ±49 1429 BC - 1372 BC [S] 1387 BC ±37
Tuil 2	II	GrA64243	3300 ±60	3529 ±70 3379 ±30[S]	1639 BC – 1580 BC 1583 BC ±70 1457 BC - 1412 BC [S] 1430 BC ±30
Tuil 3	0	GrA64633	3170 ±35	3397 ±40 3424 ±32[S]	1496 BC – 1416 BC 1447 BC ±40 1501 BC - 1444 BC [S] 1475 BC ±32

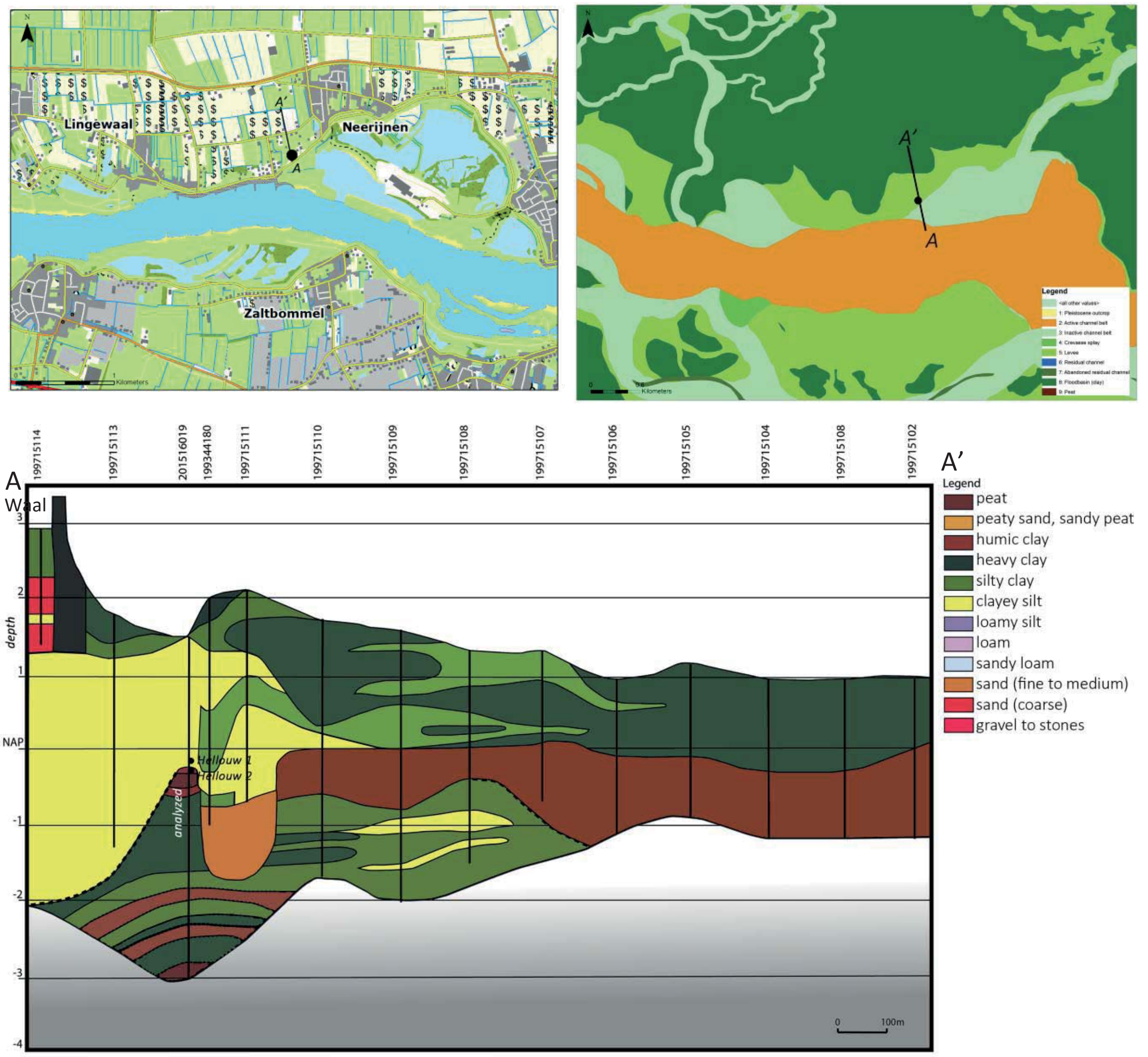


Figure 17 | **Lithological cross-section, analyzed interval and sampling locations for site Hellouw.** River Waal is located left in the profile. Location of ^{14}C-samples shown on the topographic map (left: Kadaster) and AD 900 paleo levee-map (right: Pierik, unpublished).

Table 6 | **^{14}C dates for the site Hellouw.**

Sample	River Phase	**Lab nr.**	**Lab age ± error**	Calibrated age mean ±σ [cal yrs BP] BR/R	**Historical age [yr BC/AD] BR/R**
Hellouw 1	III	GrA64244	2920 ±150	3081 ±178	1367 BC – 926 BC 1138 BC ±178
Hellouw 2	II	-	-	-	-

4.2.3 site Est

The sampling site of Est (RD 150298, 429818) was selected based on the approach that a residual channel might collect a sediment signal from a major flood which was the onset for the Waal-avulsion and might still collect sediment in the abandoning phase (phase IV). Samples were taken at the base of the residual channel fill (see lithological profile in figure 18). Results for the site of Est are summarized in table 7.

Samples Est 4 (+1.37 NAP) and Est 6 (+1.97 NAP) are presumably exchanged. Sample names are linked to Groningen-numbers and cannot be changed manually afterwards. In this report Est 4 and Est 6 dates are assumed to be exchanged before dating (in the preparation phase). By a re-analysis of the samples, the original sample Est 4 showed more human interference (higher species richness and cultivated plants) in the pollen and based on lithology (gyttja for Est 6) a location higher in the sequence than Est 4 seems plausible. For sequence modelling dates Est 4 and Est 6 are turned in the rearranged sequence.

Est 4 (1740 ±55 cal yr BP, 212 ±55 AD) marks the begin of channel infill for the residual channel of Est and can be seen als TPQ-date. The extra clastic input dated with sample Est 5 (1467 ±44 cal yr BP, 483 ±44 AD, +1.82 NAP) represents a reactivation phase of the residual channel of Est and this extra clay input can be related to the beginning of the maturation phase (phase III) of the river Waal, which is in line with the begin of sedimentation date of downstream Waal site Dalem II (1485 ±58 cal yr BP, Törnqvist, 1993 AMS-date). Est 6 (1222±44 yr BP, 728 ±44 AD) can be considered to date extra clastic input in the system of the river Waal.

4.2.4 integration of results: regional river channel development of the river Waal

Only dates of the site of Est seem to support formation of the river Waal in the beginning of the first millennium after Christ and are consistent with dates of Törnqvist (1993) downstream near Dalem. In this scenario the Waal was preceded by a proto-Waal which was active around 369 BC (Venusweg 1). From 212 AD (Est 4) the river Waal got a clear sedimentary signal with maturation from 483 AD onwards (Est 6).

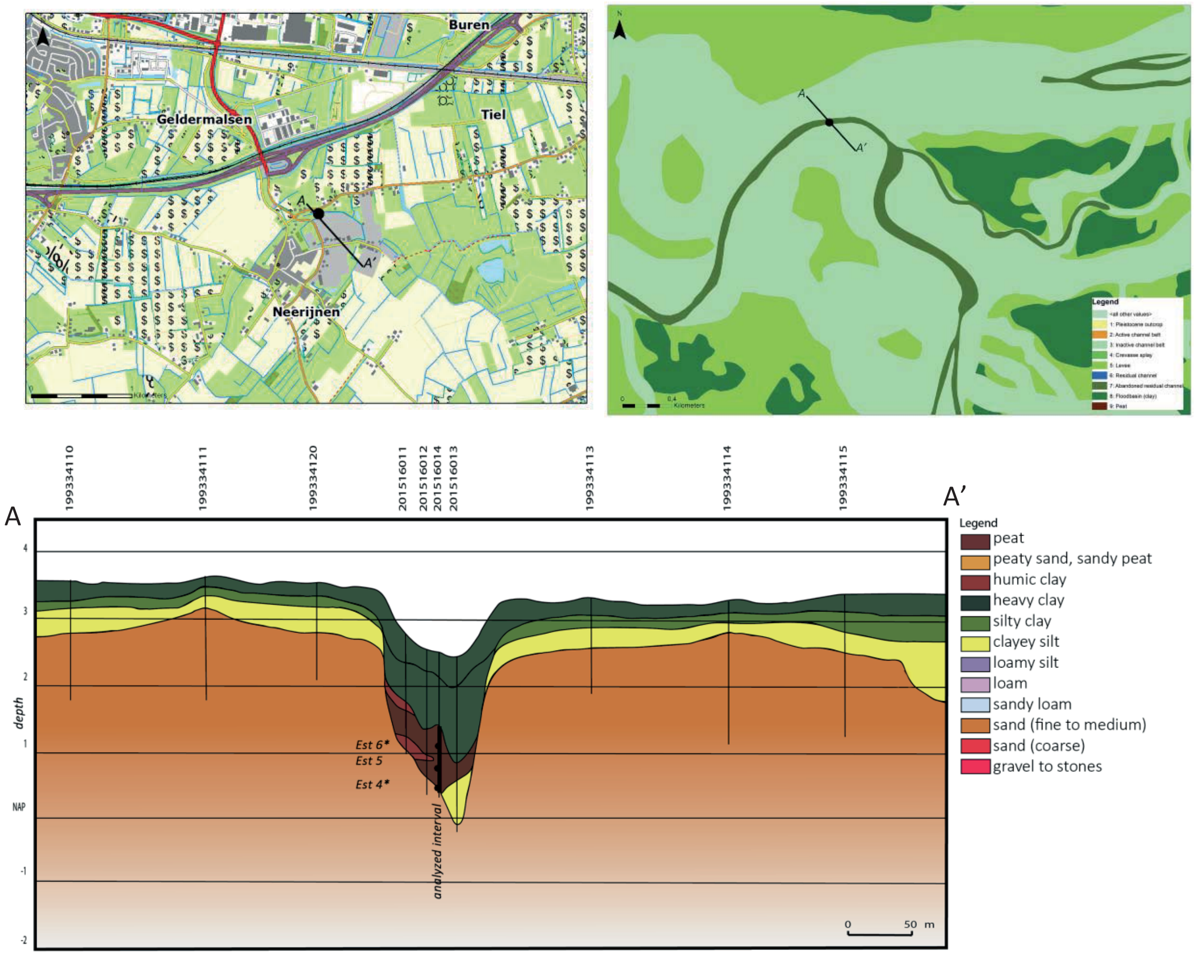


Figure 18 | **Lithological cross-section, analyzed interval and sampling locations for site Est.** River Waal is located on the right site of the profile. Location of ^{14}C-samples shown on the topographic map (left: Kadaster) and AD 900 paleo levee-map (right: Pierik, unpublished).

Table 7 | **^{14}C dates for the site Est.** Calibrated ages using sequence dating in blue. *** Monsters are presumably exchanged, sample names are linked to Groningen-numbers, in this report Est 4 and Est 6 dates are assumed to be exchanged. For sequence modeling dates Est 4 and Est 6 are turned in the sequence.

Sample	River Phase	**Lab nr.**	**Lab age ± error**	Calibrated age mean ±σ [cal yrs BP] BR/R	**Historical age [yr BC/AD] BR/R**
Est 4***	II	GrA64252	1830 ±35	1767 ±49 1740 ±55^{S}	135 AD – 224 AD 184 AD ±49 149 AD – 313 AD^{S} 212 AD ±56
Est 5	III	GrA64253	1535 ±30	1438 ±50 1467 ±44^{S}	432 AD – 570 AD 509 AD ±50 428 AD – 545 AD^{S} 483 AD ±44
Est 6***	IIIb	GrA64254	1275 ±30	1228 ±38 1222 ±38^{S}	685 AD – 767 AD 727 AD ±38 685 AD – 767 AD^{S} 728 AD ±38

4.3 River Nederrijn-Hollandse IJssel/Lek

4.3.1 site Nieuwegein

So far, the site of Nieuwegein is the only place between Wijk bij Duurstede and Vianen where the river Lek has been dated (sample 'Lek', 1950 ±30 ^{14}C yr BP, 1900 ±35 cal yr BP; Berendsen, 1982). Extensive desktop research of the section Wijk bij Duurstude-Vianen did not reveal new possible dating locations as there is almost continuous presence of crevasse splays and older channel belt depoits which are incised by the river Lek.

As the sample of Berendsen (1982) was a bulk sample, new samples have been taken at almost the same location: sampling site Nieuwegein (RD 136246, 446378). The lithological profile (figure 20) shows the location under clay deposits related to the river Lek. The river Lek has relatively small natural levees (see cross-section D; Gouw, 2007). The LOI-curve (appendix A4-VII) shows a clear breaking point for peat formation and restarted clastic input. Nieuwegein 1 (-2.25 NAP), considered to date the beginning of sedimentation of the river Lek revealed an age of 1775 ±42 cal yr BP (175 ±30 AD). A small sample of 1 cm thick was used. For whitin-coring time control sample Nieuwegein 2 (-1.61 NAP) was taken at the base of the peat bed. The start of peat formation is dated at 1911 ±39 cal yr BP (39 AD ±39 cal yr), which is more in line with the 'begin of sedimentation'-date of Berendsen (1982).

4.3.2 site Linschoten

The sampling site Linschoten (RD 121214, 453502) was sampled with the same conceptual approach as the residual channel of Est. The residual channel of Linschoten is estimated to have a reactivation period coinciding with the formation of the Hollandse IJssel between 1800 and 1250 yr BP during flood waters (Horsten, 1990 as cited by Cohen et al. , 2012). Results of the residual channel of Linschoten are summarized in table 9.

Samples were not taken at the base of the residual channel, but within the younger fill of the residual channel (see lithological profile in figure 21). Samples Linschoten 2 (3647 ±49 yr BP, 1698 ±49 BC; -1.21 NAP) and Linschoten 1 (3350 ±51 cal yr BP, 1401 BC; -0.90 NAP) however yielded much older dates.

4.3.3 sites Hollandse IJssel and Lek (results fieldwork H.J. Pierik)

In this section ^{14}C dates of the river Hollandse IJssel (table 10) and the river Lek (table 11) are summarized. Underlying LOI-curves and lithological descriptions can be found in appendix A7. For the river Hollandse IJssel five samples have been taken. Linschoten (1949 ±36yr BP, 1 ±36 AD) and Gouderak (1837 ±41 yr BP, 113 ±41) revealed consistent ages for the clay-on-peat transition (phase II-date). Clay-on-peat sampling location Snelrewaard (2778 ±38 yr BP, 829 ±38 BC), Oudekerk 1 (2423 ±64 yr BP, 474 ±38 BC) and Oudekerk 2 (2602 ±100 yr BP, 653 ±100 BC) show older ages, presumably resulting from oxidation of peat material, as the clay-peat contact was close to the surface above the groundwater table.

For the river Lek the sampling locations of Schoonhoven (1626 ±44 yr BP, 324 ±44 AD) and the somewhat older Ameide 3A (1933 ±35, 17 ±35 AD) are considered to be the most promising clay-on-peat transition (phase II) dates, as they show no oxidation. Streefkerk 1 (2224 ±57 yr BP, 275 ±57 BC) and Nieuw Lekkerland 1 (2254 ±59 yr BP, 305 ±59 BC) probably are prone to an aging effect by oxidation. Within the analysed interval for Ameide (see LOI-curve in appendix A6) two stages can be identified as begin of sedimentation (clay-on-peat) for which Ameide 2 (2160 ±77 yr BP, 213 ±77 BC) seems to reflect a first onset of clastic input and the previous mentioned Ameide 3A the actual transition from peat to clay. Samples Lexmond 1 (851 ±49 yr BP, 1099 ±49 AD) and Lexmond 2 (1409 ±55 yr BP, 541 ±55 AD) appear to be too young and are probably enriched with younger material (roots, see coring 201307001).

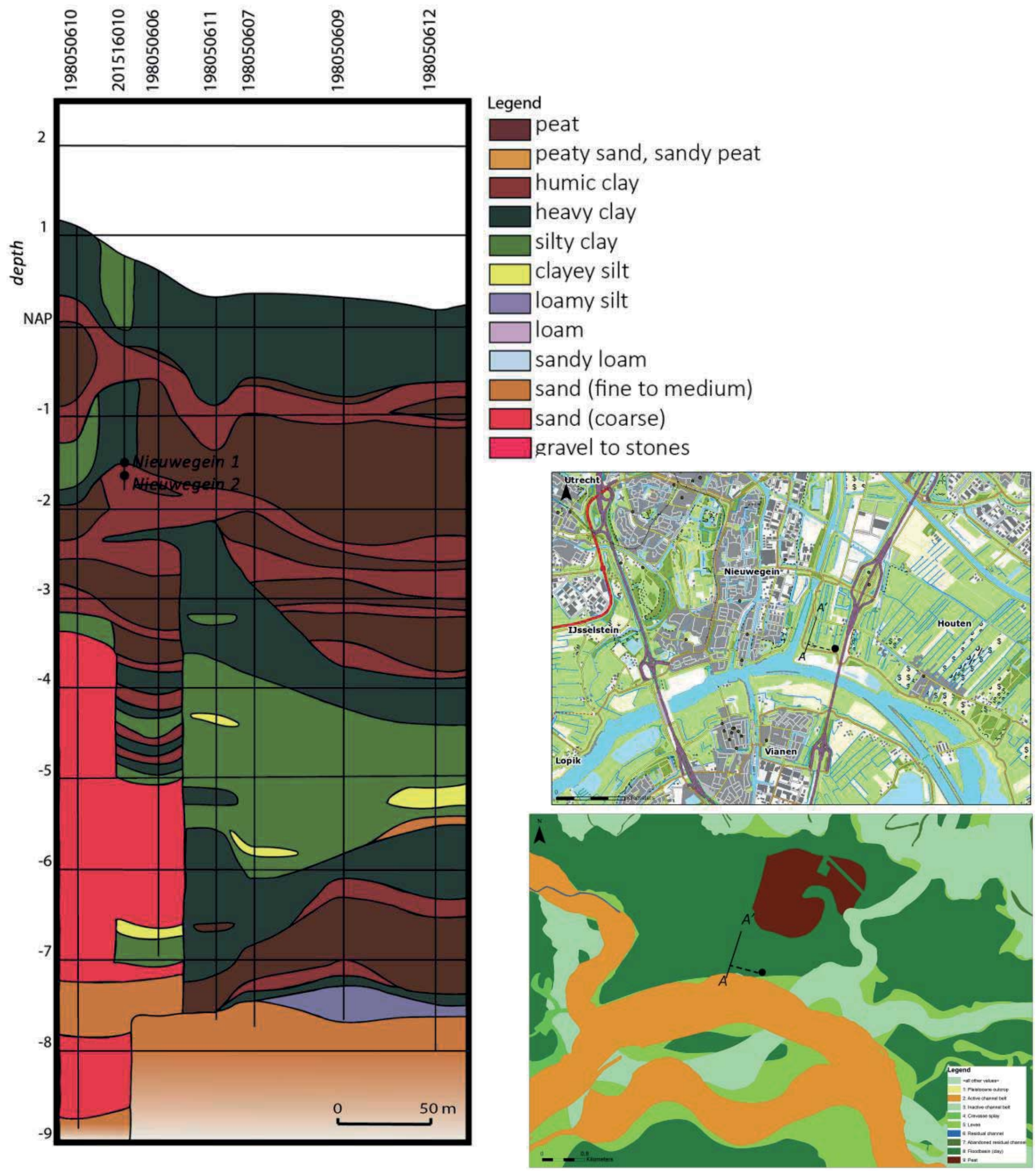


Figure 20 **| Lithological cross-section, analyzed interval and sampling locations for site Nieuwegein.** River Lek is located left in the profile. Location of ^{14}C-samples shown on the topographic map (left: Kadaster) and AD 900 paleo levee-map (right: Pierik, unpublished). Coring 201516010 is projected on an existing profile.

Table 8 | **^{14}C dates for the site Nieuwegein.** Calibrated ages using sequence dating in blue.

Sample	River Phase	**Lab nr.**	**Lab age ± error**	Calibrated age mean ±σ [cal yrs BP] BR/R	**Historical age [yr BC/AD] BR/R**
Nieuwegein 1	II	GrA64240	1830 ±30	1768 ±43 1775 ±42S	137 AD – 220 AD 183 AD ±43 132 AD – 214 ADS 175 AD ±42
Nieuwegein 2	0	GrA64632	1965 ±35	1916 ±40 1911±39S	1 AD – 75 AD 33 AD ±40 3 AD– 78 ADS 39 AD ±39 S

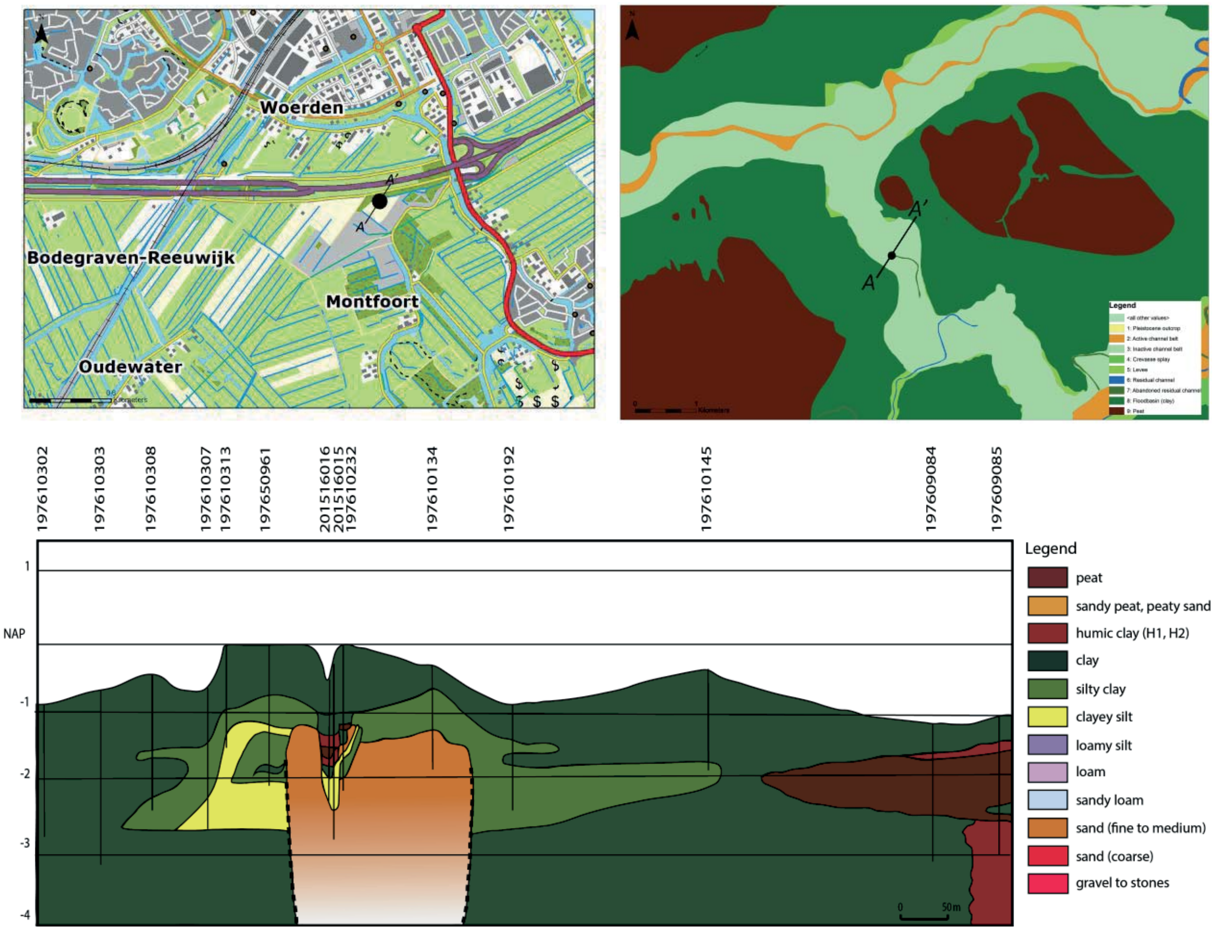


Figure 21 | **Lithological cross-section, analyzed interval and sampling locations for site Linschoten.** The residual channel of Lange Linschoten is visible in the cross-section. Location of ^{14}C-samples shown on the topographic map (left: Kadaster) and AD 900 paleo levee-map (right: Pierik, unpublished).

Table 9 | ^{14}C dates for the site Linschoten. Calibrated ages using sequence dating in blue.

Sample	River Phase	Lab nr.	Lab age ± error	Calibrated age mean ±σ [cal yrs BP] BR/R	Historical age [yr BC/AD] BR/R
Linschoten 1	II	GrA64250	3130 ±35	3353 ±52 3350 ±51	1443 BC – 1311 BC 1391 BC ±52 1448 BC – 1320 BC 1401 BC ±51
Linschoten 2	V	GrA64251	3405 ±35	3652 ±52 3647 ±49	1746 BC – 1659 BC 1707 BC ±52 1741 BC – 1658 BC 1698 BC ±49

Table 10 | ^{14}C dates for the sites along the river Hollandse IJssel. Fieldwork and analysis by H.J. Pierik. Calibrated ages using sequence dating in blue. For locations see figure 12.

Sample	Lab nr.	Lab age ± error	Calibrated age mean ±σ [cal yrs BP] BR/R	Historical age [yr BC/AD] BR/R
Snelrewaard *	GrA64318	2650 ±45	2778 ±38	888 BC – 793 BC 829 BC ±38
Oudekerk 1**	GrA64564	2390 ±30	2429 ±76 2423 ±64 S	507 BC – 403 BC 480 BC ±76 490 BC – 404 BC S 474 BC ±64S
Oudekerk 2**	GrA64321	2550 ±70	2608 ±105 2602 ±100 S	803 BC – 547 BC 659 BC ±105 800 BC – 542 BC S 653 BC ±100S
Gouderak 1**	GrA62970	1895 ±30	1837 ±41	70 AD – 132 AD 113 ±41
Linschoten**	GrA62969	2000 ±30	1949 ±36	40 BC – 47 AD 1 AD ±36

Table 11 | ^{14}C dates for the sites along the river Lek. Fieldwork and analysis by H.J. Pierik. Calibrated ages using sequence dating in blue. For locations see figure 12.

Sample	Lab nr.	Lab age ± error	Calibrated age mean ±σ [cal yrs BP] BR/R	Historical age [yr BC/AD] BR/R
Lexmond 1**	GrA64319	930 ±45	846 ±50 851 ±49 S	1040 AD – 1154 AD 1104 AD ±50 1033 AD – 1141 AD S 1099 AD ±49 S
Lexmond 2**	GrA64323	1515 ±40	1416 ±56 1409 ±55 S	435 AD – 602 AD 534 AD ±56 438 AD – 609 AD S 541 AD ±55 S
Ameide 2**	GrA62997	2160 ±30	2190 ±77 2160 ±77 S	352 BC – 167 BC 241 BC ±77 348 BC – 115 BC S 213 BC ±77 S
Ameide 3A**	GrA64635	1975 ±30	1926 ±34 1933 ±35 S	18 BC – 65 AD 24 AD ±34 37 BC – 58 AD S 17 AD ±35 S
Schoonhoven**	GrA62968	1715 ±30	1626 ±44	259 AD – 384 AD 324 AD ±44
Streefkerk 1**	GrA62966	2190 ±30	2224 ±57	356 BC – 199 BC 275 BC ±57
Nieuw Lekkerland 1**	GrA64317	2260 ±35	2254 ±59	390 BC – 234 BC 305 BC ±59

4.3.3 integration of results: regional river channel development of the river Nederrijn-Hollandse IJssel/Lek

The new received date of Nieuwegein (175 ±30 AD) seems to be in conflict with the somewhat older begin of sedimentation ages for the river Hollandse IJssel found by Linschoten (GrA62969, 1 ±36 AD) , although Gouderak (GrA62970, 113 ±41) seems to confirm. Further downstream of the Lek the clay-on-peat date for Ameide 3A (GrA64635, 17 ±35 AD) seems to be in favour of a scenario starting around AD/BC. Although on the other hand the close sample of Schoonhoven just indicated a somewhat younger age of 324 ±44 AD. So first the Hollandse IJssel formed (Linschoten, Gouderak) with discharge from the Hagestein river channel, than the upstream part Lek formed as a crevasse (Niewegein-Ameide) and later on the downstream part along Schoonhoven was formed.

Table 12 is summarizing most likely begin age and maturation age (start '*bloeifase*) for de rivers *Gelderse Ijssel, Lek, Hollandse Ijssel and Waal*.

Table 12 | **Overview of begin age and maturation age for river branches of the Krimpen river system**

River (#Cohen et al., 2012)	**Section**	**Begin age TPQ** *"beginfase"* oldest option	**Begin age TPQ** *"beginfase"* youngest option	**Mature river** *"bloeifase"*
Gelderse IJssel (#50)	*Zutphen-Zwolle*	**509 ±50 AD** *1535 ± 30 yr BP* GrA-38085 **±650 AD**	**1260 ±23 AD** *780 ± 35 yr BP* GrN-34961 **850 AD**	**700 AD to ± 950 AD** Cohen et al., 2012 **> 735 ± 62 AD** Cohen et al., 2016
Lek (#68)	*Nieuwegein - Krimpen a/d Lek*	**293 ±103 BC** *2220 ± 35 yr BP* GrN-8708 **±25 AD**	**50 ±35 AD** *1950 ± 30 yr BP* GrN-8707 **±280 AD**	**300 AD – 800 AD** Berendsen, 1982 **± 700 AD** Cohen et al., 2016
Hollandse IJssel (#91)	*Nieuwegein - Krimpen a/d IJssel*	**96 ±75 AD** *2070 ± 60 yr BP* **±150 AD**	**217 ±73 AD** *1805 ± 50 yr BP* GrN-7577	**< 800 AD** Cohen et al., 2016
Waal (#174)	*Tiel - Gorinchem*	**206 ±67 AD** *1815 ± 50 yr BP* GrN-6993 **±100 AD**	**465 ±56 AD** *1600 ± 50 yr BP* UtC-1899 **±400-450 AD**	**> 450 AD** Cohen et al., 2016

4.4 Spatial analysis: longitudinal and lateral river channel developments

In this section river channel development is discussed in longitudinal direction (4.4.1) and thereafter in lateral direction (4.4.2) for the rivers Gelderse Ijssel, Waal, Lek and Hollandse IJssel. New and existing ^{14}C-dates (figure 21 and appendix A6) have been classified using the new river phase model (figure 9), to not just lump all ^{14}C-dates together. For each ^{14}C-date uncertainties are depicted with error bars. ^{14}C-dates which are interpreted to reflect oxidation, reworked material or enrichment with younger material based on their underlying lithology are also indicated. In case background information on lithology (as least a description of lithological sequence) is missing, ^{14}C-dates were left out of spatial analysis.

4.3.1 Longitudinal river channel developments

Figure 23 is showing longitudinal distance along the river Gelderse IJssel versus age. No dates have been classified for phase I. There is a clear time gap in phase 0-dates and phase-II dates which might indicate a hydrological wetting of the area before an actual sedimentary signal becomes clear. This could also indicated peat material which is not dated often ('central' peat as not begin top- or bottom-peat dates). This is supported by the dendrological data as the Veeneikengroep A (Jansma, 2015) reflects a stress period from the first hydrological signal and the second group (Veeneikengroep B) coincides with the oldest phase II dates (clay-on-peat). Change in peat type-date GrN-27024 also implies change in hydrological conditions (Cohen et al., 2012). Phase II dates show large variance. The oldest classified clay-on-peat date ages are around 650 AD and the youngest around 1250 AD. The two youngest dates (GrA-34961 and GrA-34964) might reflect a younger part of the IJssel delta or a strong lateral rejuvenation, as they are even younger than all phase III (maturation) dates. Moreover sample GrA-34961 (De Slaper B4-2) is questionable as phase-II date, as it dates peat within two sandy layers in the flood plain area. Dates for Grafhorst (GrA-64338, GrA-64248) are in line with Poz-20197, Westenholte WH-2 (KIA 38645) and Vorchten (GrA-44639) and indicate begin of sedimentation around 650 AD. Dates of the Vreugderijkerwaard (GrA-64249 and GrA-64341) site seem to reflect a somewhat older scenario for begin op sedimentation starting around 850 AD, in line with samples GrA-38096, Poz-20198, Westenholte (UtC-14771 and UtC-14722). For both scenario's no clear longitudinal trend is visible.

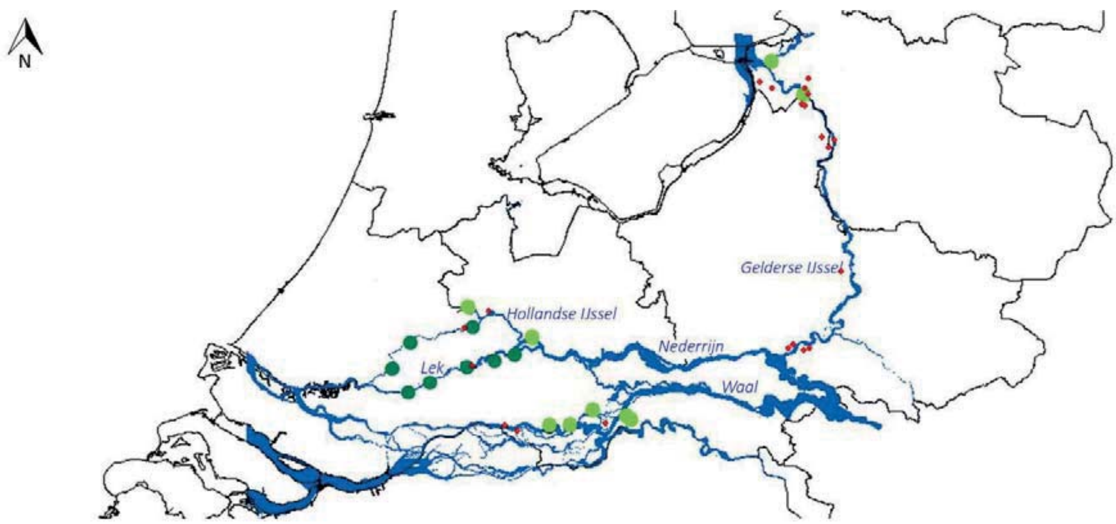


Figure 22**| Spatial analysis locations.** Sites of this research are depicted in light green. Site of consonant (new) fieldwork by H.J. Pierik in dark green. Existing ^{14}C-locations in red.

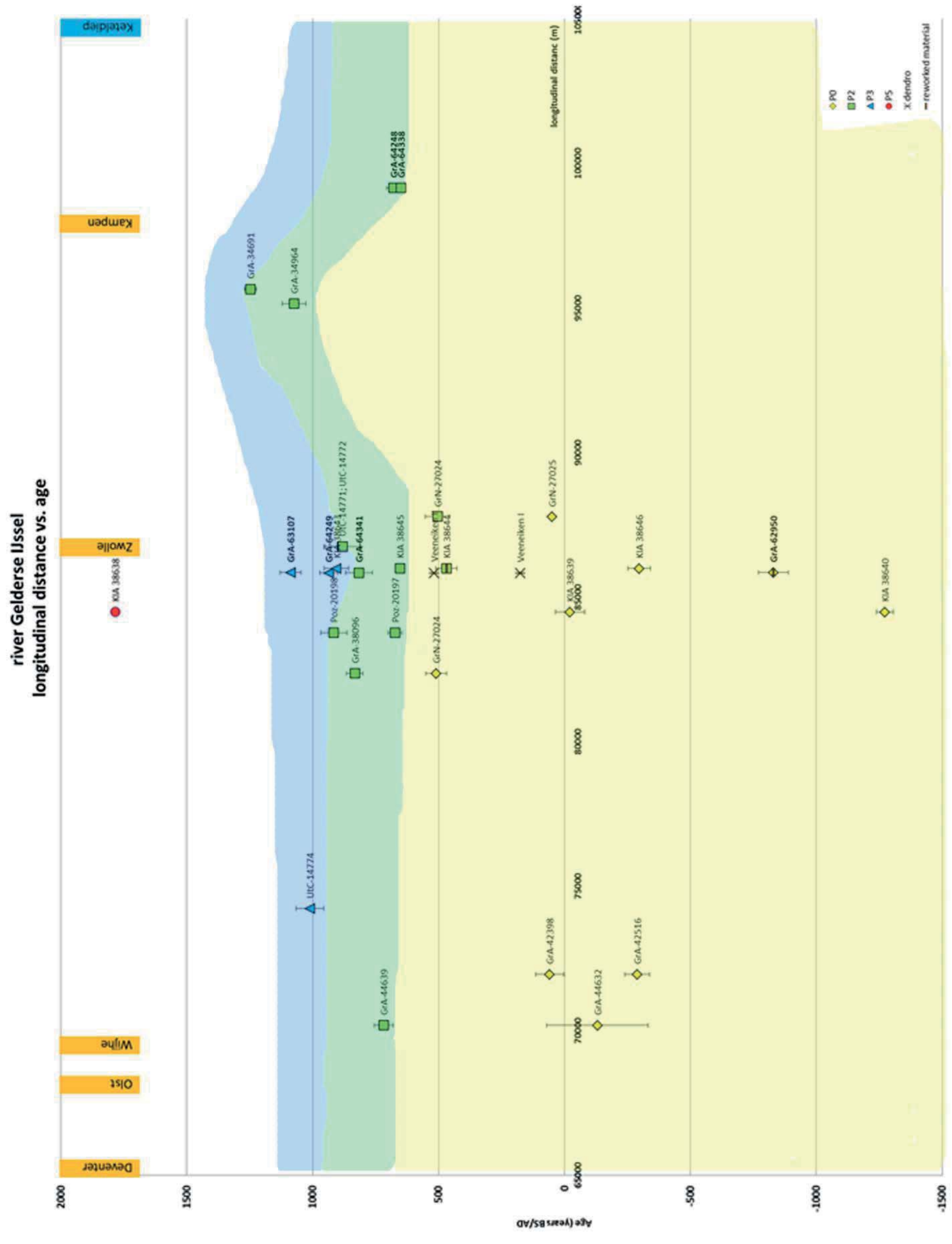


Figure 24 | **Longitudinal distance vs. age for the river Gelderse IJssel.**

For the river Hollandse IJssel (figure 24) only sites GrN-7555 and Gouderak revealed usable dates. Both dates confirm each other indicating begin of sedimentation for the Hollandse IJssel around AD 150. No longitudinal trend is visable.

For the river Lek (figure 25) a less clear signal becomes clear from the phase-II datings. Sample GrN-8707 (site Willege Langrak -0.30 NAP, bulk ^{14}C-date) respresents an older scenario starting around 283 BC. Other phase-II samples (GrN-8707, GrA-64240, GrA-64635, GrA-62968) seem to indicate a younger begin of sedimentation age of around 1 AD to 324 AD. Eventually, this scenario can be split itself, with GrN-8707 and GrA-64635 indicating a formation around 25 AD (and so slightly younger than the river Hollandse IJssel) and GrA-64240 and GrA-62968 indicating a begin of sedimentation age of around 280 AD (an so slightly older than the the river Hollandse IJssel). Each scenario has too few points to possibly indicate a longitudinal trend. No sutable phase III-dates are present for the river Lek.

For the river Waal (figure 25) peat-on-clay or phase-II dates show a multidirectional pattern. Site Hoefkamp (UtC-11136) indicates begin of sedimentation of around 290 BC which is contradicted by the phase-0-dates further downstream of GrN-12457 and GrN-13505. Dreumel II (GrN-6993) and Waal I (GrN-12456) indicate begin of sedimentation around 100 AD. Dalem II (UtC-1899) and the alkali extract of Waal I (GrN-13504) indicate a slightly younger begin of sedimentation of around 400-450 AD. The extra clastic input dated with sample Est 5 (483 ±44 AD) seems to confirm this last scenario. Also for the river Waal no clear longitudinal trend can be deduced from the data.

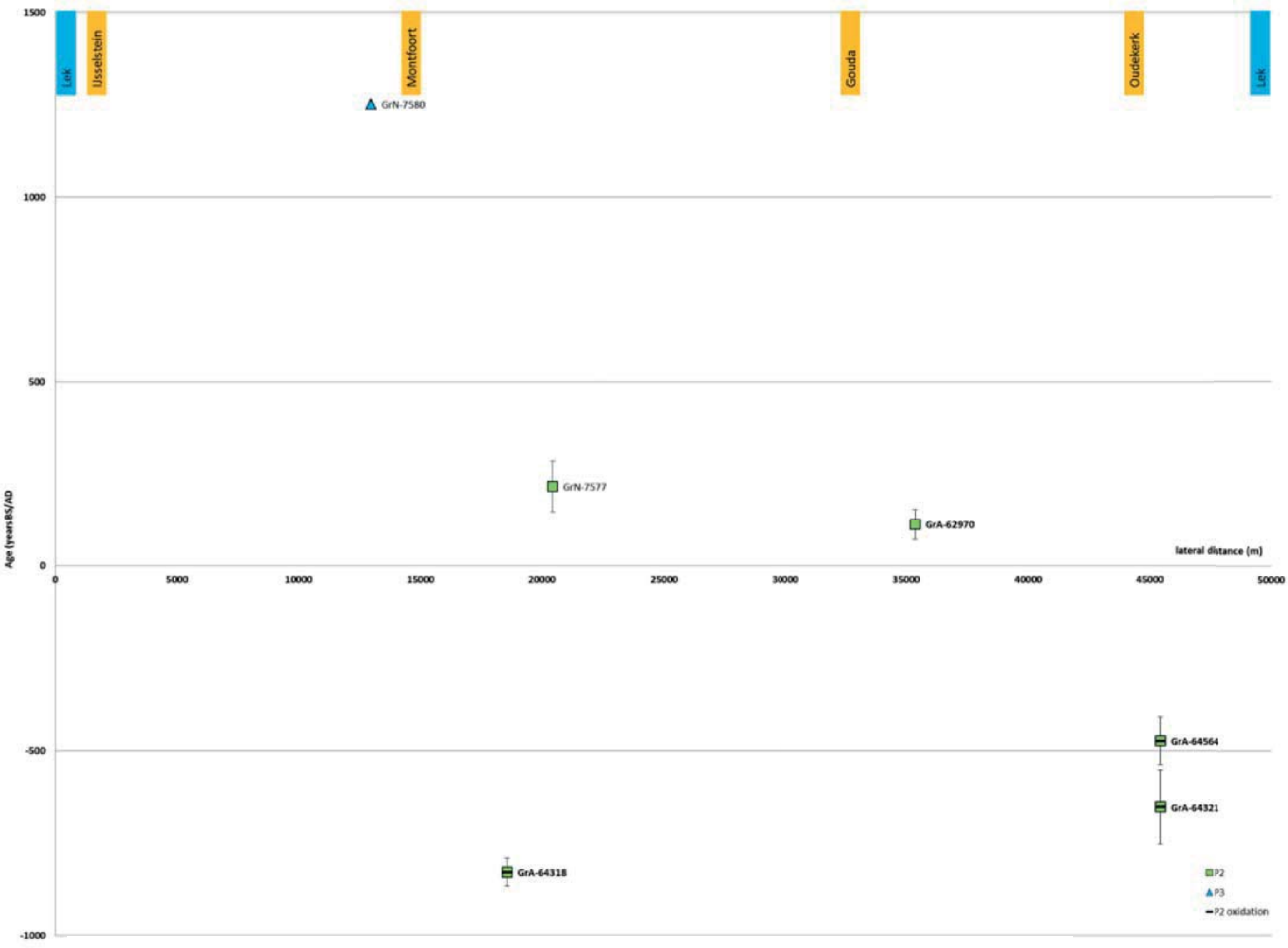


Figure 24 | **Longitudinal distance vs. age for the river Hollandse IJssel**

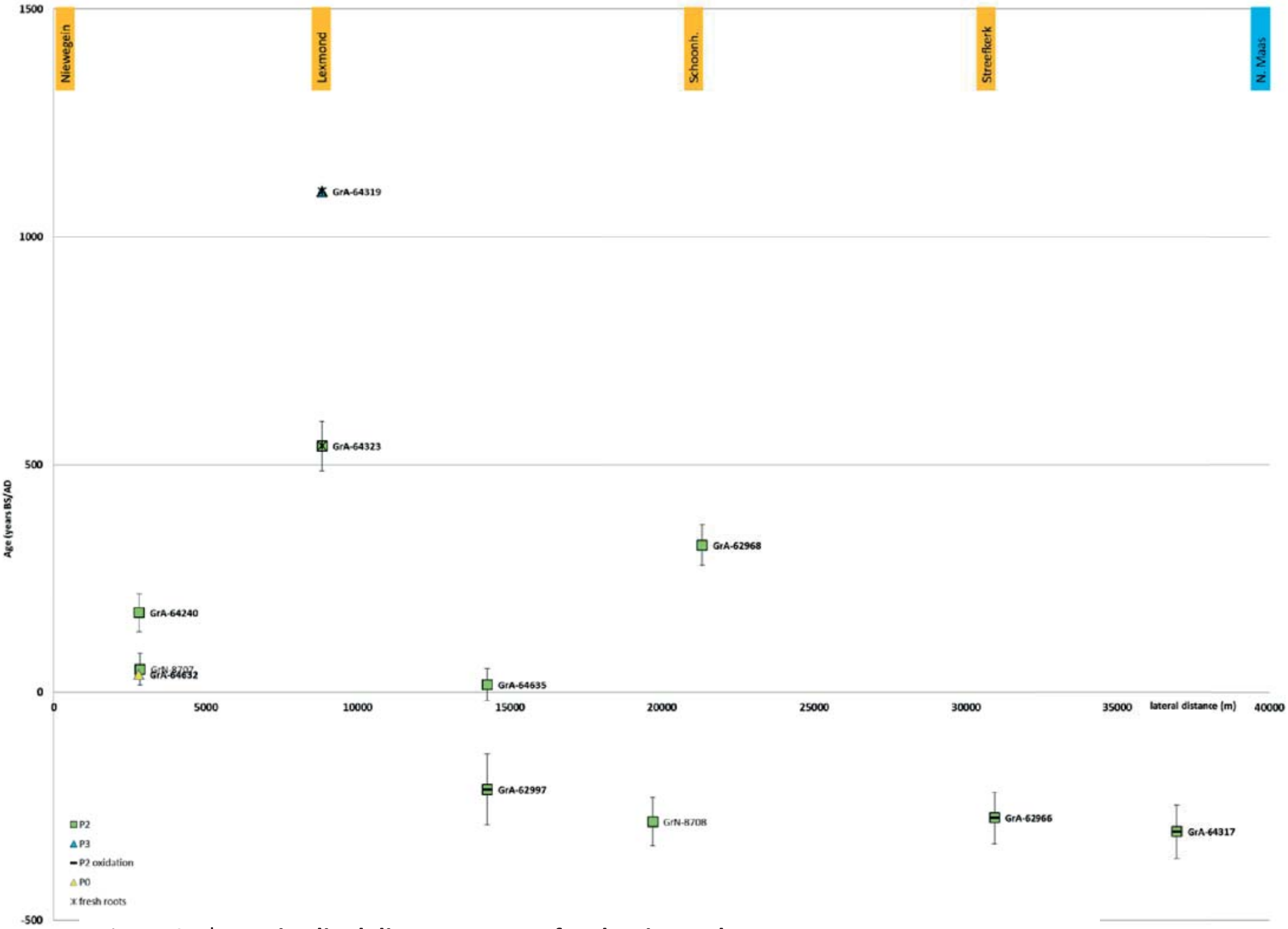


Figure 25 | **Longitudinal distance vs. age for the river Lek**

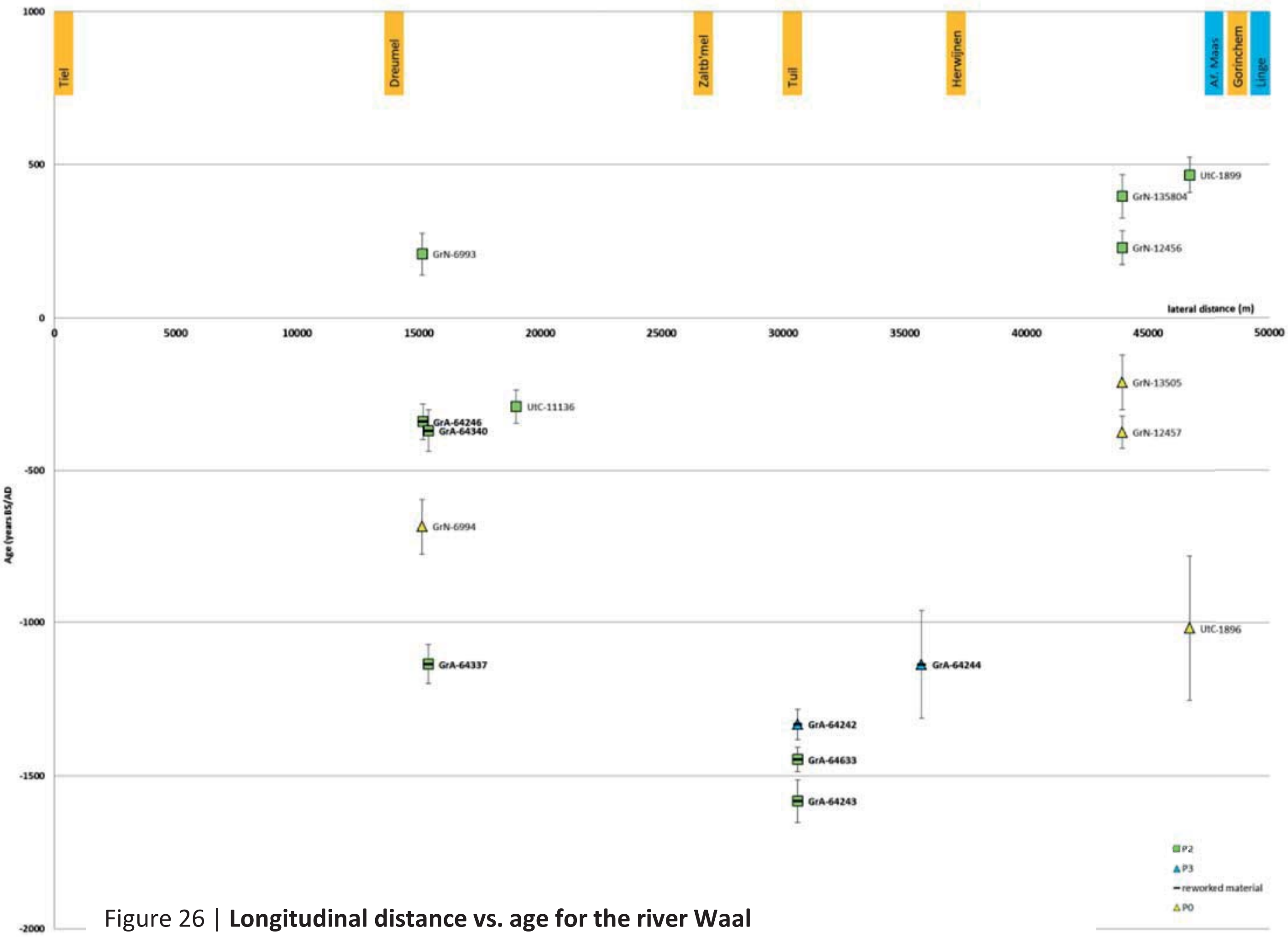


Figure 26 | **Longitudinal distance vs. age for the river Waal**

4.3.2 lateral river channel developments

Figure 28 is showing the lateral distance proximal to the river plotted against age (BC/AD) for the river IJssel. For the river IJssel also trend lines have been added for the phase-II and phase-III dates. A sensitivity analysis revealed, as a result of the number of samples and the variance within them that these trend lines are not as fixed as shown. Especially, the positive trend line for the phase II-dates is depending on date GrA-34961 of which the origin (a peaty layer within sand) is rather questionable. Without this date the trend line is nearly horizontal. Also for the rivers Waal (figure 27), Hollandse IJssel (figure 29) and Lek (figure 30) no clear lateral trend can be deduced from the data.

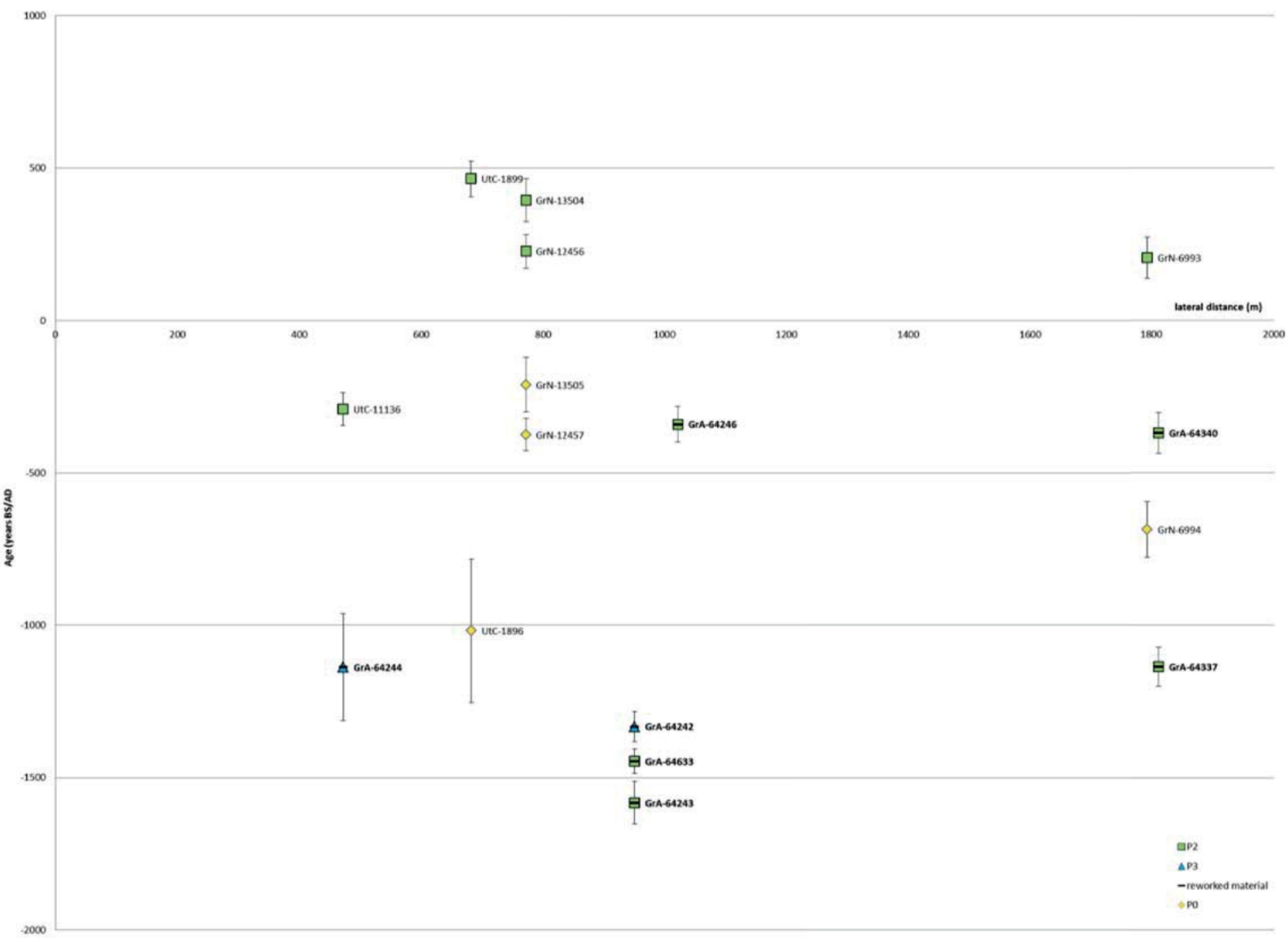


Figure 27 | **Lateral distance vs. age for the river Waal**

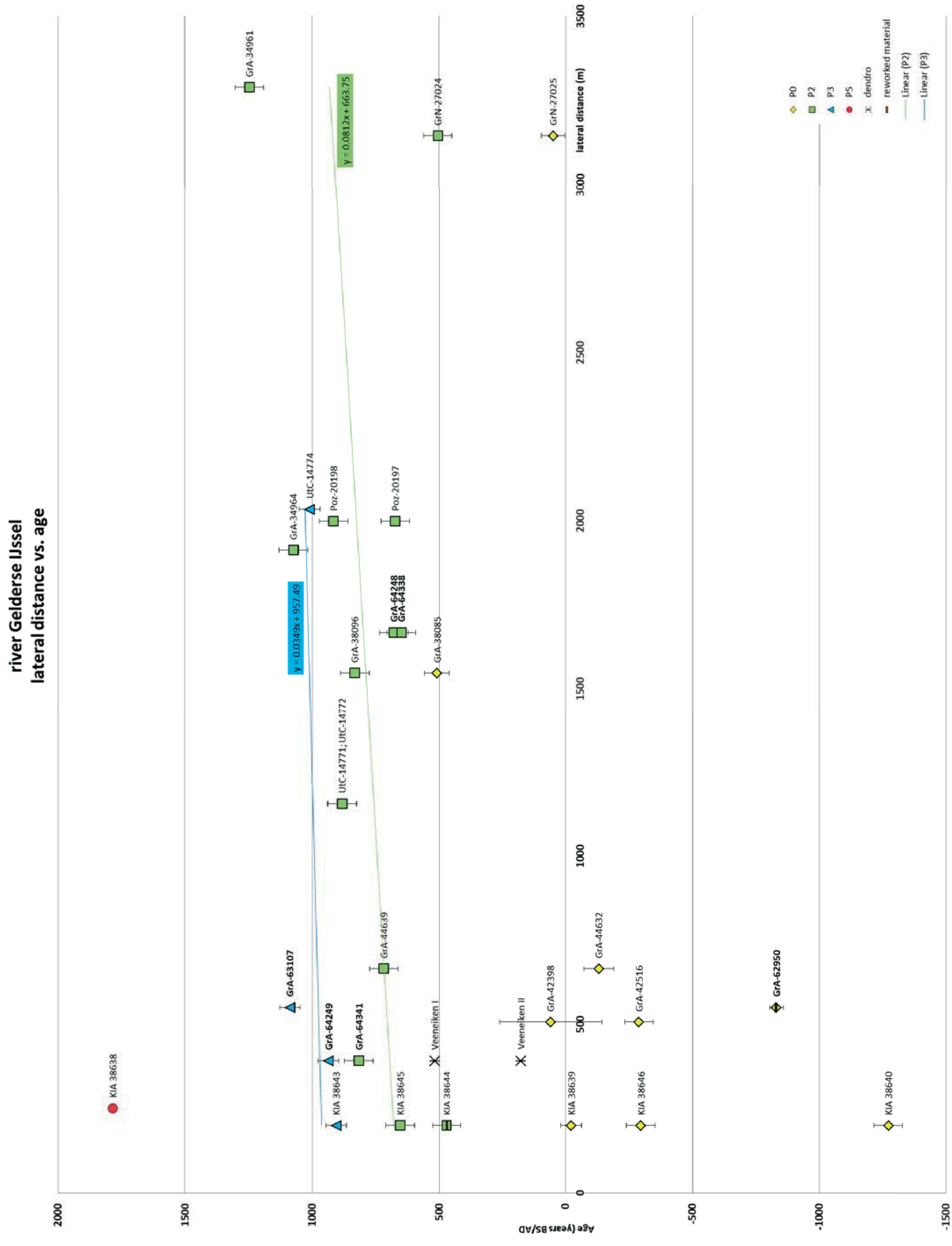


Figure 28 | **Lateral distance vs. age for the river Gelderse IJssel**

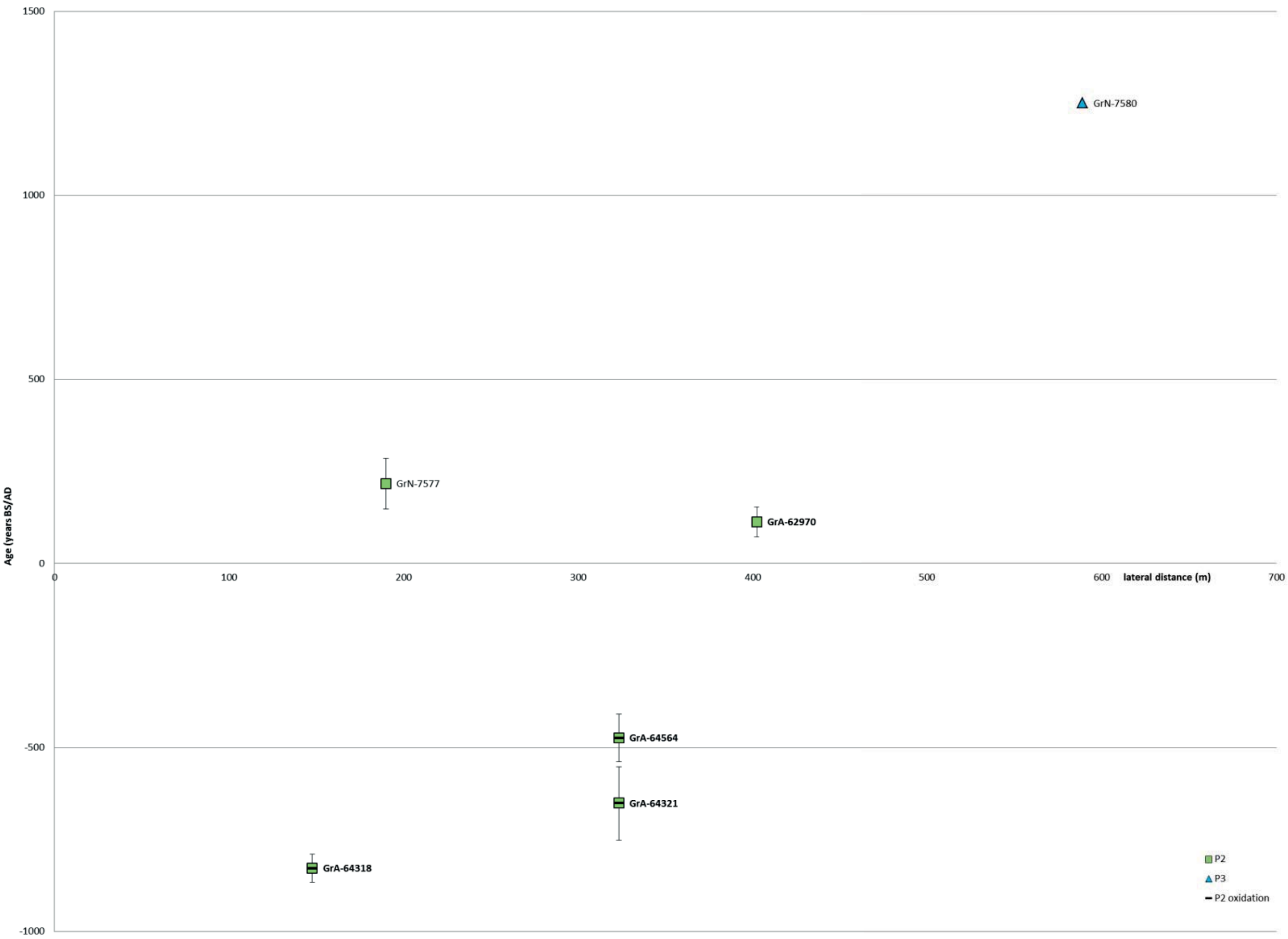


Figure 29 | **Lateral distance vs. age for the river Hollandse IJssel**

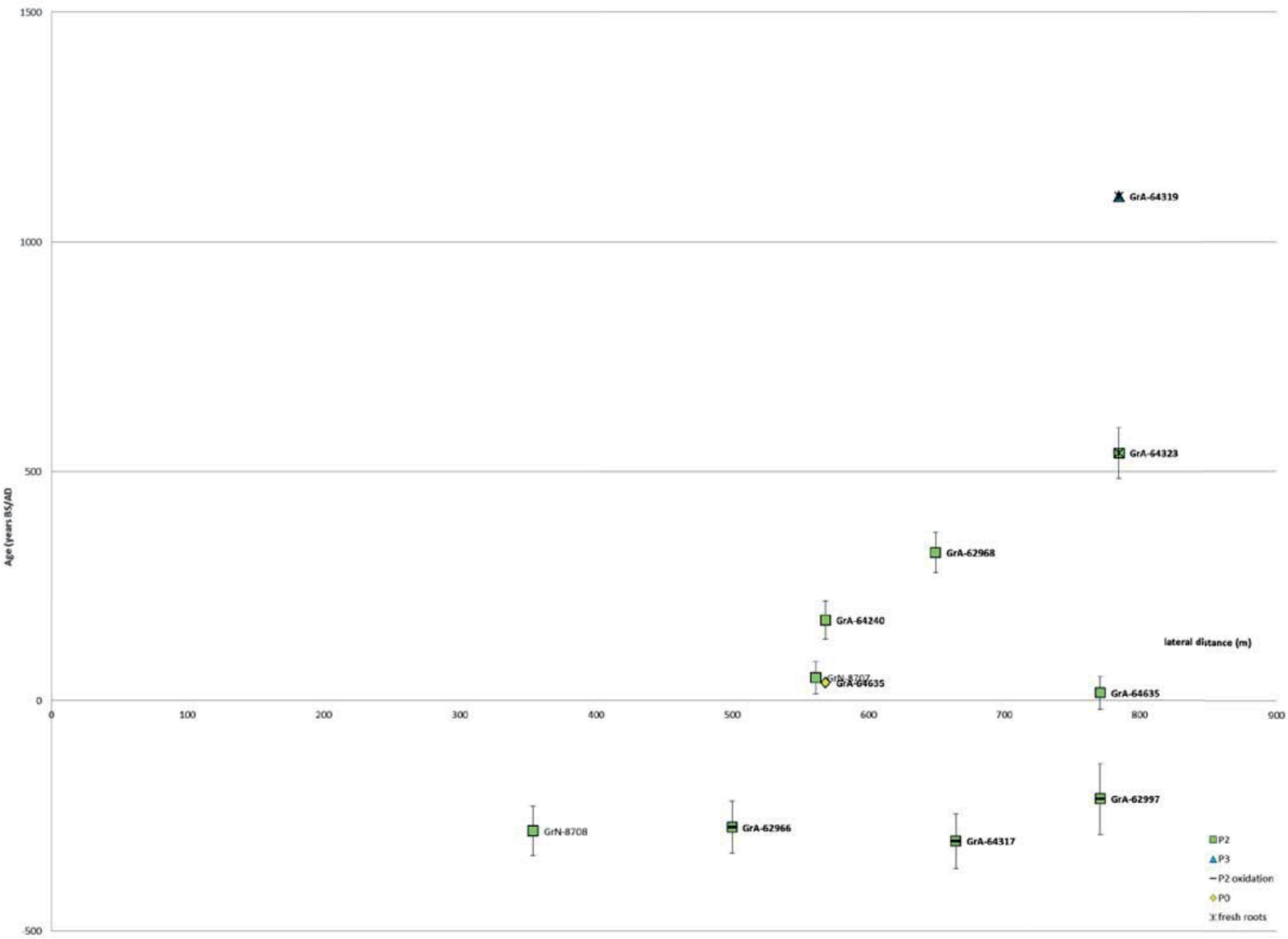


Figure 30 | **Lateral distance vs. age for the river Lek**

5. Discussion

In this discussion first the pitfalls and recommendations of the proposed phase model for multidisciplinary dating and the implementation of existing ^{14}C-dates to new ^{14}C-dates will be outlined (section 5.1). Thereafter implications of longitudinal and lateral spatial diachronicity for future research are discussed (5.2). To make a first contribution to the broader study aim to provide 'an unifying and interconnected description of, and sets of explanations for, the environmental and cultural changes and their interactions in the Netherlands between AD 300 and 1000' (Jansma et al., 2014) implications of river channel development for archaeology (landscape-settlement relations), is discussed in the last section (5.3).

5.1 The use of a phase model for multidisciplinary dating and combining data

The proposed phase model was developed not only for integration of multidisciplinary dating, but also for implementation of existing ^{14}C-dates to new ^{14}C-dates. As an integrated or quality-weighted interpretation of different types of ^{14}C-dates (e.g. bulk vs. AMS-dates) may yield difficulties, it is important to mention in the first place that each ^{14}C-dating has been taken with a specific research goal, a research specific sampling strategy and research specific acceptable error margins. Thereby, every ^{14}C-sample is prone to a local geomorphologic overprint and same event might be reflected by a (slightly) different sediment record: upstream flood plains might consist clayey silt, as more for more downstream parts flood plains consist mainly heavy clays.

In the classification of existing ^{14}C-ages, most of them appeared to be top-of-peat dates (TPQ/ type-1-dates). However, the dated material lithologically ranged from 'slightly humic clay' to 'peat', indicating different sampling locations within clay-peat transitions, indicating a range a of type-1-dates. Most of these clay-peat transitions are gradual, as a direct change might indicate a erosional contact, over intervals up to 30-40 cm. Törnqvist and Van Dijk (1993) took samples <10 cm long from this clay-peat transition and assumed this to represent a time interval of <100 years. For most of the dates only lithological information is available and a lithological cross-section, core description, core photograph or detailed description of the sampled material relative to the surrounding material is missing. Moreover, most of the dating material is sampled at sight and not based on objective analysis such as the LOI-analysis. Analyzing the transitional interval with LOI yields the opportunity to distinguish between first clastic input and a clear blooming-stage of the river (significant clastic signal). Although the identification of the actual break point is still semi-objective, for most of the older dates, the first clastic input and blooming-stage of rivers might have been taken together in one sample. The use of lithological sequence information and LOI in determining the sampling depth improves meaningful further analysis of ^{14}C dates later on. Using LOI is more transparent and makes sub-selection more accurate and verifiable. Old dates (conventional bulk ^{14}C) may still be used and useful, but may need a re-interpretation based on new insights in local stratigraphy. It have to be mentioned though, that also LOI-curves are prone to a local lithological footprint. Boundaries between different phases cannot be directly related to a specific LOI-value.

For rapid aggrading environments, as the Rhine-Meuse delta can considered to be, it has been assumed for a long time (till nineties) that no hiatuses occur at lithologic boundaries (Törnqvist and Van Dijk, 1993). However, top of organic beds may be eroded during deposition of overlying levee material and to a lesser extent of overlying clastic floodplain material (Törnqvist and Van Dijk, 1993). As most of the samples for dating material around medieval times are taken at shallow depths to the surface, especially oxidation of organic material occurred to be a major issue, yielding too old ^{14}C-ages.

The use of the river phase model for multidisciplinary dating has been validated in this research with dendrological information for the site of Vreugderijkerwaard (river *Gelderse IJssel*). Local hydrological information from natural wood appeared to be strongly complementary to carbon dates, especially for the onset of the blooming-stage of the rivers. As ^{14}C-dates and dendrochronological ages might yield a *terminus post quem* ("limit after which") date, archaeological finds and historical data indicate a *terminus ante quem* ("limit before which") and may narrow ages further. Although especially the uncertainty of archaeological data can be assumed to be sometimes too large compared to the time interval in which river maturation takes place. Multidisciplinary event-chronology with the new river phase model as framework might improve dating of rivers even further in the future, as it is not possible to link ^{14}C dates from and archeological founds simply on correlation of the dated years (Cohen et al., 2016).

The phase model itself revealed difficulties with dating phase I. As for most situations phase I is rather a local phenomenon and is characterized more by hydrological changes than actual sedimentary changes, so leaving no clear lithological signal. This phase indicates more a process of development stage than a phase which is defined on paleogeography or lithology, as the other phases are. Introducing a new phase model for river channel development might yield a phase model with a lot of phases, but with questions on dating of each phase. By definition, a balance has to be found between heterogeneity between phases and maximum homogeneity within phases. As mentioned before, with an example of within phase heterogeneity of phase II, ^{14}C-dates within this phase still show a lot of variation.

5.2 Implications of spatial diachronicity

Cohen et al. (2012; 2016) indicated a trend in lateral direction with samples close to the river channel revealing younger dates then samples taken in the floodplain area, mainly based on a first analysis of dates of the river Gelderse IJssel. Analysis of ^{14}C-dates against lateral distance of this research showed that this hypothesis is rather questionable and depending strongly on single ^{14}C-dates. As no lateral trend was found for each of the four rivers. Phase II-dates taken in the floodplain do not have to be corrected for a time-lag effect. As these results are mainly focused on the clastic or lithological footprint of river maturation it is important to mention that a lateral trend for the hydrological wetting phase might still be likely. Difference in compaction of underlying peat by loading of overlying clastic sediment might argue for the opposite hypothesis of ^{14}C dates under natural levees revealing older ages than ^{14}C-dates originating from the floodplain area. By compaction peat is compressed and 1cm peat presumably reflects more time. Moreover, sampling location under natural levees are more likely to erosive contacts.

Even with the use of the river phase model as framework for integration of different ^{14}C-dates, combining all these dates to an integrative view on river maturation continues to be a challenge. Multiple dates at one location, for which with the help of LOI begin of sedimentation and maturation can be dated, seems to be a more favorable approach for future research. For the reasons that it gives more age control (precision) especially when combined with LOI-based sub-sampling. Gathering only clay-on-peat samples on multiple locations gives an optic high accuracy, but with questionable precision of each sample.

In the spatial analysis also no longitudinal trend in river channel development or maturation was visible. However, the composition of original material (peat and clay or sand) and the morphology of the flood plain can be assumed to influence the development time of new rivers as suggested by Hobo (2015). New rivers developed in the eastern part of the Holocene Rhine-Meuse delta migrate in an environment with shallow Pleistocene substrate and relative silty flood basin as in the western part more resistant material is present. Although not assessed in this research, subsurface erodibility is also likely to influence the time of river channel development (Törnqvist, 1993).

5.3 Implications of river channel development for archeology

Specific understanding of the timing of river avulsions may be explanatory for prolonged inhabited settlements or the occurrence of new settlements along new river branches (Cohen et al., 2016). In the Netherlands the clear relation between landscape settings and settlement location has often been suggested (e.g. Van Leusen *et al.*, 2005; Deeben, 2008; Van Beek, 2009). Higher elevated parts in the landscape, such as Holocene channel belts and Pleistocene river dunes were favorable settlement locations in the river area due to their relative elevation in the landscape (e.g. Willems, 1986; Berendsen, 2008). Van Beek (2009) mentioned that, besides changes in subsistence and socio-political and ideological aspects, less attention has been paid so far on the heterogeneity of the paleogeographical landscape development within a large scale landscape. A paleogeographical landscape approach is often used for reconstructions of the physical landscape. However, the recently demonstrated path dependency approach (Zarina, 2010), which asserts that previous human activities in the landscape will influence the subsequent sequence of events, can be seen as a promising new conceptual model in landscape history and again stresses the importance of a multi-disciplinary approach.

Especially in the western part of the delta natural levees might be important determents for land routes and settlements, as they are relatively high areas. First results of a combination of a new levee map and a groundwater model seems to confirm this hypothesis and show regional differences in the importance of natural levees for occupation (H.J. Pierik, *unpublished*). Improved timing on river maturation and abandonment presumably has a large influence on trade routes and therefore cities along the rivers, as is clear from the decay of some IJssel cities coinciding with decreasing discharge and decay of major trading cities with avulsions in the central river area.

6. Conclusion

New ^{14}C-dates did give better insight in the begin of sedimentation ages of the three river branches of the Krimpen river system. First the *Hollandse IJssel* formed (around AD/BC) with discharge from the *Hagestein* river channel, than the upstream part *Lek* formed as a crevasse (175 AD) and later on the downstream part along Schoonhoven was formed (280 AD). Results from the residual channel of Est seem to confirm a begin of sedimentation age of the river *Wa*around 400-450 AD. For the river *Gelderse IJssel* still two scenarios are plausible with begin of sedimentation around 650 AD and 850 AD.

The river phase model proposed in this study was useful for classification of existing and new ^{14}C-dates, although still a large within phase heterogeneity of ^{14}C-date was visible for phase II. Dendrochonological data seems to fit well in the phase model. Future research has to reveal the value of the model for further multidisciplinary research (archaeology, historical data).

Existing begin of sedimentation ages for the rivers were tightened with new ^{14}C-dates. However, longitudinal or lateral trends in river channel development of maturation could not be deduced from the data, so phases seems to be synchronous. Between different phases a difference in time cannot be ruled as, as dates of different phases do not cover the full sequence. For the river *Gelderse IJssel* a maturation time of 119±88 years was received. Comparing the first hydrological signal (phase I) with the mature river phase (phase III) yields a maturation time of 614 years for the river *Gelderse IJssel*.

7. Recommendations for future research

Better insight in river channel development and maturation might contribute to future research on causal understanding of the developments and transition in the history of settlements in the Dutch river plain area. With implementation of archaeological data and historical data into the river phase model the validity for integration of multidisciplinary data by the conceptual model can be tested. Analysis of flood deposits in residual channels and meander cut-offs might, when coupled to phase II dates, increase insights in landscape dynamics which are connected to settlement dynamics (Cohen et al., 2016).

Loss-on-ignition appeared to be a useful tool for sub-sampling. LOI-curves clearly show the local lithological footprint of the sampled core. Future research can be done on the upscaling of those individual LOI-curves to a general river 'LOI-pattern' which is thought to be a good approach in comparing maturation patterns of different rivers. Steep LOI-curves might indicate a generally fast maturation time as gentle LOI-curves indicate a more gradual maturation phase. Also phase IIIb-dates, for example by an increase in clastic input, might be visible along the river (as is was for the Waal-sites Tuil and Hellouw).

Considering sampling strategies for future clay-on-peat transitions, samples can be taken in the flood plain area without a need for a time correction as no lateral aging effect appeared from the spatial analysis. Moreover, coring locations close to the channel belt (natural levee) are more likely prone to erosion rather than sampling locations at greater distance from the river in the flood basin.

Dating of different phases on one sampling location seems to be a more fruitful approach for future river channel maturation research then dating the same event on different places, as the last option is lacking time control. Further insight in the maturation duration of natural rivers can also be iteratively used to validate computer models for river channel development (e.g. Kleinhans et al., 2011). High time and space resolution natural data of avulsion maturation can improve control of such modelling approaches.

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Appendices

Appendix A1 | Loss-on-Ignition procedure

Loss-on-ignition is a method for estimating the organic and inorganic content of sediments, mainly based on the fact that ignition of the sediment at 500-550°C results in the chemical conversion of organic matter in CO_2 and ash. So organic rich sediments result in high LOI-values.

In line with the recommendations of Heiri et al. (2001) sample size, ignition temperatures, exposure times and laboratory measurements were taken as consistent as possible. Samples are weighted before analysis to obtain a sample bulk weight (W). The samples. of about 1cm^3 were dried at 105°C for a period of at least 24 hours. The dried samples are weighted (DW_{105}) and heated at 550°C for a period of 4 hours in an oven. After this ignition of organic matter, the samples are weighted again (DW_{550}). The difference between the sample bulk weight (W) and the dried sample weight (DW_{105}) is assumed to represent the moisture content of the sample. The difference between the dried sample weight (DW_{105}) and the ignited sample weight (DW_{550}) is assumed to represent the organic content of the sample. Using the formula of Heiri et al. (2001) the LOI can be calculated:

$$(1) \quad LOI_{550}(\%) = \frac{DW_{105} - DW_{550}}{DW_{105}} * 100 \qquad DW_{105} = dry\ weigth\ of\ sample\ before\ ignition \quad DW_{550} = weigth\ of\ sample\ after\ ignition$$

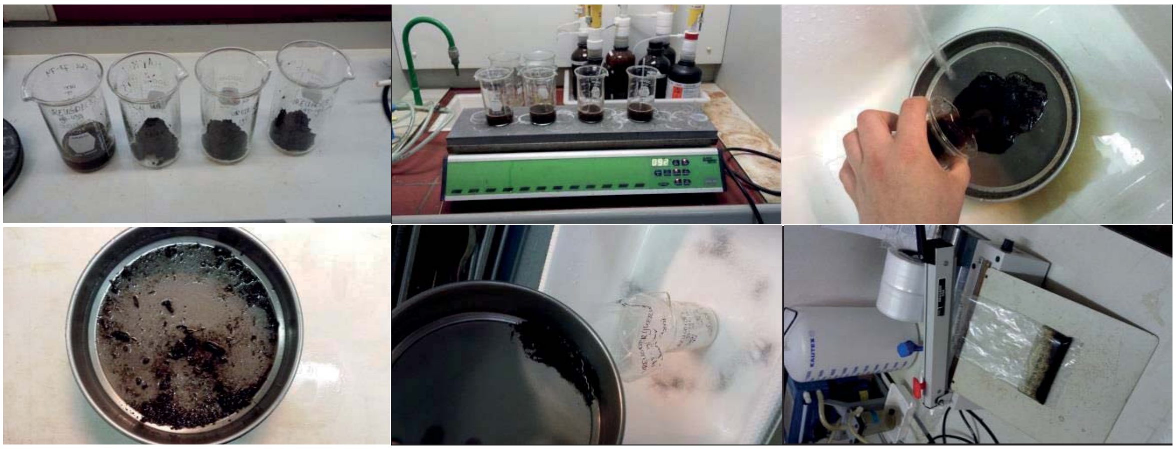
. For a more comprehensive review on this method see Heiri et al. (2001). For LOI-research on the organic infills of pingo remnants Hoek (W.Z. Hoek, Utrecht University, personal communication) made a first attempt to predict LOI-values based on moist percentage. Based on existing LOI-curves and associated moisture content the following empirical relation is suggested:

$$(2)\ LOI_{predicted}(\%) = 0.824 * e^{\frac{W - DW_{105}}{W} * 100 * 0.0521} \qquad W = wet\ weigth\ of\ sample\ before\ heating \quad DW_{150} = weigth\ of\ sample\ after\ heating$$

. The difference between LOI_{550} and $LOI_{predicted}$ might indicate a loss in organic material by irreversible dehydration when peat material was above the water table (and as such an indirect indication for oxidation) as well as it might indicate compaction. For now the formula is also assumed to be valid for clayey deposits, even though further research on validity for these clayey materials is needed. The predicted LOI might differ for different clays minerals and be influenced by the fraction of clay which is drying during either the warming or the ignition phase. For each LOI-graph LOI_{550}, $LOI_{predicted}$ as well as the moist percentage (%) will be presented to support the selection of intervals for AMS ^{14}C-dating.

Appendix A2 | Procedure for preparation of AMS ^{14}C samples

In this appendix the followed procedure for preparation of AMS 14C samples can be found. The procedure is based on (personal) communication with W.Z. Hoek and H.J. Pierik and base protocol of Blaauw (Uva).



(1) Get the macro remain sample out of the core without inter- or intra core contamination.
(2) Warm the macro remains sample with KOH 5% for the necessary time up to a maximum of 90°C (do not boil).
(3) Sieve the boiled sample with a 150mm sieve, rinse thoroughly with demi water.
(4) Work always very clean and use demi water.
(5) The sieves are to be washed with tap- and rinsed with demi- water.
(6) Calcareous samples (e.g. fresh water shells) have already been treated with 5% HCl in this stage of preparation during this research.
(7) Select the material to be dated, either by fishing leaves and branches or fishing all what is nog leaves and branches.
(8) Check carefully and fish a second time.

Next step is the AAA (5%-1%-5%) Procedure (all with millipore water):

(9) Put the selected material in HCl 5%; let is react for 60 minutes.
(10) Filter the material on a stainless steel sieve and rinse with millipore water.
(11) Wash the selected material with NaOH (or KOH) 1% warm for a short time.
(12) Filter the material on a stainless steel sieve and rinse with millipore water.
(13) Put the material in HCl 5% and warm up to 90°C.
(14) Filter the material on a stainless steel sieve.
(15) Rinse the material with millipore water for two or three times.
(16) Weight the bottles.
(17) Put the samples in the little bottles and weigh again for wet weight.
(18) Put the bottles, covered with glass mushroom, in the oven at 80°C for at least a night, but paying attention not to burn the material.
(19) Put the corks in the oven for one night at 30°C.
(20) Close the bottle and weigh the sample.
(21) Monsters are ready to send to Centre of Isotope Research for Radiocarbon dating in Groningen (The Netherlands).

AAA (5%-1%-5%) Procedure (all with millipore water); shortened procedure for samples that were already boiled with 5%KOH (used in this research):

(9) Store the material in vials, in millipore water with a few drops of 5% HCL, at 4°C.
(10) Decant as much water as possible and put the samples in larger glass-ware.
(11) Put the material in HCl 5%; let it react for one night with a glass mushroom on the glass-ware.
(12) Filter the material on a stainless steel or textile mesh sieve and put it in glass again.
(13) Wash the material with millipore water for two or three times until its pH is neutral.
(14) Decant as much water as possible.
(15) Put the material in a petri-dish and check for impurities by binocular.
(16) Put the material in 100ml glass-ware, if enough material is left.
(17) If samples are small (As they are most of the times), put them directly in pre-weighed tin cups. Put these in a 100ml beaker-glass.
(18) Cover glass-ware with glass-mushroom and put in stove at 80°C until samples are dried for one night or two nights for safety.
(19) For large samples; scrape as much of the samples as possible (=4mg) into the tin cups.
(20) Weight the tin cups, close them and bring them to Centre of Isotope Research for Radiocarbon dating in Groningen (The Netherlands).

Samples have been studied by Nelleke van Asch (ADC ArcheoProjecten) for identifying macrofossils before sending them to Centre of Isotope Research for Radiocarbon dating.

More information on sample treatment and measuring ^{14}C using an Accelerator Mass Spectrometer (AMS) can for example be found in Bayliss et al. (2004).

Appendix A3 Lithological core descriptions

Pierik = 2013.07

Schuring = 2015.16

Boorpunt: 201307001 Namen: HJP/KK/ES Jaar: 2013 Groep: 07 Datum: 9-9-2013

Coordinaten		Hoogte	Diepte	KAARTEENHEID	Geomorfogenetische kaart:	Oeverwal
Xco	Yco	Z [m]	[cm]	Geologische kaart:	Grondwatertrap:	
131864	442736	1.25	420	Begroeiingskaart: Weiland	Bodemkaart: Rd10A	

Eerste boring Lek campagne, op oeverwal tussen Lexmond en Vianen. Doel: bovenste veenlaag dateren voor uitbouw Lek

Diepte	Textuur	Org	Plr	Kleur	Redox	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	MZL			brgr	o			2	1				Bo	
20	ZZL			brgr	o			2	1				Bo	
30	ZZL			brgr	o			2	1				Bo	
40	ZZL			brgr	o			2	1				Bo	
50	ZZL			brgr	o			2	1				Bo	
60	MZL			brgr	o			2	1				Bo	
70	ZZL			brgr	o			2	1				Bo	sch rest
80	LK			brgr	o			2	1				Bo	
90	LK			brgr	o			2	1				Bo	
100	MK			brgr	o			2	1				Bk	
110	MK			brgr	o			2	1				Bk	
120	ZK			brgr	o			2	1				Bk	
130	ZK	H2	h	zwgr	or			0	1				Bk	onderste helft is al veen
140		V1	h	zwgr	r			0		GLG			Vb	
150	ZK	H1	hz	zwgr	r			0					Bk	
160	ZK	H0	z	gr	r			0					Bk	zeggewortels
170	ZK		z	gr	r			0					Bk	
180	ZK		rz	gr	r			0					Bk	
190	ZK	H0	rz	grbr	r			0					Bk	
200	ZK	H0	rz	grbr	r			0					Bk	
210	ZK	H0	r	grbr	r			0					Bk	
220	ZK	H0	rz	grbr	r			0					Bk	
230	MK			gr	r			1					Bk	hum. vl. schrest
240	MK			gr	r			1					Bk	riet fragmenten
250	MK			gr	r			1					Bk	
260	MK			gr	r			1					Bk	
270	MK		z	gr	r			1					Bk	
280	MK		z	gr	r			2					Bk	
290	ZK		r	gr	r			0				-	Bk	
300	ZK		rz	gr	r			0				-	Bk	overgang scherp
310		V2	r	br	r			0					Vr	5 cm br onder dgr zk
320		V1	r	dbrgr	r			0					Vr	
330	ZK		r	zwgr	r			0				+	Bk	
340	ZK		z	zwgr	r			0				+	Bk	
350	MK		r	gr	r			0					Bk	
360	MK		rz	gr	r			0					Bk	bovenin humvl
370	MK		rz	gr	r			0					Bk	
380	MK		rz	gr	r			1					Bk	sch-restjes
390	MK	H0	rz	gr	r			1					Bk	cm brgr bandjes
400	MK		rz	gr	r			2					Bk	
410	MK	H0	rz	gr	r			2					Bk	
420	MK		rz	gr	r			2					Bk	

Einde boring: 201307001

Boorpunt: 201307002	Namen: KK/HJP/ES	Jaar: 2013	Groep: 07	Datum: 9-9-2013

Coordinaten		Hoogte	Diepte
Xco	Yco	Z [m]	[cm]
131967	442572	1.18	200

KAARTEENHEID	Geomorfogenetische kaart: Oeverwal
Geologische kaart: F3g	Grondwatertrap: VI
Begroeiingskaart: Weiland	Bodemkaart: Rd10A

Oeverwal tussen Vianen en Lexmond, Doel: veen onder lekklei dateren, monster genomen 120-150

Diepte	Textuur	Org	Plr	Kleur	Redox	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	MZL			brgr	o			2					Bo	
20	MZL			brgr	o			2					Bo	baksteen, grind
30	ZZL			brgr	o			2					Bo	
40	ZZL			brgr	o			2	1				Bo	
50	ZZL			brgr	o			2	1				Bo	
60	MZL			brgr	o			2	1				Bo	
70	MZL			brgr	o			2	1				Bo	
80	MZL			brgr	o			2	1				Bo	
90	LK			brgr	o			2	1				Bo	
100	LK			brgr	o			2	1				Bo	
110	LK			brgr	o			2	1				Bo	MnO2, gevl, schgr
120	MK		plr	gr	r			2			M1		Bk	schrest
130	MK		plr	gr	r			2			M1		Bk	
140	ZK		plr	gr	r			0			M1		Bk	
150	ZK			dbrgr	r			0			M1		Bk	laatste 3 cm veen V1 hout
160		V2	h	dbr	r			0					Vb	BV
170		V2	r	grbr	r			0					Vr	RV
180		V1	r	grbr	r			0					Vr	RV
190		V1	r	grbr	r			0					Vr	RV
200		V1	r	grbr	r			0					Vr	RV

Einde boring: 201307002

Boorpunt: 201307003	Namen: HJP/KK/ES	Jaar: 2013	Groep: 07	Datum: 9-9-2013

Coordinaten		Hoogte	Diepte	KAARTEENHEID	Geomorfogenetische kaart: 1M23-46
Xco	Yco	Z [m]	[cm]	Geologische kaart: F3k	Grondwatertrap: IIIb
127453	441165	0.05	320	Begroeiingskaart: Boomgaar	Bodemkaart: Rn66A

EPE 6.99, Ameide, perenboomgaard. Weersgesteldheid:regen. Doel: veen onder Lek monsteren, Monsters: M1 40-72 en M2 70-107 cm-mv

Diepte	Textuur	Org	Plr	Kleur	Redox	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	MK			brgr										ger+
20	MK			dgr					1					ger
30	ZK		h	dgr					1					
40	ZK			gr							M1			
50	ZK		plr	gr							M1			
60		V1	z	grbr	r						M1			vergane plr
70		V2	z	br	r						M1			
80		V2	r	br	r						M2			
90		V2	r	br	r						M2			5 cm lbr V1
100		V2	r	br	r						M2			
110		V2	rz	br	r									
120		V2	rz	br	r									5cm V1 bandje
130		V3	rz	br	r									RV
140		V3	r	br	r									RV
150		V3	r	br	r									RV
160		V3	rz	br	r									RV, #
170		V2	rz	br	r									
180		V2	rz	br	r									
190		V2	r	br	r									
200		V2	r	br	r									
210		V2	r	br	r									
220		V3	rz	dbr	r							-		5 cm lichte oxidatie
230		V3	r	br	r									
240		V3	r	br	r									#
250		V3	r	dbr	r									
260		V3	r	dbr	r									
270		V2	r	dbr	r									
280		V1		grbr	r									
290		V1		grbr	r									
300		V1	rz	br	r									
310	LK			gr	r			1						
320	LZL			gr	r			2						#

Einde boring: 201307003

Boorpunt: 201307004	Namen: HJP/KK/ES	Jaar: 2013	Groep: 07	Datum: 9-9-2013

Coordinaten		Hoogte	Diepte	KAARTEENHEID	Geomorfogenetische kaart: 2M35
Xco	Yco	Z [m]	[cm]	Geologische kaart: 2F2k	Grondwatertrap: II
112608	436097	0	270	Begroeiingskaart: weiland	Bodemkaart: eMv41C

EPE = 7.9 In percelen west van boorpunt crevassemorfologie, naast een crevassegeul haaks op de Lek cf AHN. Doel: monsters nemen top veen te dateren,
Monsters: M1: 85-127 M2: 45-85

Diepte	Textuur	Org	Plr	Kleur	Redox	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	MK			brgr	o			0	1				Bk	ger
20	MK			grbr	o			0	1				Bk	ger
30	ZK			grbr	o			0	1				Bk	ger
40	ZK			gr	o			0	1				Bk	ger
50	MK		h	gr	o			0	1				Bk	
60	ZK		h	dgrbr	o			0					Bk	organisch aan de punt
70		V2	h	dgrbr	o			0					Vb	
80		V2	h	dgrbr	o			0					Vb	
90		V2	h	dgrbr	o			0					Vb	
100		V2	h	br	r			0		GLG			Vb	
110		V2	hz	br	r			0					Vb	
120		V3	hz	br	r			0					Vb	
130		V3	hz	br	r			0					Vb	
140		V3	hz	br	r			0					Vb	
150		V3	hz	br	r			0					Vb	
160		V3	hz	br	r			0					Vb	
170		V3	hz	br	r			0					Vb	
180		V3	hz	br	r			0					Vb	
190		V3	hz	br	r			0					Vb	
200		V3	hz	br	r			0					Vb	
210		V3	hz	br	r			0					Vb	
220		V3	hz	br	r			0					Vb	
230		V3	hz	br	r			0					Vb	
240		V3	hz	br	r			0					Vb	
250		V3	hz	br	r			0					Vb	
260		V3	hz	br	r			0					Vb	
270		V3	hz	br	r			0					Vb	

Einde boring: 201307004

Boorpunt: 201307005 Namen: HJP/MB/ES Jaar: 2013 Groep: 07 Datum: 12-9-2013

Coordinaten		Hoogte	Diepte
Xco	Yco	Z [m]	[cm]
107533	433761	-155	240

KAARTEENHEID	Geomorfogenetische kaart: 2M35
Geologische kaart: rF2k	Grondwatertrap: II
Begroeiingskaart: Grasland	Bodemkaart: eMv41C

Locatie: Boringen zuidkant van de Lek oostelijk van Nw. Lekkerland, Doel: Veen onder Lek voor datering ontstaan van de Lek, Overg k/v droog, moeilijk te monsteren, Monsters: M1: 46-81; M2 43-86; M3 86-153

Diepte	Textuur	Org	Plr	Kleur	Redox	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	Z-MK			grbr	o			1	0					ger
20	Z-MK			brgr	o			1	0					ger
30	Z-MK			brgr	o			1	1					
40	LK			gr	or			0	1	GHG				
50	LK			gr	or			0	1		M1M2			Mn-concr
60	MK	H0		gr	or			0	1		M1M2			Mn-concr
70		V2	zh	br	or			0	0		M1M2			licht veraard veen, Vzb
80		V2	zh	br	or			0	0	GLG	M1M2			Vb(z)
90		V2	zh	br	r			0	0	GW	M3			Vb(z), iets kleiiger dan boven
100		V2	zh	br	r			0	0		M3			Vb(z)
110		V2	hz	br	r			0	0		M3			#, Vb
120		V2	hz	br	r			0	0		M3			Vb
130		V2	hz	br	r			0	0		M3			Vb
140		V2	hz	br	r			0	0		M3			Vb
150		V2	hz	br	r			0	0		M3			Vb
160		V2	rz	br	r			0	0					#, Vzr
170		V2	hz	br	r			0	0					Vb
180		V2	hz	br	r			0	0					Vb
190		V2	hz	br	r			0	0					Vb, Els
200		V2	hz	br	r			0	0					Vb
210		V2	hz	br	r			0	0					Vb
220		V2	hz	br	r			0	0					Vb
230		V2	hz	br	r			0	0					Vz
240		V2	hz	br	r			0	0					#, Vz

Einde boring: 201307005

Boorpunt: 201307006 Namen: ES/HJP/MB Jaar: 2013 Groep: 07 Datum: 12-9-2013

Coordinaten		Hoogte	Diepte
Xco	Yco	Z [m]	[cm]
103618	439348	-170	230

KAARTEENHEID	Geomorfogenetische kaart: 2M35
Geologische kaart: rA2k	Grondwatertrap: II
Begroeiingskaart: weiland	Bodemkaart: dMv41C

Locatie: Benedenstrooms monster Hollandse IJssel, Doel: 14C monster van laatste veenactiviteit. Stroomrug in diepe ondergrond #134, niet bereikt, M1 45 - 65; M2 65 - 80; M3 48 - 65; M4 80 - 100; M5 100 - 120; M6 120 - 140

Diepte	Textuur	Org	Plr	Kleur	Redox	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	Z-MK		hz	grbr										ger +
20	Z-MK			brgr					1					ger +
30	Z-MK			brgr					1					ger +
40	MK			gr					1		M1			
50	MK			gr					1		M1			Mn-C, overgang binnen 40 cm
60		V2		dgrbr							M1M3			Av1
70		V2		dgrbr							M2M3			Av1
80		V2	zr	dgrbr							M2			Av1
90		V2	hr	dgrbr							M4			Av1
100		V3	zr	dgrbr							M4			plat riet
110		V3	h	br							M5		Vb	
120		V3	hz	br							M5		Vb	els
130		V3	zr	br							M6		Vr	riet rechtop
140		V3	zr	br							M6		Vb	
150		V3	zr	br									Vb	#, plat riet
160		V3	zr	br									Vb	
170		V3	zr	br									Vb	plat riet
180		V3	zr	br									Vb	
190		V3	zr	br									Vb	
200		V3	zr	br									Vb	
210													Vb	Gm
220													Vb	Gm
230													Vb	#, Gm

Einde boring: 201307006

Boorpunt: 201307007 | Namen: MB/ES/HJP | Jaar: 2013 | Groep: 07 | Datum: 12-9-2013

Coordinaten		Hoogte	Diepte
Xco	Yco	Z [m]	[cm]
107948	445419	-170	240

KAARTEENHEID	Geomorfogenetische kaart: 2M35
Geologische kaart: rA0k	Grondwatertrap: II
Begroeiingskaart: grasland	Bodemkaart: pMv81

Locatie: Gouderak, EPE 3.9, Doel: Onstaan Hollandse IJssel (veen onder klei dateren), In paardenwei, Mid-Hol. channels diep, crev in de buurt, M1: 60-75; M2 75-90; M3 90-100; M4 100-120; M5 120-150

Diepte	Textuur	Org	Plr	Kleur	Redox	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	Z-MK			brgr				0	1				Bk	ger
20	Z-MK			brgr				0	1				Bk	ger
30	Z-MK			brgr				0	1				Bk	ger, Mn-C
40	MK			brgr				0	1				Bk	ger
50	MK			gr				0	1				Bk	
60	MK			gr				0	1				Bk	
70	MK	H1	h	brgr				0	1		M1		Bk	
80	MK	H2		brgr				0	1		M1M2		Bk	
90	MK	H1	h	brgr				0	1	GW	M2		Bk	
100	MK	H1	h	brgr				0			M3		Bk	geleidelijke overg.
110		V2	h	br				0			M4		Vb	h+
120		V2	zh	br				0			M4		Vb	h+
130		V3	zh	br				0			M5		Vb	h+
140		V3	zh	br				0			M5		Vb	h+
150		V3	zh	br				0			M5		Vb	h+
160		V3	zh	br				0					Vb	h+
170		V3	zh	br				0					Vb	#, h+
180		V3	zh	br				0					Vb	h+
190		V3	zh	br				0					Vb	h+
200		V3	zh	br				0					Vb	h+, 1 groen plat rietje
210		V3	zh	br				0					Vb	h+
220		V3	zh	br				0					Vb	h+
230		V3	r	br				0					Vr	h+
240		V3	zh	br				0					Vb	#, h+

Einde boring: 201307007

Boorpunt: 201307010	Namen: HJP/HW/TW/RvL	Jaar: 2013	Groep: 07	Datum: 23-5-2014

Coordinaten		Hoogte	Diepte
Xco	Yco	Z [m]	[cm]
120993	439622	-0.7	240

KAARTEENHEID	Geomorfogenetische kaart: 2M22
Geologische kaart: F3k	Grondwatertrap: IIIb
Begroeiingskaart: Weiland	Bodemkaart: Rn44C

Lek bij Langerak, dichtbij Wiel. Overgang klei-veen mooi. M1a 140-115; M1b 114-95; M1C 95-65 cm-mv.

Diepte	Textuur	Org	Plr	Kleur	Redox	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	LK			dbrgr	o			2					Bk	
20	LK			dbrgr	o			2					Bk	
30	LK			grbr	o			2					Bk	
40	LK			grbr	o			2					Bk	
50	LK			grbr	o			2					Bk	
60	LK			gr	or			2			M1		Bk	
70	ZK			dgr	r			1			M1		Bk	
80	ZK	H1		dgr	r			1			M1		Bk	
90		V2		dbr	r			0			M1		Vb	brokkelig, compact
100		V1	h	brgr	r			0			M1		Vb	geleidelijke overg
110		V1	h	brgr	r			0			M1		Vb	compact
120		V1	h	brgr	r			0			M1		Vb	
130		V1	h	brgr	r			0			M1		Vb	
140		V1	rh	brgr	r			0			M1		Vb	
150		V2	rh	br	r			0					Vb	geleidelijke overgang
160		V2	rh	br	r			0					Vb	els
170		V2	rh	br	r			0					Vb	#, els
180		V2	h	orbr	r			0					Vb	elshout
190		V2	h	orbr	r			0					Vr	niet compact, donkerder
200		V2	h	orbr	r			0					Vr	
210		V2	h	dbr	r			0					Vr	riet rechtop
220		V2	r	dbr	r			0					Vr	
230		V2	r	dbr	r			0					Vr	#
240														GM

Einde boring: 201307010

Boorpunt: 201307011 Namen: HJP/HW/TW/RvL Jaar: 2013 Groep: 07 Datum: 26-5-2014

Coordinaten		Hoogte	Diepte	KAARTEENHEID	Geomorfogenetische kaart: 1M46
Xco	Yco	Z [m]	[cm]	Geologische kaart: F3k	Grondwatertrap: II
117889	447562	-1.6	180	Begroeiingskaart: weiland	Bodemkaart: kVb

EPE 4.7 Hollandse IJssel Oudewater. Veen ondiep en bovenste 30cm geoxideerd. Te ver van Hollandse IJssel af (300 m) Foto M2a 84-67; M2b 67-51; M2c 51-30

Diepte	Textuur	Org	Plr	Kleur	Redox	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	MK			dgrbr	o				1					
20	MK			dgrbr	o				1					
30	MK			grbr	o				1		M2			
40	MK	H2		grbr	o				1		M2			
50		V3		dbr	o						M2			geoxideerd
60		V3		dbr	o						M2			geoxideerd; slap
70		V3		dbr	o						M2			geoxideerd; slap
80		V3	r	br	r					GW	M2			slap
90		V3	h	br	r									
100		V3	h	br	r									
110		V3	rh	br	r									
120		V3	rh	br	r									
130		V3	rh	br	r									
140		V3	rh	br	r									
150		V3	rh	br	r									
160		V3	rh	br	r									
170		V3	rh	br	r									
180		V3	rh	br	r									#

Einde boring: 201307011

Boorpunt: 201307012 Namen: HJP/HW/TW/RvL Jaar: 2013 Groep: 07 Datum: 23-5-2014

Coordinaten		Hoogte	Diepte
Xco	Yco	Z [m]	[cm]
120955	450321	-1.5	160

KAARTEENHEID	Geomorfogenetische kaart: 3K26
Geologische kaart: F3k	Grondwatertrap: IV
Begroeiingskaart: weiland	Bodemkaart: Rn47C

EPE 5 Lange Linschoten, in kom, veen is hier te geoxideerd. Boring verplaatst naar stroomrugje

Diepte	Textuur	Org	Plr	Kleur	Redox	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	MK			grbr	o									
20	MK			grbr	o									
30	MK			grbr	o									
40	ZK	H2		dgr	o									geoxideerd veen
50		V1	plr	zw	o									oxidatie, wel plr
60		V1	plr	zw	o					GW				oxidatie, wel plr
70		V1	h	brgr	o									
80		V1	h	brgr	o									
90		V1	h	brgr	r									
100		V1	h	brgr	r									
110		V3	h	br	r									
120		V3	h	br	r									
130		V3	h	br	r									
140		V3	h	br	r									
150		V3	h	br	r									
160		V3	h	br	r									#

Einde boring: 201307012

Boorpunt: 201307013	Namen: HJP/HW/TW/RvL	Jaar: 2013	Groep: 07	Datum: 26-5-2014

Coordinaten		Hoogte	Diepte
Xco	Yco	Z [m]	[cm]
120855	450244	-1.1	160

KAARTEENHEID	Geomorfogenetische kaart: 3K26
Geologische kaart: F3k	Grondwatertrap: IV
Begroeiingskaart: weiland	Bodemkaart: Rn47C

EPE 6.1, Lange Linschoten op flankje oeverwal.

Diepte	Textuur	Org	Plr	Kleur	Redox	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	MK			gr	o			0						ger, klak-concr
20	MK			gr	o			0						ger, klak-concr
30	MK			gr	o			0						ger, klak-concr
40	MK			gr	o			0	1					
50	MK			gr	o			1	1					
60	MK			gr	o			1	1					
70	MK			gr	o			0	1					
80	ZK	H1		dgr	o			0						
90		V1		brgr	o			0						
100		V2		br	r			0						
110														
120														
130														
140														
150														
160														

Einde boring: 201307013

Boorpunt: 201307014 Namen: HJP/HW/TW/RvL Jaar: 2013 Groep: 07 Datum: 23-5-2014

Coordinaten		Hoogte	Diepte
Xco	Yco	Z [m]	[cm]
120839	450244	-0.7	180

KAARTEENHEID	Geomorfogenetische kaart: 3K26
Geologische kaart: F3k	Grondwatertrap: IV
Begroeiingskaart: weiland	Bodemkaart: Rn47C

EPE 3.5 Lange Linschoten, hoogste deel dichtbij de weg. Veen is hier niet geoxideerd, maar grens klei-veen is erosief.

Diepte	Textuur	Org	Plr	Kleur	Redox	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	LK			dgr				0					Bo	ger, baksteen
20	LK			dgr				0					Bo	ger, baksteen
30	LK			gr				0					Bo	ger, baksteen
40	LK			gr				0					Bo	kalkconcreties
50	LK			gr				0					Bo	kalkconcreties
60	LK			gr				0					Bo	kalkconcreties
70	LK			gr				0					Bo	kalkconcreties
80	LK			gr				0					Bo	
90	LK			gr				0					Bo	
100	LK			gr				0		GW			Bo	
110	MK			grbr	o			0	1				Bo	
120	ZK			grbr	o			0	1				Bo	
130	ZK			gr				0	1				Bo	Brokjes veen
140		V1		br				0					Vr	overgang zeer scherp
150	ZK	H2		gr				0					Bk	
160	ZK	H2		gr				0					Bk	
170		V3	r	br				0					Vr	
180		V3	r	br				0					Vr	#

Einde boring: 201307014

Boorpunt: 201307015 Namen: HJP/HW/TW/RvL Jaar: 2013 Groep: 07 Datum: 23-5-2014

Coordinaten		Hoogte	Diepte
Xco	Yco	Z [m]	[cm]
120848	450247	-0.9	160

KAARTEENHEID	Geomorfogenetische kaart: 3K26
Geologische kaart: F3k	Grondwatertrap: IV
Begroeiingskaart: weiland	Bodemkaart: Rn47C

EPE 4.6 Lange Linschoten, tussen boring 13 en 14. Veen op 80, licht geoxideerd. Monsters: M3a 125-100; M2b 100-87; M3c 87-60 cm-mv

Diepte	Textuur	Org	Plr	Kleur	Redox	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	MK			dgr	o									
20	MK			dgr	o									
30	MK			dgr	o									
40	MK				o				1					
50	MK				or				1					
60	MK				or				1	GW	M3			
70	ZK				or						M3			
80		V2			or						M3			
90	ZK	H1			or				1		M3			
100		V1			r						M3			
110		V3	r	br	r						M3			
120		V3	r	br	r						M3			
130		V3	r	br	r									
140		V3	h	br	r									
150		V3	h	br	r									
160		V3	h	br	r									#

Einde boring: 201307015

Boorpunt: 201307016	Namen: HJP/HW/TW/RvL	Jaar: 2013	Groep: 07	Datum: 23-5-2014

Coordinaten		Hoogte	Diepte	KAARTEENHEID	Geomorfogenetische kaart:
Xco	Yco	Z [m]	[cm]	Geologische kaart:	Grondwatertrap:
122463	448833	0	260	Begroeiingskaart:	Bodemkaart:

EPE 5.3 M4a 90-80; M4b 80-40 M4c brokkelig opnieuw hele guts meegenomen

Diepte	Textuur	Org	Plr	Kleur	Redox	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	MK			dgrbr	o			0	0					
20	MK			dgrbr	o			0	0					
30	MK			grbr	o			0	1					
40	MK			grbr	o			0	1		M4			
50	MK			grbr	or			0	1		M4			
60	MK			grbr	or			0	1		M4			
70	MK	H2		dgr	or			0	1		M4			
80		V2	h	dbr	or			0	0		M4			
90		V2	h	dbr	or			0	0		M4			
100		V2	h	dbr	or			0	0		M4			
110		V2	h	dbr	r			0	0	GW	M4			
120		V2	h	dbr	r			0	0		M4			
130		V2	h	dbr	r			0	0					geleidelijke overgang
140	ZK		h	gr	r			0	0					
150	ZK		h	gr	r			0	0					
160		V1	h	orbr	r			0	0					geleidelijke overgang
170		V3	h	orbr	r			0	0					
180		V3	h	orbr	r			0	0					
190		V3	h	orbr	r			0	0					
200		V3	h	orbr	r			0	0					# elshout
210	MK		h	gr	r			0	0					
220	MK		h	gr	r			0	0					veel hout
230	MK		h	gr	r			0	0					
240			h	gr	r			0	0					
250			h	gr	r			0	0					
260			h	gr	r			0	0					#

Einde boring: 201307016

Boorpunt: 201516001 Namen: HJP TS HW Jaar: 2015 Groep: 16 Datum: 1-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
191457	210452	RD	-0.65	270

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart: gras	Bodemkaart:

GPA = 3.9m prospectieboring GRAFHORST

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	MZL			grbr	o			2						
20	MZL			grbr	o			2						
30	MZL			grbr	o			2						
40	MZL			grbr	o			2						
50	MZL			grbr	o			2						
60	MZL			grbr	o			2						
70	MZL			grbr	o			2						
80	MZL			grbr	o			2						
90	MZL			grbr	o			2						
100	MZL			grbr	o			2						
110	MZL			grbr	o									
120	MZL		r	gr	r									
130	UFZ	H0		gr	r		50-105							
140	LK	H0		dgr	r			0						1cm zandband sch.gr.
150	LK	H0		dgr	r			0						
160	LK	H1		dgr	r			0						sch
170	LK	H1		dgr	r			0						sch
180	LK	H0		dgr	r			0						GM
190	LK	H0		dgr	r			0						#
200	LK	H0		dgr	r			0						plr
210	LK	H0		dgr	r			0						plr
220		V3		br	r			0						5cm MZ125 sch gr /1 zand=Ca2
230		V3		br	r			0						zegge
240		V3		br	r			0						zegge
250		V3		br	r			0						zegge
260		V3		br	r			0						
270		V3		dbr	r			0						#

Einde boring: 201516001

Boorpunt: 201516003 Namen: HJP TS HW Jaar: 2015 Groep: 16 Datum: 1-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
191512	510417	RD	-0.21	370

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart: gras	Bodemkaart:

GPA = 5.0 boring in ander weiland, meer richting dijk (verder weg van Ganzerdiep) boer = 0302721444 GRAFHORST 1A 100-160 GRAFHORST 1B 120-220

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	LK			brgr	o									ger
20	LK			brgr	o									
30	LK			brgr	o									schgr
40	MZL			brgr	o			2						schgr
50	MZL			brgr	o			2						
60	MZL			brgr	o			2						
70	MZL			brgr	o			2						
80	ZZL			brgr	o			2						1cm zand
90	ZZL			brgr	o			2						
100	LK	H0		brgr	o									
110	LK	H1		brgr	o									
120	LK	H1		gr	or									# /6
130	LK	H1		dgr	r									plr /6
140	LK	H1		grbr	r									/6
150		V1		dbr	r									/6
160		V2		dbr	r									
170		V3	hz	dbr	r									bz stuk hout
180		V3	zh	dbr	r									z
190		V3	z	dbr	r									
200		V3	z	br	r									#
210		V3	zr	br	r									#
220		V3	rz	br	r									
230		V3	rz	br	r									tikje compact
240		V3	rz	br	r									
250		V3	rz	br	r									
260			rz	br	r									# GM
270		V3		br	r									#
280		V3	zh	br	r									
290		V3	zh	br	r									
300		V3	zh	br	r									
310		V3	zh	br	r									
320		V3	zh	br	r									
330		V3	z	br	r									
340		V3	z	br	r									
350		V3	z	dbr	r									# /1
360	Z			zw	r			0						# zand gevoeld
370	Z			zw	r			0						# zand gevoeld

Einde boring: 201516003

Boorpunt: 201516004 Namen: HJP TS HW Jaar: 2015 Groep: 16 Datum: 1-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
192986	508190	RD	-0.66	350

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart:	Bodemkaart:

Oosterhold GPA = 5.0m in weiland naast weg +/- 50m van oosterhold, donkje +/- 30m van weg OOSTERHOLD 1 40-110 -mv OOSTERHOLD 2 120-155 (basisveendatering) OOSTERHOLD 3 30-105

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	LK			grbr										ger
20	LK			grbr										
30	LK			grbr										
40	ZK			grbr	or				1					
50	ZK			grbr	or				1					ger baksteen
60		V3		br	r									els, lichtgeaard
70		V3	z	br	r									
80		V3	hz	br	r									
90		V3	hz	br	r									#
100		V3	hz	br	r									
110		V3	hz	br	r									
120		V3	hz	br	r									
130		V3	hz	br	r									
140	FZ	H2		zw	r		150-210							
150		V3		zw	r									zandige bijmenging
160	FZ	H2		zw	r		150-210							# wortel
170	FZ	H2		zw	r		150-210							#
180	FZ	H2		zw	r		150-210							
190	FZ	H2		zw	r		150-210							
200	FZ	H2		zw	r		150-210							
210	FZ	H2		zw	r		150-210							#
220	FZ	H2		br	r		150-210							$
230	MZ			grbr	r		210-300							grovere bijmenging
240	MZ			gebr	r		210-300							
250	MZ			gegr	r		210-300							geel
260	MZ			gegr	r		210-300							
270	MZ			gegr	r		210-300							
280	MZ			gegr	r		210-300							
290	MZ			gegr	r		210-300							
300	MZ			gr	r		210-300							
310	ZFZ			gr	r		105-150						TD	lemig bandje op overgang (5cm)
320	ZFZ			gr	r		105-150						TD	
330	ZFZ			gr	r		105-150						TD	
340	ZFZ			gr	r		105-150						TD	
350	ZFZ			gr	r		105-150						TD	$

Einde boring: 201516004

Boorpunt: 201516005 Namen: HJP TS RVL Jaar: 2015 Groep: 16 Datum: 7-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
157750	428460	RD	4.95	420

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart: gras	Bodemkaart:

in weiland direct achter huis GPA = 4.6m

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	LK			dgrbr				1	0				Bo	
20	LK			dgrbr				1	0				Bo	
30	LK			dgrbr				1	0				Bo	
40	LK			dgrbr				1	0				Bo	
50	LK			dgrbr				1	0				Bo	
60	LK			dgrbr				2	0				Bo	
70	ZZL			dgrbr				2	0				Bo	
80	ZZL			brgr				2	1				Bo	Fe-con schgr
90	ZZL			brgr				2	2				Bo	schgr
100	MZL			brgr				2	2				Bo	schgr
110	MZL			brgr				2	2				Bo	schgr
120	MZL			brgr	o			2	2				Bo	Mn-con
130	MZL			brgr	o			2	2				Bo	
140	MZL			brgr	o			2	2				Bo	sch
150	MZL			brgr	or			2	2	GW			Bo	Mn-con sch
160	MZL			brgr	or			2	2				Bo	Mn-con sch
170	LK			dgr	or			2	2				Bo	
180	MK			grbr	or			0					Bo	#
190	MK			grbr	or			0					Bo	
200	LK			grbr	or			0					Bo	
210	LK			gr	r			0					Bo	/2
220	LK		plr	gngr	r			0					Bo	plr
230	LK		plr	gngr	r			0					Bo	plr
240	ZZL			gr	r			0					Bo	
250	ZZL			gr	r			0					Bo	#
260	ZZL			gr	r			0					Bo	#
270	FZ			gr	r		150-210	0					Bo	
280	ZK	H0		gr	r			0					Bk	1cm zand
290	ZK	H1	plr	dgr	r			0				+	Bk	1cm heumeuze geband bovenin pl
300	ZK	H1		dgr	r			0				+	Bk	plr
310	ZK	H1		gr	r			0					Bk	
320	ZK		r	gr	r			0					Bk	riet
330	ZK			gr	r			0					Bk	# 335 5 cm veel riet
340	ZK			gr	r			0					Bk	#
350	ZK			gr	r			0					Bk	witte concreties
360	ZK			gr	r			0					Bk	#
370														#, GM
380														GM
390														GM
400														GM
410														GM
420														#, GM

Einde boring: 201516005

Boorpunt: 201516006 Namen: HJP TS RVL Jaar: 2015 Groep: 16 Datum: 7-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
157764	428471	RD	5.05	420

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart: gras	Bodemkaart:

GPA = 5.0m +/- 50m naast 201516006 datering Waal begin monsterboring kern DREUMEL I 210-270

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	Z-LK			dgrbr	o			0					Bo	ger
20	Z-LK			dgrbr	o			0					Bo	ger
30	Z-LK			dgrbr	o			2					Bo	ger
40	Z-LK			dgrbr	o			2					Bo	ger
50	Z-LK			dgrbr	o			2					Bo	ger baksteen
60	MZL			brgr	or			2	2				Bo	Mn-con sch
70	MZL			brgr	or			2	2				Bo	Mn-con sch
80	MZL			brgr	or			2	2				Bo	
90	MZL			brgr	or			2	2				Bo	sch
100	MZL			brgr	or			2	2	GW			Bo	sch
110	LK			gr	or			2	1				Bo	#
120	LK			gr	or			2	1				Bo	
130	ZK			brgr	or			2	1				Bo	hele schelpen
140	ZK			brgr	or			2	2				Bo	Mn-con sch
150	ZK			brgr	or			2	2				Bo	Mn-con sch
160	ZK	H1		dgr	or			2	0			-	Bk	
170	ZK			gr	or			0	0				Bk	
180	ZK			gr	or			0	0				Bk	#
190	ZK			gr	or			0	1				Bk	#
200	ZK			gr	or			0	1				Bk	ijzervlekjes
210	ZK		plr	gr	or			0	1				Bk	plr
220	LK		plr	dgr	or			1	1				Bk	plr
230	ZK	H2	plr	gr	r			0	0			+	Bk	
240	ZK			gr	r			0	0				Bk	
250	ZK			gr	r			0	0				Bk	
260	ZK		plr	gr	r			1	0				Bk	# plr
270	ZK		plr	gr	r			1	0				Bk	# plr
280	ZK			gr	r			0	0				Bk	
290	ZK		plr	gr	r			0	0				Bk	plr
300	ZK		r	brgr	r			0	0				Bk	plr r
310	ZK	H1	plr	zwgr	r			0	0			+	Bk	plr
320	ZK	H1	r	zwgr	r			0	0			+	Bk	plr r
330	ZK		h	brgr	r			0	0				Bk	plr h
340	ZK		plr	brgr	r			0	0				Bk	# plr
350	ZK			gr	r			0	0				Bk	# witte concreties
360	ZK			dgr	r			0	0			-	Bk	witte concreties
370	ZK			gr	r			0	0				Bk	witte concreties
380	ZK			gr	r			0	0				Bk	
390	LZL			gr	r			0	0					
400	LZL			gr	r			0	0					
410	LZL			gr	r			0	0					
420	LZL			gr	r			0	0					

Einde boring: 201516006

Boorpunt: 201516007 Namen: HJP TS RVL Jaar: 2015 Groep: 16 Datum: 7-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
158392	427943	RD	3.7	260

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart: fruit	Bodemkaart:

GPA 3.8m Dating waal begin VENUSWEG I = 90-190 -mv VENUSWEG II = 90-170-mv

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	ZZL			brgr				0	0				Bk	
20	ZZL			brgr				0	0				Bk	
30	ZZL			brgr				0	0				Bk	
40	ZZL			brgr				0	0				Bk	
50	LK		plr	brgr				0	2				Bk	
60	MK			brgr				0	2				Bk	
70	MK			brgr				0	1				Bk	
80	MK	H0		dgr				0	1			-	Bk	
90	MK		plr	gr				0	2				Bk	
100	ZK	H2	plr	dgr				0					Bk	
110	ZK	H2	plr	dgr				0					Bk	
120		V1		dgrbr				0					Vr	#
130	ZK			gr				0					Bk	
140		V1	r	dgrbr				0					Vr	
150		V2	r	dgrbr				0					Vr	
160	LK	H2	r	zw				0				+	Bo	Bo/Bc stug
170	LK		r	gr				0					Bo	Bo/Bc
180	LK		r	gr				0					Bo	Bo/Bc
190	LK		r	gr				0					Bo	Bo/Bc
200	LK		r	gr				0					Bo	# Bo/Bc
210	LK		r	gr				0					Bo	# Bo/Bc
220	LK		r	gr				0					Bo	Bo/Bc
230	LK		r	gr				0					Bo	Bo/Bc br-hum-b-riet
240	LK		r	gr				0					Bo	Bo/Bc
250	LK		r	gr				0					Bo	Bo/Bc
260	LK		r	gr				0					Bo	Bo/Bc

Einde boring: 201516007

Boorpunt: 201516008 Namen: HJP TS Jaar: 2015 Groep: 16 Datum: 7-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
136525	446303	RD	0.94	70

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart: gras	Bodemkaart:

GPA = 3.7m boring bij Lekdijk

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	LK			brgr										ger kiezel
20	LK			brgr										zandige bijmening
30	LK			brgr										
40	LK			brgr										
50	MZL			brgr										
60	MZL			brgr										
70	MZL			brgr										einde boring; harde laag/buis

Einde boring: 201516008

Boorpunt: 201516009 Namen: HJP TS Jaar: 2015 Groep: 16 Datum: 7-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
136524	446308	RD	0.88	320

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart: gras	Bodemkaart:

Datering Lek oostkant A27 NIEUWEGEIN I = 1.10-2.10 -mv

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	LK			brgr	o			0	0					ger
20	LK			brgr	o			0	0					ger
30	LK			brgr	o			0	0					ger
40	LK			brgr	o			0	0					ger
50	LK			brgr	o			0	0					ger baksteen
60	LK			brgr	o			0	0					
70	LK			brgr	o			0	0					
80	LK			brgr	or			0	1					
90	ZK			gr	or			0	1					Mn-con
100	ZK			gr	or			0	1	GW				kiezel
110	MK			gr	or			0	1					siltig
120	MK		plr	gr	or			0	1					siltig, plr
130	ZK	H0	plr	dgr	r			0	0					# plr
140	ZK	H2	plr	zw	r			0	0			-		plr
150		V2	r	dbr	r			0	0					riet
160	ZK	H2	r	zw	r			0	0					riet, geoxideerd?
170		V1		br	r				0					# plr r
180		V1	r	br	r				0					#
190		V3	r	br	r				0					riet
200		V3		br	r				0					riet /6
210		V1	rz	br	r				0					
220	ZK		r	gr	r				0					plr riet
230	ZK		r	gr	r				0					plr riet
240	LK		r	gr	r				0					# plr riet
250	MK			gr	r			1	0					# siltig
260	MK		plr	gr	r			1	0					siltig plr
270	MK		plr	gr	r			1	0					siltig plr
280		V1	z	gr	r			1	0					5cm veen zegge, plr
290	LK		plr	gr	r			1	0					
300	LK		r	gr	r			1	0					plr riet
310	LK		r	gr	r			1	0					plr riet
320	LK		r	gr	r			1	0					# plr riet

Einde boring: 201516009

Boorpunt: 201516010 Namen: HJP TS Jaar: 2015 Groep: 16 Datum: 7-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
136246	446379	RD	0.78	260

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart: gras	Bodemkaart:

GPA = 3.4m Dating Lek ter vervanging van Berendsen 1950 14-C naast peilbuis NIEUWEGEIN II 210-260, 3 meter van peilbuis

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	LK			brgr					1					ger grind
20	LK			brgr					1					ger
30	LK			brgr					1					ger
40	LK			brgr					1					ger
50	LK			brgr					1					ger
60	LK			brgr					1					ger
70	LK			brgr					1					ger
80	LK			brgr					1					ger
90	MK			dbrgr					1					
100	MK			gr					1					
110	MK	H1		dgr					1					
120	ZK	H1		dgr					1					
130	ZK	H1		dgr				0	1					
140	ZK	H2		dgr				0	1					
150	ZK			dgr				0	1					
160	ZK			dgr				0	1					
170	ZK			gr				0	1					
180	ZK			gr				0	1					
190	ZK			gr				0	1					
200	ZK			gr				0	1					# stug
210	ZK			gr				0	0					stug groene vlekjes
220	ZK			gr				0	0					#
230	ZK	H0		gr					0					#
240	ZK	H1		gr					0					
250	ZK	H2		gr					0					gelaagd
260	ZK	H1		dgr					0					#

Einde boring: 201516010

Boorpunt: 201516011 Namen: HJP TS HW AVE Jaar: 2015 Groep: 16 Datum: 15-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
150305	429803	RD	2.76	180

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart: gras	Bodemkaart:

restgeul EST prospectieboring 1 mogelijk rand van de restgeul > boring richting kas, verste van weg af

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	Z-MK			grbr				0	0					ger
20	Z-MK			grbr				0	1					ger
30	Z-MK			grbr				0	1					ger
40	ZK			brgr				0	1					
50	ZK			brgr				0	1					Mn-con
60	ZK			gr				0	2					Mn-con
70	ZK			gr				0	2					Mn-con
80	ZK			gr				0	2					Fe-con
90	ZK			gr				0	2					
100	MK			gr				0	2					#
110	ZK	H1		dgr				0						
120		V2		br				1						gyttja-achtig
130		V1		br				1						gyttja-achtig
140		V1		br				2						gyttja-achtig sch
150		V1		br				2						gyttja-achtig sch
160	MK	H1		gngr				2						gyttja-achtig sch
170	MK	H1		dgr				2						gyttja-achtig schgr
180	MZ			gngr			210-420	2						#, gyttja-achtig siltig

Einde boring: 201516011

Boorpunt: 201516012	Namen: HJP TS HW AVE	Jaar: 2015	Groep: 16	Datum: 15-4-2015

Coordinaten			Hoogte	Diepte	KAARTEENHEID	Geomorfogenetische kaart:
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]	Geologische kaart:	Gondwatertrap:
150298	429818	RD	2.54	220	Begroeiingskaart: gras	Bodemkaart:

restgeul Est prospectieboring 2, meer richting weg EST IV-A 110-200 met Bohnke, 35cm monster GECOMPACTEERD EST IV-B 142-200 met Bohnke, 58cm monster GECOMPACTEERD EST IV-C 110-210 met brede guts, goed monster

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	Z-MK			grbr	o				0					ger
20	Z-MK			grbr	o				0					ger
30	Z-MK			grbr	o				1					ger
40	MK			grbr	o				2					
50	MK			brgr	o				2					
60	MK			brgr	o				2					
70	MK			brgr	o				2					
80	MK			brgr	o				2					
90	MK			brgr	o				2					
100	MK			gr	o				2					
110	MK			gr	or				1					
120	MK			grbr	r									#
130		V1		grbr	r			1						gyttja-achtig blad (foto)
140		V1		br	r			1						gyttja-achtig kleibandje
150		V2		br	r			2						gyttja-achtig sch/schgr zan.-b
160		V1		br	r			2						gyttja-achtig sch
170	MK	H2		gngr	r			2						gyttja-achtig sch schgr
180		V1		gngr	r			2						gyttja-achtig
190		V1		gngr	r			2						# gyttja-achtig schgr
200	MZ			gngr	r		210-420	2						# PS siltig
210	MZ			gr	r		210-420	2						PS
220	MZ			gr	r		210-420	2						# PS

Einde boring: 201516012

Boorpunt: 201516013 | Namen: HJP TS HW AVE | Jaar: 2015 | Groep: 16 | Datum: 15-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
150292	429840	RD	2.41	260

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart: gras	Bodemkaart:

restgeul Est GPA = 4.6m boring meest richting straat, aan rand van weiland EST IIIA = 110-160 EST IIIB = 160-230 EST IIIC = 230-264 (230-280, 16cm zand verlies)

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	Z-MK			grbr	o			0						ger, z-bijm
20	Z-MK			grbr	o			0						ger, z-bijm
30	Z-MK			grbr	or			1	1					ger, GZ
40	Z-MK			grbr	or			1	1					ger, GZ
50	MK			grbr	or			1	1					
60	MK			grbr	or			0	2					
70	MK			brgr	or			0	1					
80	MK			gr	or			0	1					
90	ZK			gr	r			1						stug
100	ZK			gr	r			1						stug
110	ZK			gr	r			2						slap
120	ZK			gr	r			2						# slap
130	ZK			brgr	r			2						schgr
140	ZK			brgr	r			2						schgr
150	ZK			brgr	r			2						sch schgr
160	MK	H0		brgr	r			2						
170	MK	H1	r	brgr	r			2						# schgr
180	ZK	H2	r	gr	r			2						#
190	MZL	H2	rz	gr	r			2						
200	MZL			gr	r			2						
210	MZL			gr	r			2						z-band
220	MZL			gr	r			2						
230	MZL			gr	r			2						z-bad, blad
240	MZL			gr	r			2						cm-z-band
250	MK	H2		zw	r			2						/1 z-bijm
260	MZ			dgr	r		210-420	2						# PS, siltig, /1

Einde boring: 201516013

Boorpunt: 201516014 Namen: HJP TS HW AVE Jaar: 2015 Groep: 16 Datum: 15-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
150295	429827	RD	2.53	220

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart:	Bodemkaart:

tussenboring guts kern gecomprimeerd, z-diepte klopt tussen 012 en 013 ingenomen.

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	Z-MK			grbr										ger
20	Z-MK			grbr										ger
30	Z-MK			grbr										ger
40	MK			grbr										
50	MK			grbr										
60	MK			grbr										
70	MK			grbr										
80	MK			grbr										
90	MK			gr										
100	MK			gr										
110	MK			gr										#
120		V3		br				1						
130		V2		br				1						
140		V3		br				2						doorworteld
150		V2		br				2						gyttja-achtig
160		V2		br				2						gyttja-achtig sch
170		V2	plr	br				2						gyttja-achtig
180		V2	plr	grbr				2						gyttja-achtig
190		V1	plr	gngr				2						gyttja-achtig blad
200		V1	plr	gngr				2						gyttja-achtig
210		V1	plr	gngr				2						gyttja-achtig
220	MZ			gngr			210-420	2						# PS siltig

Einde boring: 201516014

Boorpunt: 201516015	Namen: HJP TS HW AVE	Jaar: 2015	Groep: 16	Datum: 15-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
121219	453506	RD	-0.28	250

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart: gras	Bodemkaart:

prospectieboring restgeul Linschoten duidelijk zichtbaar als laagte in grasland bemonstering HJP

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	MK			brgr				0						
20	MK			brgr				0						
30	MK			brgr				0	1					
40	MK			gr				0	2					
50	MK			gr				0	2					
60	ZK			gr				0	2					
70	ZK			gr				0	2					
80	ZK			gr	o			0	2					
90	ZK			dgr	o			0	2					hout band / veenbrok
100	ZK			dgr	o			0	2					
110	ZK	H1		dgr	o			0	2					geoxideerd
120	LK	H1		gr	o			2	2					# geoxideerd
130	LK			gr	o			2	0					1cm zand +org
140	LK			gr	o			2	0					5cm zavel, geband
150	MZL		r	gr	o			2	0					geband
160	MZL		r	gr	o			2	0					geband
170	MZL		rh	gr				2	0					# geband
180	MZL			gr				2	0					#
190	MZL			gr				2	0					
200	MZL			gr				2	0					
210	MZL			gr				2	0					
220	FZ			gr			150-210	2	0					
230	FZ			gr			150-210	2	0					GM
240	FZ			gr			150-210	2	0					GM
250	FZ			gr			150-210	2	0					#GM

Einde boring: 201516015

Boorpunt: 201516016 Namen: HJP TS HW AVE Jaar: 2015 Groep: 16 Datum: 15-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
121214	453503	RD	-0.51	170

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart:	Bodemkaart:

restgeul LINSCHOTEN GPA 3.6m 2 meter naast 015 LINSCHOTEN 1A 0-60 onder slootpeil LINSCHOTEN 1B 20-120 onder slootpeil

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	MK			dgr										
20	MK			dgr										
30	MK			dgr										
40	MK			brgr					1					
50	MK			brgr					1					
60	MK			brgr					2					baksteen
70	MK			brgr					2					
80	MK			brgr					2					
90	MK	H2		brgr					2					
100		V2		dbr					1					#
110		V2		dbr										
120	ZK	H1		br										/3
130	ZK			gr										
140	ZK			gr										FZ
150	MZL			gr										1 cm zandband
160	MZL			gr										5cm zandband
170	MZL			gr										

Einde boring: 201516016

Boorpunt: 201516017 Namen: HJP TS HW AVE Jaar: 2015 Groep: 16 Datum: 15-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
121223	453491	RD	-0.35	170

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart: gras	Bodemkaart:

GPA = 4.2m boring meer van sloot af, drassig (nat), water aan maaiveld, lastig boorbaar

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	ZK			gr										
20	ZK			gr										
30	ZK			gr										
40	ZK			gr										
50	ZK			gr										
60	ZK			gr										
70	MK			gr				0	2					stug
80	MK	H1		dgr				0	2					stug
90	MK	H1		dgr				0	1					
100		V1		br				0	1					/5
110		V1		br					1					
120	ZK	H2	plr	br					1					plr roestvlekken geband
130	MZL		plr	gr										plr geband
140	MZL		plr	gr										geband
150	FZ			gr			150-210							1cm plr-b geband
160	LK		plr	gr										5cm FZ band
170	LK			gr										

Einde boring: 201516017

Boorpunt: 201516018 Namen: HJP TS Jaar: 2015 Groep: 16 Datum: 21-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
144798	426257	RD	2.68	350

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart:	Bodemkaart:

EPE 5.5m boring waal, achterin boomgaard TUIL IA 140-225 -mv TUIL IB 225-284-mv TUIL II 200-288 -mv

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	MK			grbr				0	0				Bo	
20	MK			grbr				0	0				Bo	
30	MK			brgr				0	0				Bo	
40	MK			brgr				0	0				Bo	
50	MK			brgr				0	0				Bo	
60	LK			brgr				0	0				Bo	sch
70	LK			brgr				0	0	GHG			Bo	
80	LK			brgr				0	1				Bo	
90	LK			brgr				1	1				Bo	
100	ZZL			brgr				1	1				Bo	
110	LK			grbr				1	2				Bo	
120	ZZL			grbr				1	2				Bo	
130	ZZL			blgr				1	2			-	Bo	
140	ZZL			brgr				2	1				Bo	
150	MZL			grbr				2	2				Bo	
160	MZL			grbr				2	2				Bo	#
170	LK			grbr				1	1	GLG			Bo	
180	LK			gr				1	0					siltig, slap
190	LK	H0	h	dgr				0	0					siltig, slap, hout
200	LK		plr	gr				0	0					siltig, slap
210	LK			gr				0	0					siltig, slap
220	LK	H0	plr	dgr				0	0					siltig, slap
230	LK			gr				0	0					gelaagd siltig
240		V1		br				0	0				Vb	# gel overg
250		V2	h	br				0	0				Vb	#
260	LK		r	gr				0	0				Bk	veenvlek, verstoord in boring
270	LK	H0		dgr				0	0				Bk	slap
280	ZZL			gr				2	0				Bo	
290	ZZL			gr				2	0				Bo	
300	MZL		h	gr				2	0				Bo	
310	MZL		h	gr				2	0				Bo	
320				gr				2	0					#
330	LZL		plr	gr				2	0				Bb	# kleibandje
340	LZL		plr	gr				2	0				Bb	
350	MZ		plr	gr			210-420	2	0				Bb	# PS

Einde boring: 201516018

Boorpunt: 201516019 Namen: HJP TS Jaar: 2015 Groep: 16 Datum: 21-4-2015

Coordinaten			Hoogte	Diepte
XCO	YCO	Coord. sys	Z [m +/- NAP]	[cm]
140238	425906	RD	1.48	450

KAARTEENHEID	Geomorfogenetische kaart:
Geologische kaart:	Gondwatertrap:
Begroeiingskaart:	Bodemkaart:

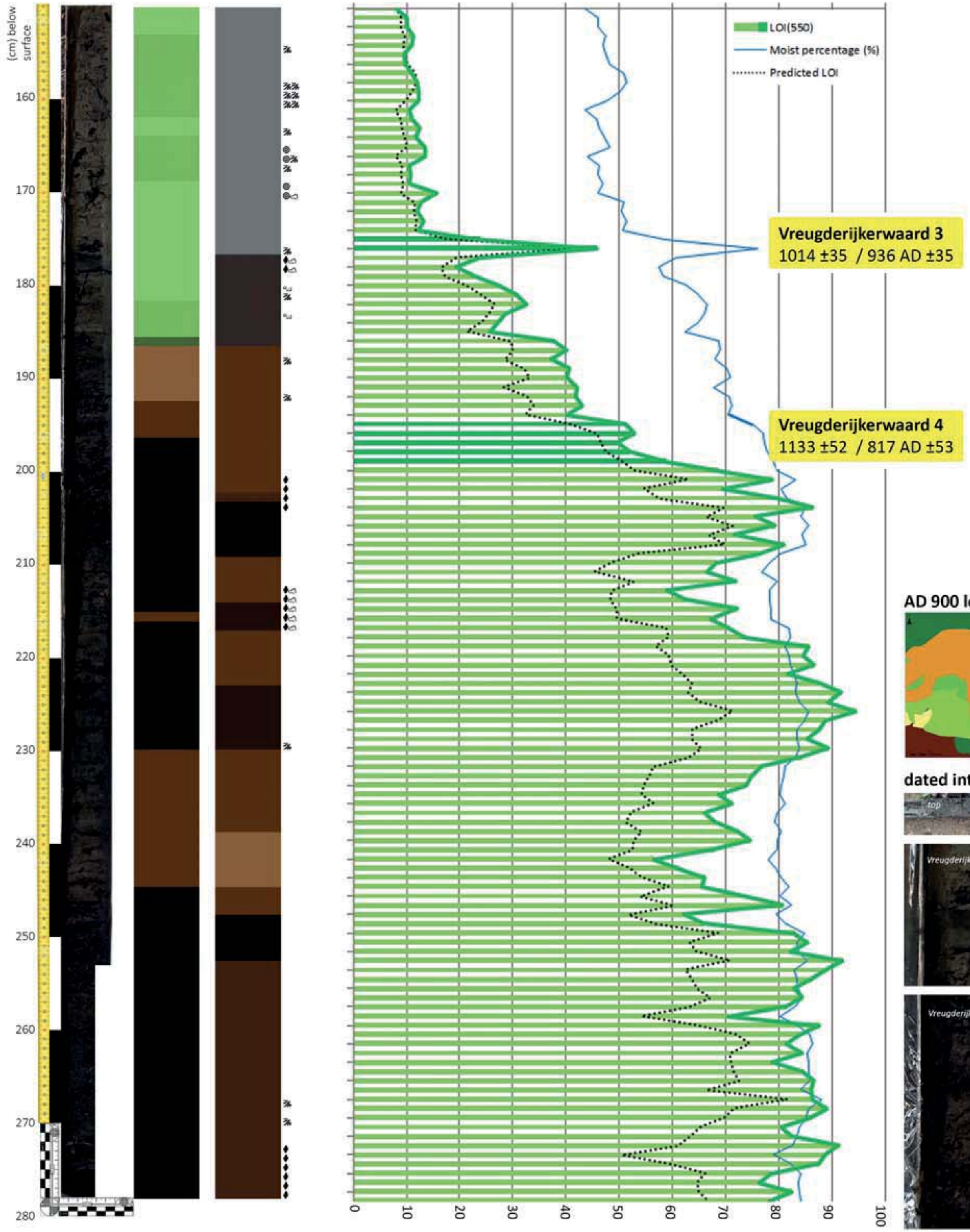
Boring monstername begin Waal EPE = 3.4 boring enkele 10tal meters van Waal-dijk locatie WAAL-C (Schuring) HELLOUW I 153-240 HELLOW II 160-225 > veen scheef geboord

Diepte	Textuur	Org	Plr	Kleur	RedOx	Grind	M50	Ca	Fe	GW	M	LKL	Strat	Bijzonderheden
10	MZL			grbr	or			2	1				Bo	ger
20	MZL			grbr	or			2	1				Bo	ger
30	MZL			grbr	or			2	1				Bo	ger
40	ZZL			grbr	or			2	1				Bo	
50	ZZL			grbr	or			2	1	GLG			Bo	
60	MZL		r	gr	r			2	0				Bo	
70	MZL		r	gr	r			2	0				Bo	
80	LZL		r	gr	r			2	0				Bo	z-laag
90	LZL		r	gr	r			2	0				Bo	#
100	LZL		r	gr	r			2	0				Bo	gelaagd
110	LZL		plr	gr	r			2	0				Bo	gelaagd
120	LZL		plr	gr	r			2	0				Bo	detritus-laag
130	MZL		plr	gr	r			2	0				Bo	detritus-laag
140	MZL		plr	gr	r			2	0				Bo	schgr
150	MZL		plr	gr	r			2	0				Bo	z-band
160	MZL		plr	gr	r			2	0				Bo	
170	ZZL		plr	gr	r			2	0				Bo	# geleidelijk
180	MK	H1		br	r			1	0				Bo	# detritus-lagen
190		V3		br	r			1	0				Vr	
200		V2		br	r			1	0				Vr	
210	ZK	H2		zw	r			1	0			+	Bk	
220	ZK	H0	r	dgr	r			1	0			+	Bk	schgr
230	ZK		r	dgr	r			2	0			-	Bk	fifianiet-con gela.overgng
240	ZK		r	gr	r			2	0				Bk	fifianiet-concreties
250	MK		r	gr	r			2	0					# sch
260	MK			gr	r			2	0					
270	MK			gr	r			2	0					
280	MK		h	gr	r			2	0					
290	MK			gr	r			2	0					schgr
300	MK			gr	r			2	0					schgr
310	MK		hr	gr	r			2	0					#
320	LK		hr	gr	r			2	0					sch
330	LK			gr	r			2	0					
340	LK	H1		gr	r			2	0					geband, schgr
350	LK	H1		gr	r			2	0					geband, schgr
360	LK		r	gr	r			2	0					schgr
370	LK		r	gr	r			2	0					#
380	MK		r	gr	r			2	0					
390	MK	H2	r	brgr	r			2	0					
400	MK	H1	r	gr	r			1	0					zw-band
410	MK		r	gr	r			1	0					
420	MK		r	gr	r			1	0					
430	MK	H0	r	gr	r			1	0					gelaagde overgang
440		V1	r	grbr	r			1	0					gelaagde overgang
450		V2	r	br	r			1	0					#

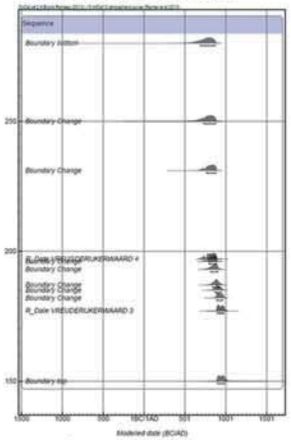
Einde boring: 201516019

I | river Gelderse IJssel | VREUGDERIJKERWAARD

x = 198968, y = 502969, z = +0.56 NAP



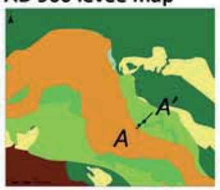
sequence dating model



samples and C14-dates

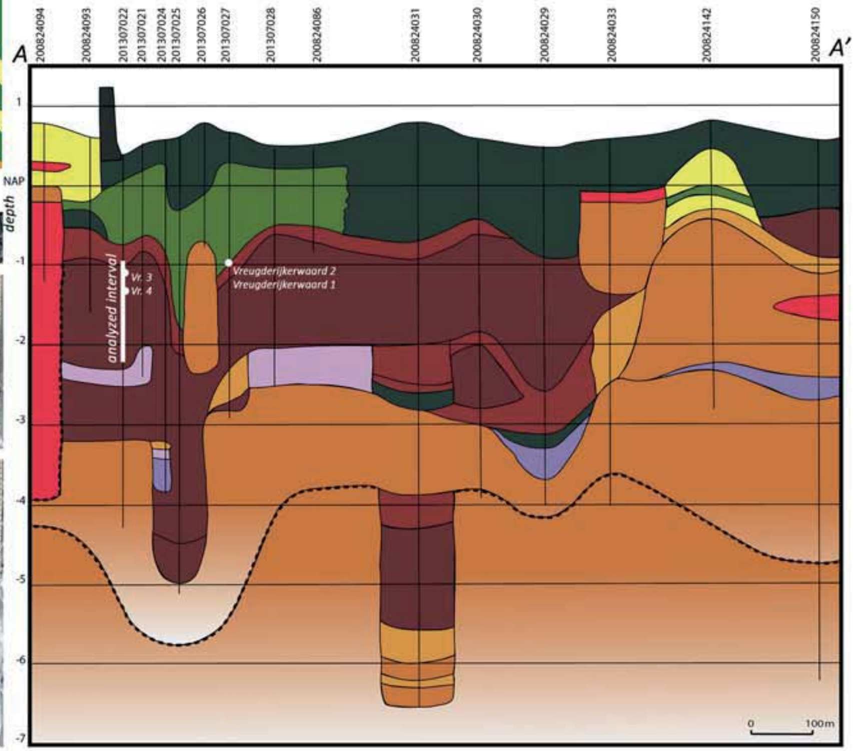
Sample	Lab nr.	Lab age ±error	$\delta^{13}C$	Location (x,y) RD New-coordinates	Depth (m below surface)	Depth (to Dutch Ordnance Level, m)	Materials	Meaning	Calibrated age mean ±σ [cal yrs BP]	Historical age [yr BC/AD]
Vreugderijkerwaard 1	GrA62950	2665 ±30	-28.79	198968, 502969	1.40-1.41	-1.01 to -1.02	**4mg** *Alnus glutinosa 1x female catkin, 2x male catkin scale, 8x fruits; 1x Carex sp. fruit; 2x Alisma plantago-aquatica fruit; 1x Plantago major seed*	Begin age of the river Gelderse IJssel, first large flood	2779 ±26	836 BC – 801 BC 830 BC ±26
Vreugderijkerwaard 2	GrA63107	960 ±30	-29.64	198968, 502969	1.39	-1.00	**47mg** *charcoal*	first large scale floodings of the river Gelderse IJssel	862 ±42	1024 AD – 1150 AD 1088 AD ±42
Vreugderijkerwaard 3	GrA64249	1105 ±30	-27.23	198839, 502877	1.75-1.77	-1.19 to -1.21	**3mg** Leaf fragments 1x; *Carex sp.* frgm 7x; *Rumex sp.* 1x + 12x frgm; *Poaceae* 8x; *Mentha aquatica* 1x; *Lythrum salicaria* 4x	Begin age of the river Gelderse IJssel, start major river stage	1009 ±37 1014 ±35	897 AD – 981 AD 938 AD ±37 895 AD – 976 AD 936 AD ±35
Vreugderijkerwaard 4	GrA64341	1210 ±35	-27.98	198839, 502877	1.95-2.00	-1.39 to -1.44	**3mg** *Carex sp.* 2x; *Urtica dioica* 2x; *Alisma plantago-aquatica* 1x; *Alnus glutinosa* 9x 2x scales	Begin age of the river Gelderse IJssel, first large clastic input	1135 ±55 1133 ±52	770 AD – 878 AD 811 AD ±55 790 AD – 880 AD 817 AD ±53

AD 900 levee map



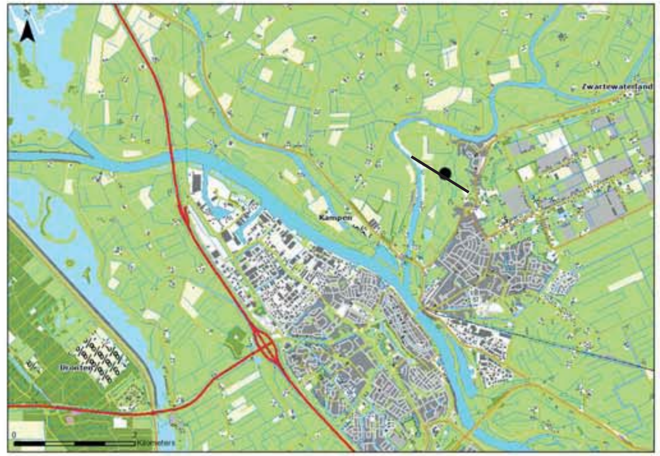
dated intervals

cross-section and coring location(s)

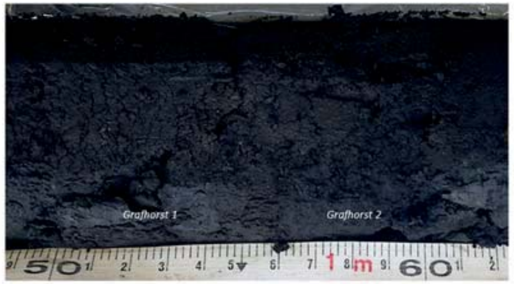


II | river Gelderse IJssel | GRAFHORST

x = 191512, y = 510417, z = -0.21 NAP

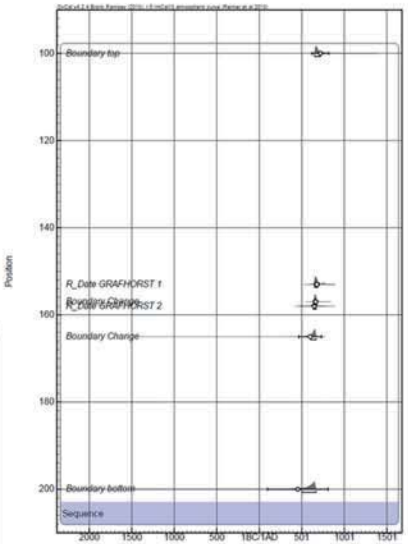


dated intervals

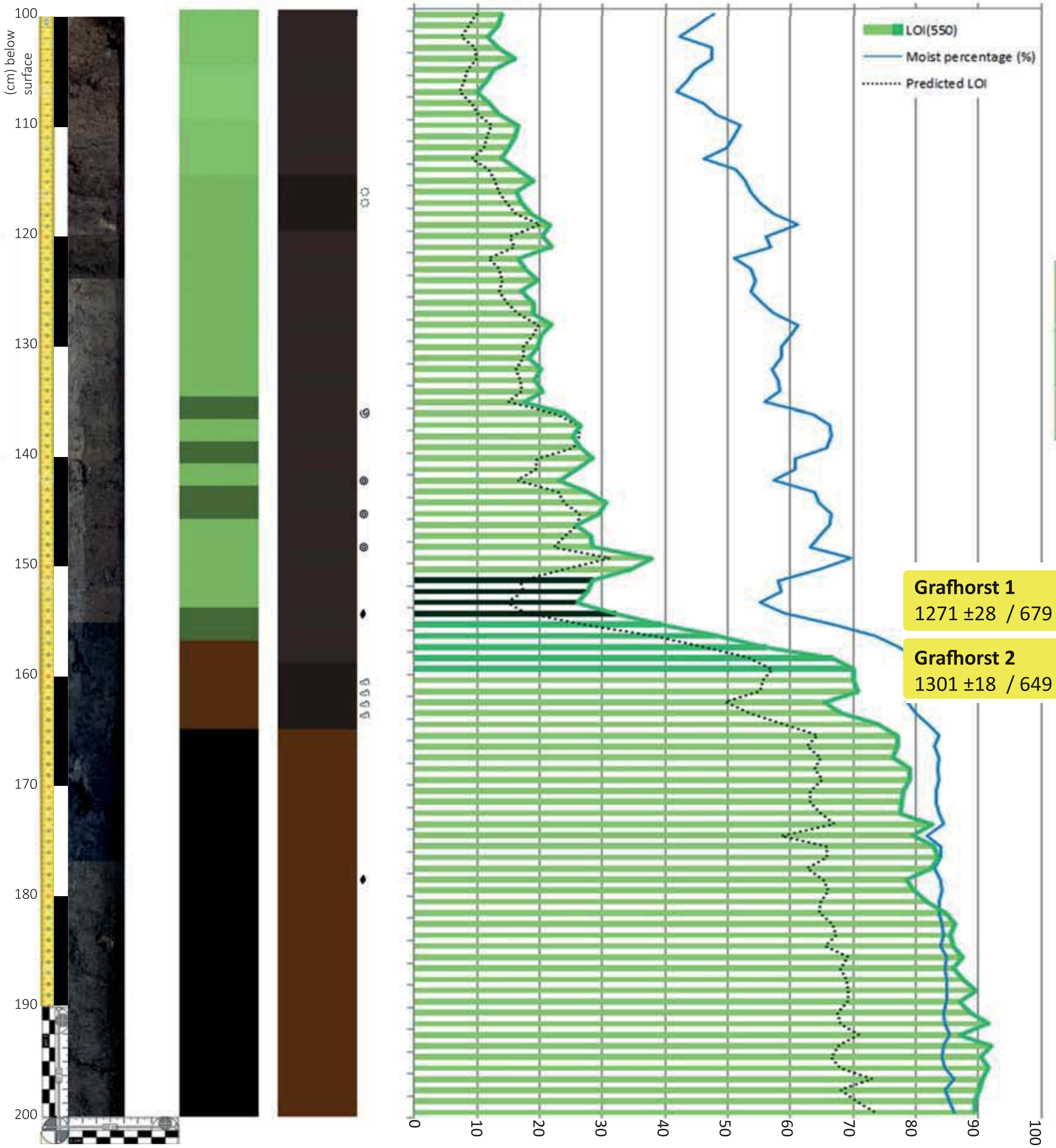


AD 900 levee map

sequence dating model



depth photo lithology colour remarks loss on ignition curve



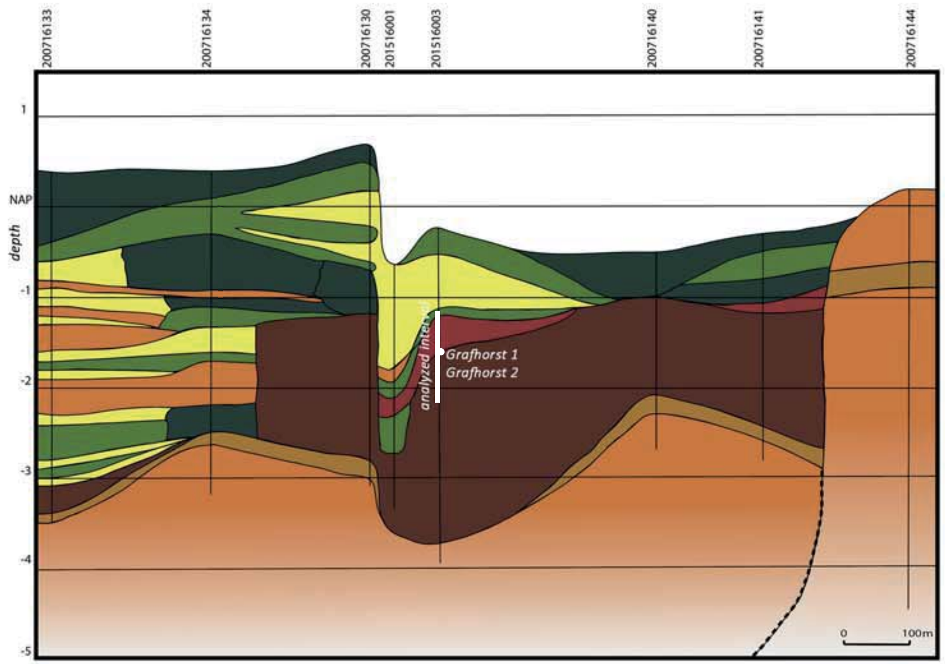
Grafhorst 1
1271 ±28 / 679 AD ±28

Grafhorst 2
1301 ±18 / 649 AD ±18

samples and C14-dates

Sample	Lab nr.	Lab age ±error	$\delta^{13}C$	Location (x,y) RD New-coordinates	Depth (m below surface)	Depth (to Dutch Ordnance Level, m)	Materials	Meaning	Calibrated age mean ±σ [cal yrs BP]	Historical age [yr BC/AD]
Grafhorst 1	GrA64248	1345 ±35	-30.04	191512, 510417	1.51-1.55	-1.72 to -1.76	**3mg** *Alnus glutinosa* 8x; *Apoaceae* 1x + 1x frgm; *Carex sp.* 1x; *Persicaria sp.* 1x	Begin age of the river Gelderse IJssel, start major river stage	1280 ±35 1271 ±28[3]	647 AD – 758 AD 681 AD ±35 651 AD – 686 AD[3] 679 AD ±28[3]
Grafhorst 2	GrA64338	1375 ±45	-29.37	191512, 510417	1.55-1.60	-1.76 to -1.81	**3mg** *Alnus glutinosa* 12x; *Typha sp.* 1x; *Persicaria sp.* 1x frgm; *cf. Ranunculus flammula* 2x; *Urtica dioica* 1x; *Carex sp.* 4x v + 1x v+urn; *Apiaceae* 4x	Begin age of the river Gelderse IJssel, first large clastic input	1297 ±38 1301 ±18[3]	618 AD – 677 AD 655 AD ±38 638 AD – 669 AD[3] 649 AD ±18[3]

cross-section and coring location(s)



III | river Waal | DREUMEL

x = 157764, y = 428471, z = +4.99 NAP

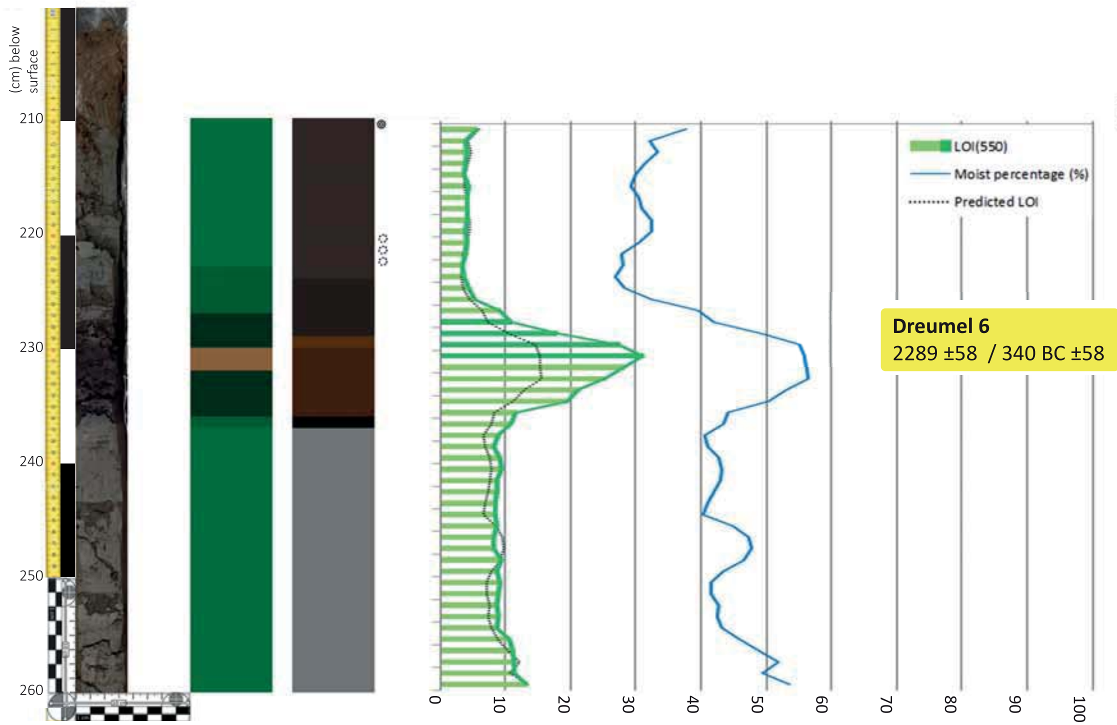
dated intervals

AD 900 levee map

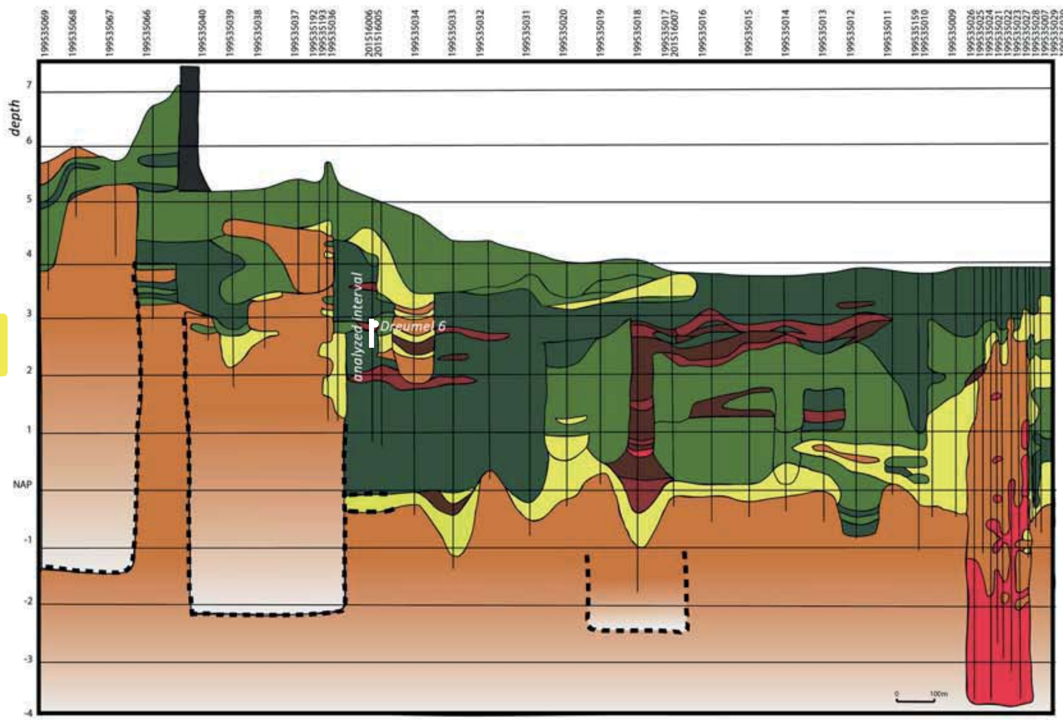
samples and C14-dates

Sample	Lab nr.	Lab age ±error	$\delta^{13}C$	Location (x,y) RD New-coordinates	Depth (m below surface)	Depth (to Dutch Ordnance Level, m)	Materials	Meaning	Calibrated age mean ±σ [cal yrs BP][a]	Historical age [yr BC/AD][a]
Dreumel 6	GrA64246	2285 ±30	-26.34	157764, 428471	2.28-2.32	+2.71 to +2.67	*Phragmites australis* 6x; *Mentha aquatica* 11x; *Ranunculus acris/repens* 1/2x; *Carex sp.* 1/2x; *Stachys sp.* 4x; *Alisma plantago-aquatica* 24x; Apiaceae 3x frgm; *Solanum dulcamara* 2x	Begin of clastic signal river Waal	2289 ±58	399 BC – 262 BC 340 BC ±58

depth photo lithology colour remarks loss on ignition curve



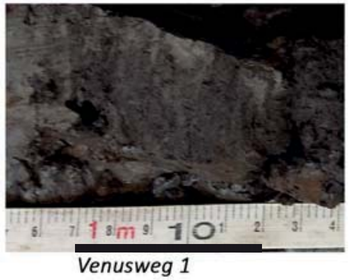
cross-section and coring location(s)

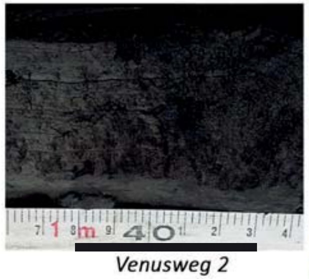


IV | river Waal | **VENUSWEG**

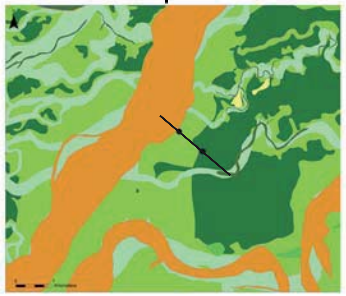
x = 158392, y = 427943, z = +3.71 NAP

dated intervals

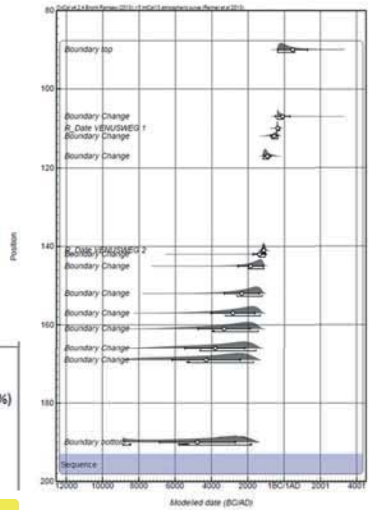




AD 900 levee map



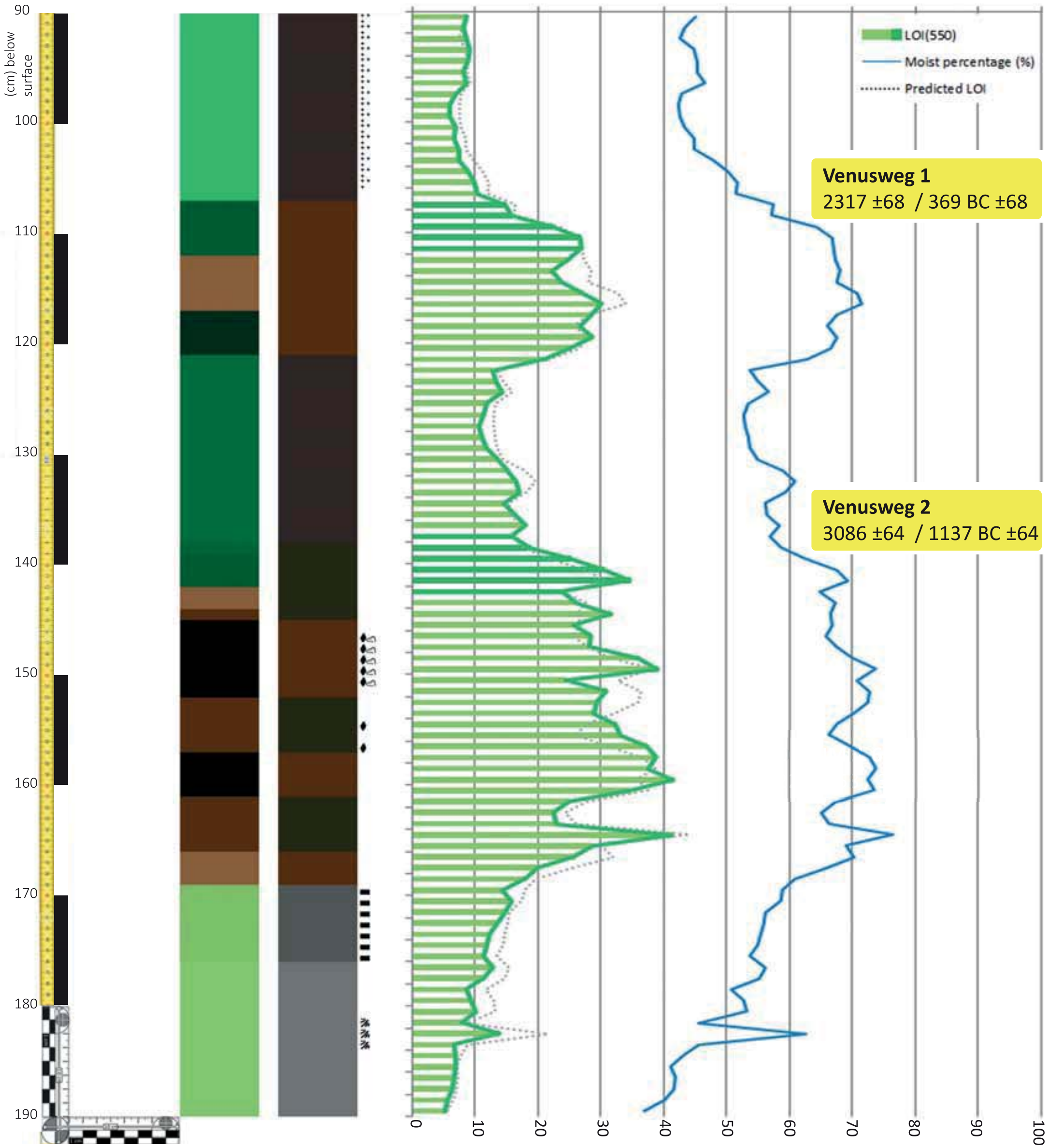
sequence dating model



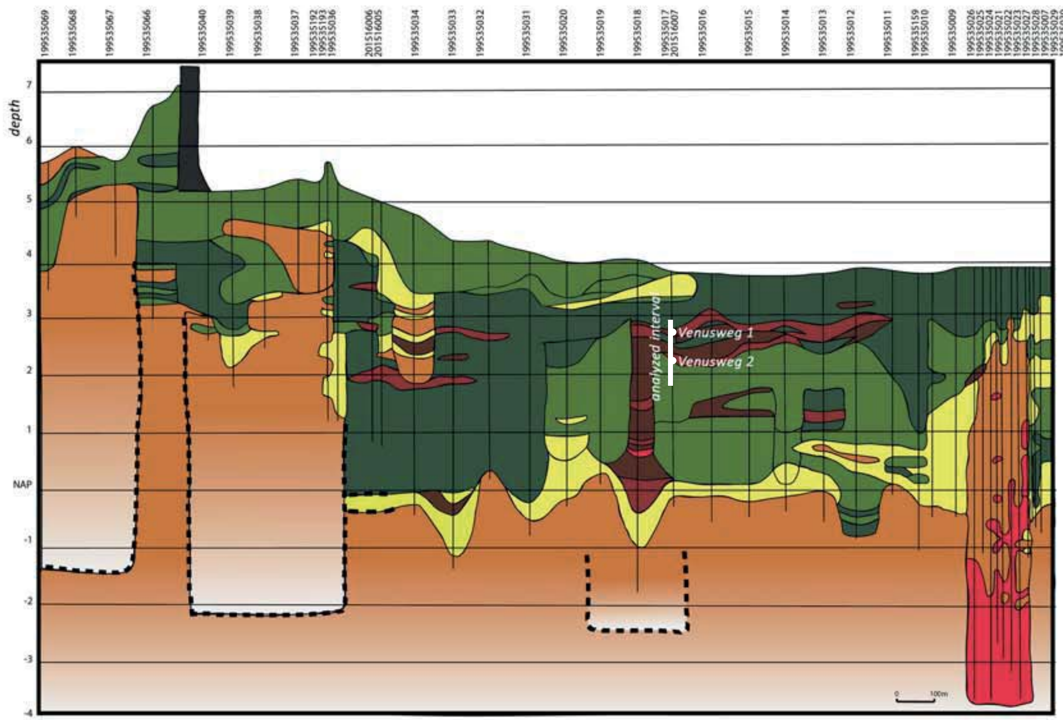
samples and C14-dates

Sample	Lab nr.	Lab age ±error	$\delta^{13}C$	Location (x,y) RD New-coordinates	Depth (m below surface)	Depth (to Dutch Ordnance Level, m)	Materials	Meaning	Calibrated age mean ±σ [cal yrs BP][##/#]	Historical age [yr BC/AD][##/#]
Venusweg 1	GrA64340	2310 ±40	-27.22	158392, 427943	1.07-1.12	+2.64 to +2.59	**3mg** Leaf fragments 1x; *Alisma plantago-aquatica* 2v + 35 z; *Carex* 1x frgm; *cf. Carex* 1x frgm; *Oenanthe aquatica* 1x; *cf. Oenanthe* 3x; *Typha sp.* 9x; *Mentha aquatica* 4x; *Poaceae* 1x; *Schoenoplectus* 1x	Begin of clastic signal river Waal	2331 ±65 2317±68[$]	408 BC – 262 BC 362 BC ±65 410 BC – 262 BC[$] 369 BC ±68
Venusweg 2	GrA64337	2940 ±40	-27.23	158392, 427943	1.38-1.43	+2.33 to +2.28	**3mg** *Alisma plantago-aquatica* 18x; *Typha sp.* 27x; *Mentha aquatica* 7x; *Carex sp.* 1x; *Apium* 1x; leaf fragments +-	Begin of clastic signal river Waal	3095 ±64 3086±64[$]	1215 BC – 1059 BC 1143 BC ±64 1210 BC – 1057 BC[$] 1137 BC ±64

depth photo lithology colour remarks loss on ignition curve



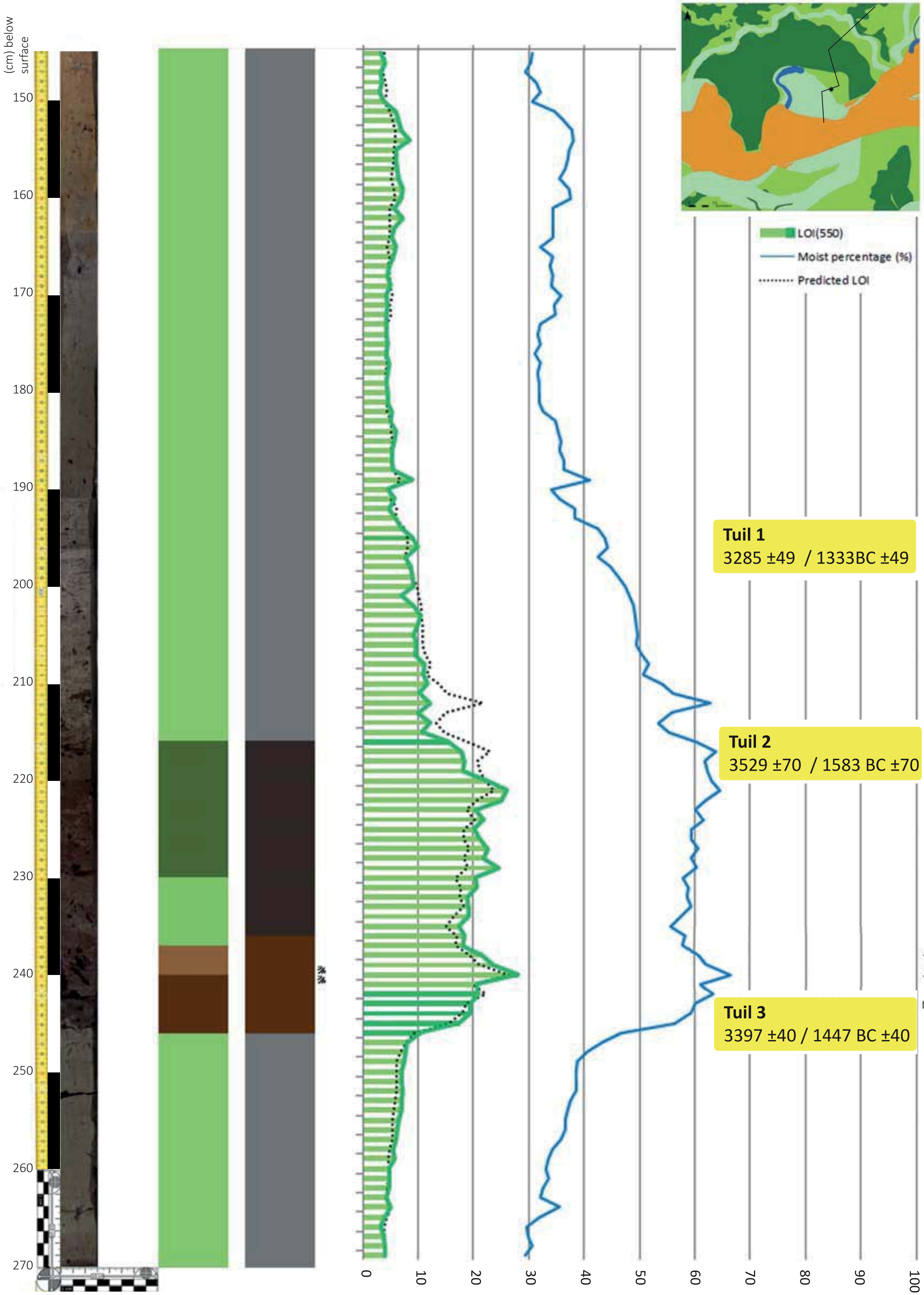
cross-section and coring location(s)



V| river Waal **| TUIL**

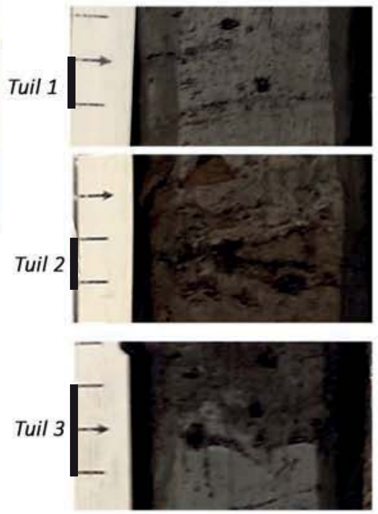
x = 144798, y = 426257, z = 2.71 NAP

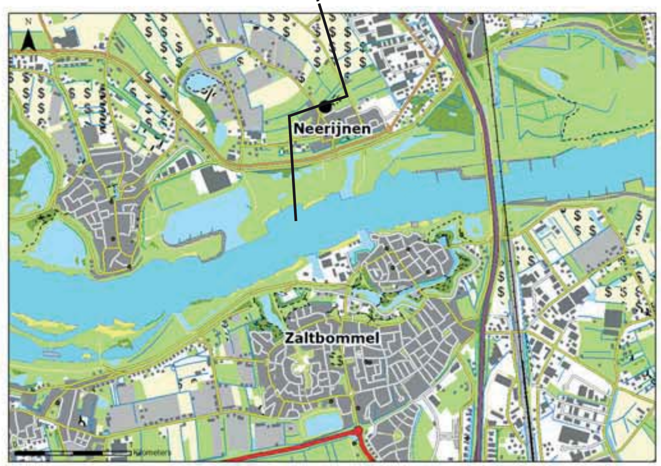
depth photo lithology colour remarks loss on ignition curve



AD 900 levee map

dated intervals

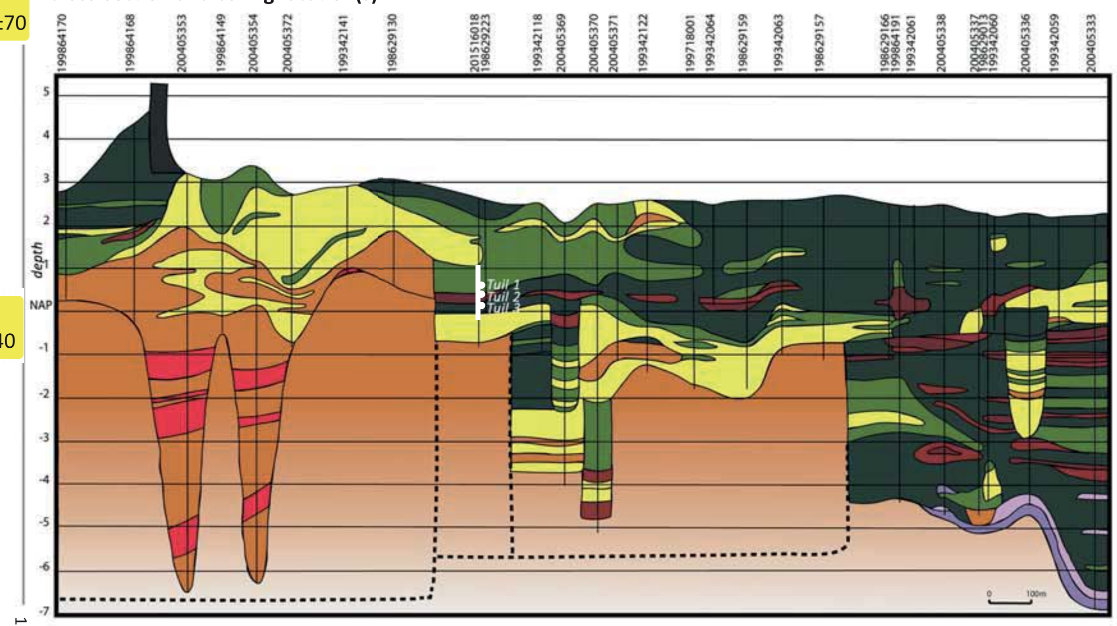




samples and C14-dates

Sample	Lab nr.	Lab age ±error	$\delta^{13}C$	Location (x,y) RD New-coordinates	Depth (m below surface)	Depth (to Dutch Ordnance Level, m)	Materials	Meaning	Calibrated age mean ±σ [cal yrs BP][M/R]	Historical age [yr BC/AD][M/R]
Tuil 1	GrA64242	3070 ±35	-28.57	144798, 426257	2.05-2.06	+0.66 to +0.65	3mg Leaf fragments	Extra clastic input (LOI 10%>5%) of river Waal	3285 ±49 3336 ±37[3]	1394 BC – 1282 BC 1333 BC ±49 1429 BC - 1372 BC[3] 1387 BC ±37
Tuil 2	GrA64243	3300 ±60	-29.40	144798, 426257	2.26-2.27	+0.45 to +0.44	3mg Leaf fragments; *Alnus glutinosa* 1x	Begin of clastic signal river Waal	3529 ±70 3379 ±30[3]	1639 BC – 1580 BC 1583 BC ±70 1457 BC - 1412 BC[3] 1430 BC ±30
Tuil 3	GrA64633	3170 ±35	-29.02	144798, 426257	2.54-2.56	+0.17 to +0.15	5mg Leaf fragments 3x; *Alnus glutinosa 6x v + 1x catkin; Persicaria minor/mitis* 1x; *Urtica dioica* 1x; *Lythrum salicaria* 1x	Start peat formation (time control)	3397 ±40 3424 ±32[3]	1496 BC – 1416 BC 1447 BC ±40 1501 BC - 1444 BC[3] 1475 BC ±32

cross-section and coring location(s)

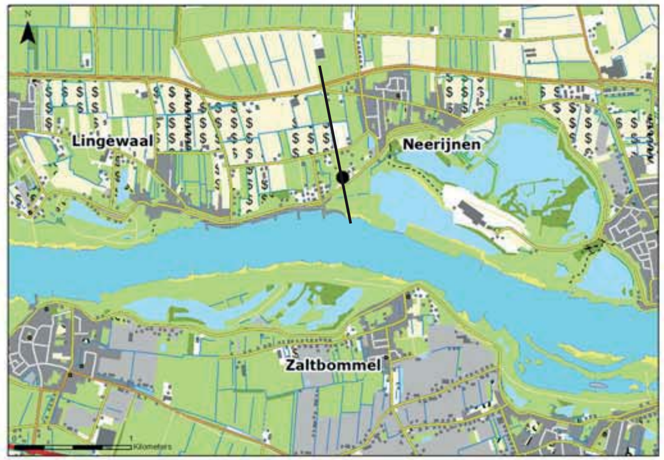


VI| river Waal | **HELLOUW**

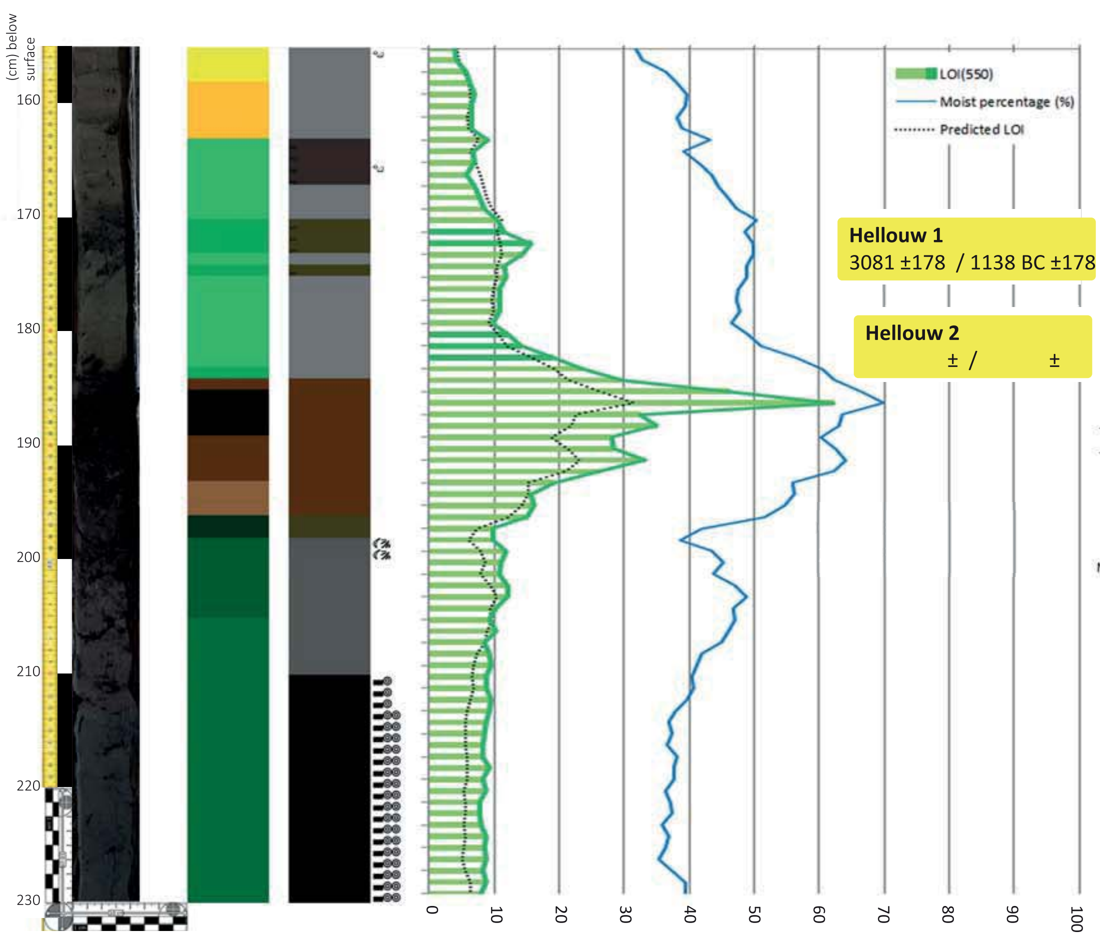
x = 144798, y = 426257, z = 2.71 NAP

dated intervals

AD 900 levee map



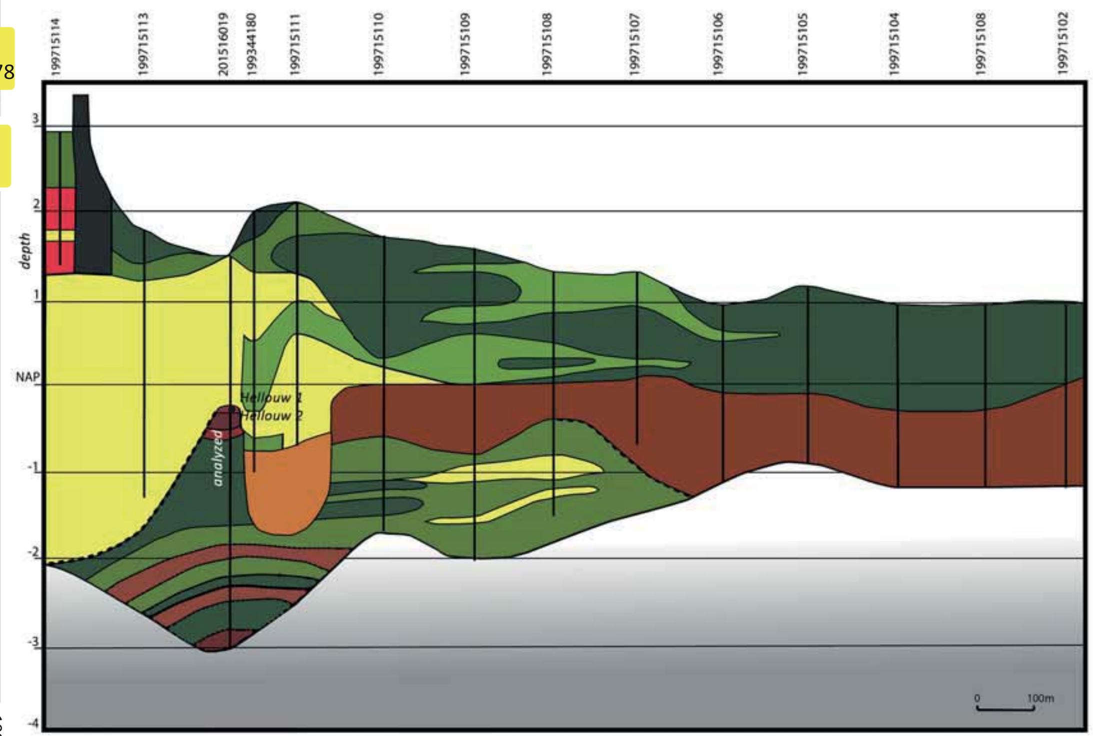
depth photo lithology colour remarks loss on ignition curve



samples and C14-dates

Sample	Lab nr.	Lab age ±error	$\delta^{13}C$	Location (x,y) RD New-coordinates	Depth (m below surface)	Depth (to Dutch Ordnance Level, m)	Materials	Meaning	Calibrated age mean ±σ [cal yrs BP][a]	Historical age [yr BC/AD][a]
Hellouw 1	GrA64244	2920 ±150	-28.89	140238, 425906	1.70-1.72	-0.17 to -0.19	**3mg** *Typha sp.* 14x; *Alisma plantago-aquatica* 7x v + 34x z; *Phragmites australis* 2x; *Rumex maritimus* 10x bd; *Rumex sp.* 2x; *Lythrum salicaria* 2x	Extra clastic input (LOI 10%>5%) of river Waal	3081 ±178	1367 BC – 926 BC 1138 BC ±178
Hellouw 2	-	-	-	140238, 425906	1.80-1.83	-0.27 to -0.30	**1mg** *Typha sp.* 65x; *Alisma plantago-aquatica* 26x z; *Mentha aquatica* 27x; *Berula erecta* 6x	Begin of clastic signal river Waal	-	-

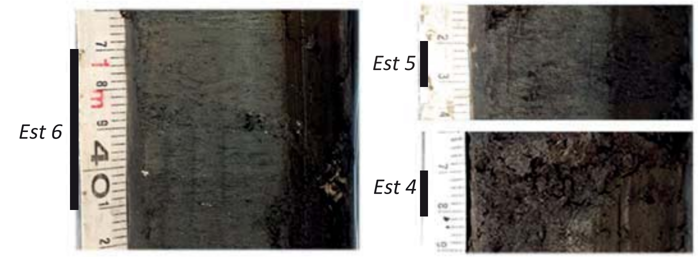
cross-section and coring location(s)



VII| river EST | EST

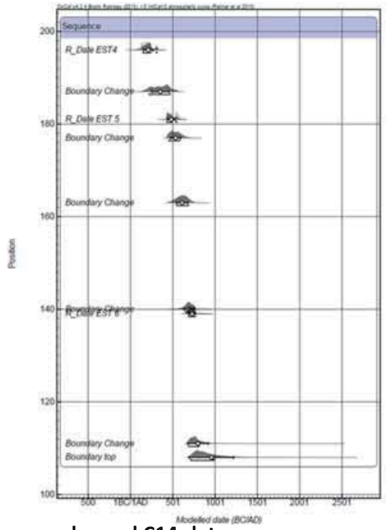
x = 144798, y = 426257, z = 2.71 NAP

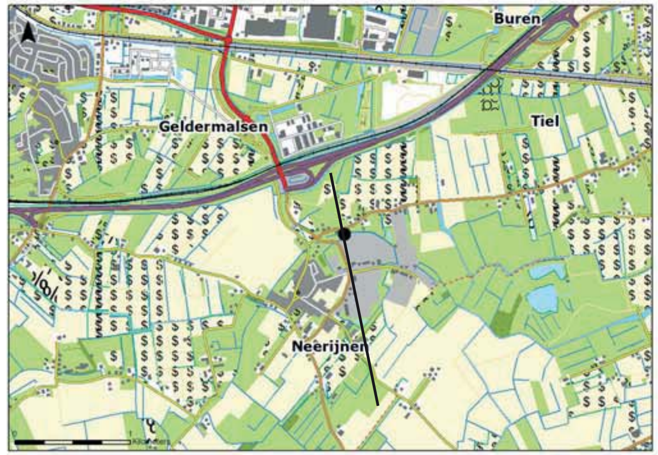
dated intervals



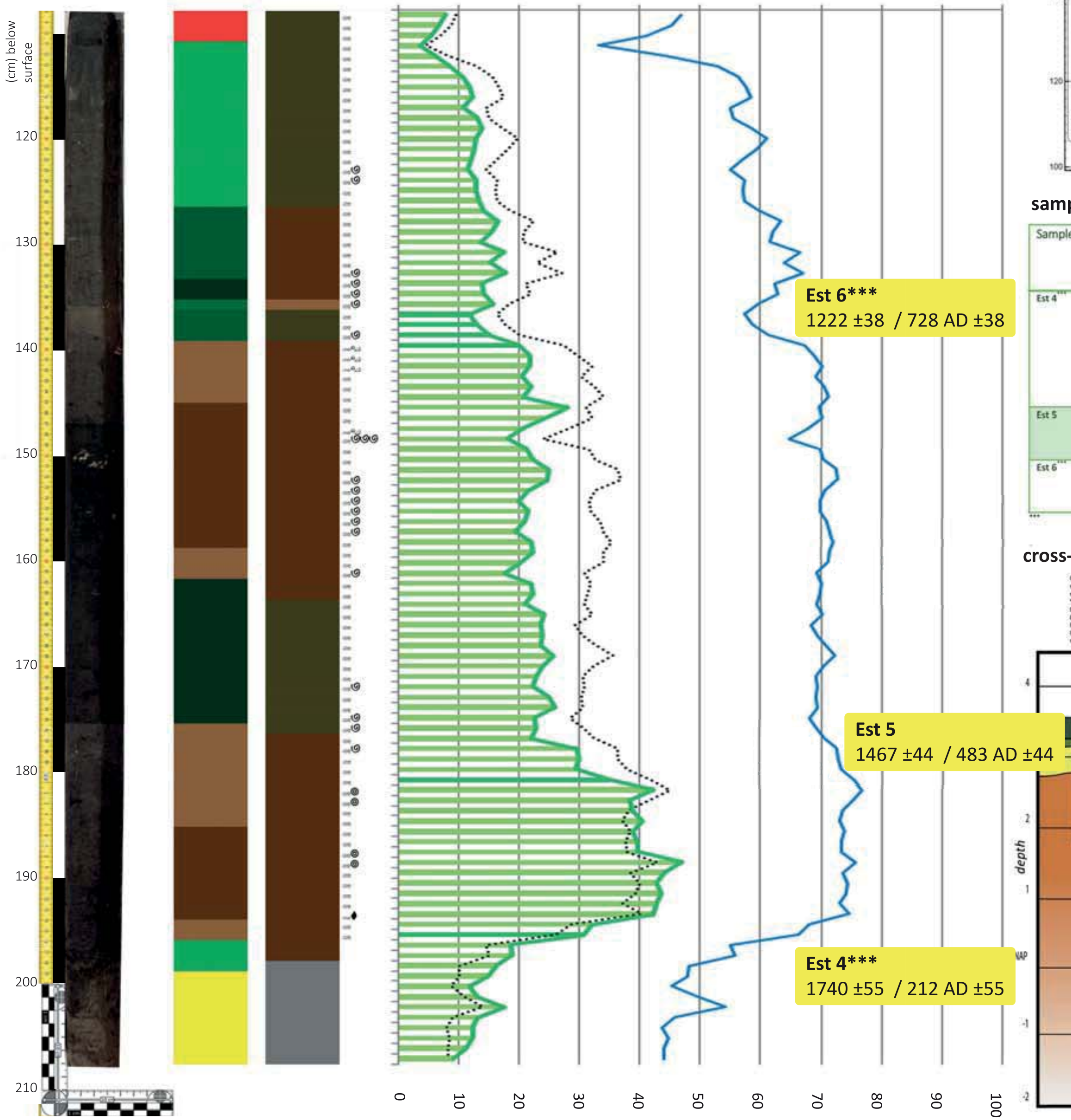
AD 900 levee map

sequence dating model





depth photo lithology colour remarks loss on ignition curve

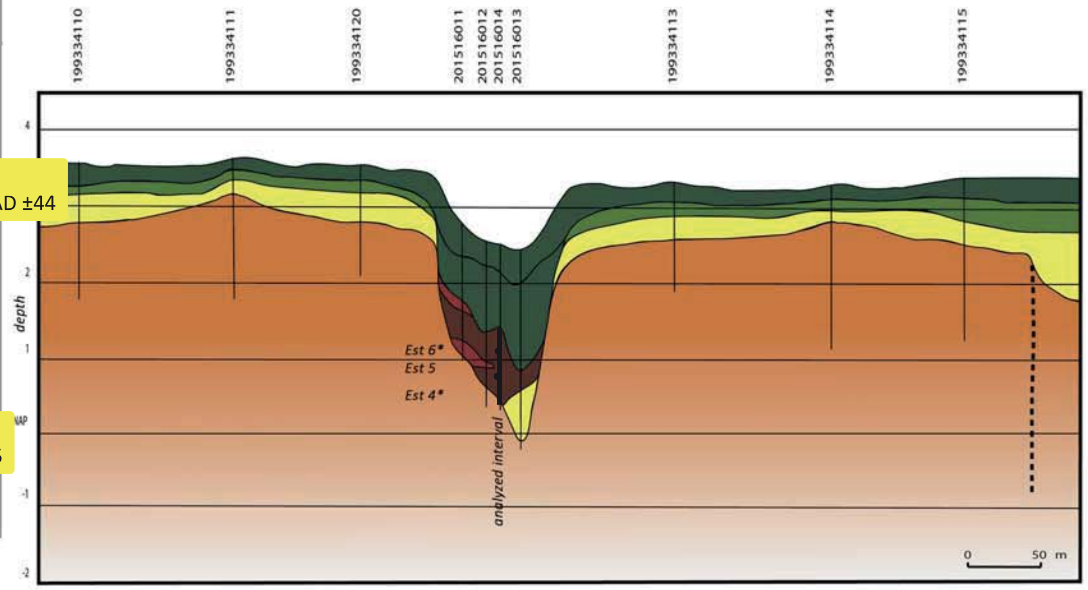


samples and C14-dates

Sample	Lab nr.	Lab age ±error	$\delta^{13}C$	Location (x,y) RD New-coordinates	Depth (m below surface)	Depth (to Dutch Ordnance Level, m)	Materials	Meaning	Calibrated age mean ±σ [cal yrs BP]$^{a\&b}$	Historical age [yr BC/AD]$^{a\&b}$
Est 4***	GrA64252	1830 ±35	-28.75	150298, 429818	1.37-1.41	+1.18 to +1.14	3mg *Poaceae* 1x; *Mentha aquatica* 3x; *Apiaceae* 2x + 1x frgm; *Cyperaceae* urn 1x frgm; *Rumex maritimus/palustris* bd 2x; *Chenopodium* sp. 1x frgm; *Atriplex patula/prostrata* 1x; *Berula erecta* 1x; *Oenanthe aquatica* 3x + 5 frgm; *Cirsium/Carduus* 1x; *Persicaria* sp. 1x; *Ranunculus acris/repens* 2x, *Stellaria media* 1x; Leaf fragments 1x	Second clastic input (possible reactivation)	1767 ±49 1740 ±55^{S}	135 AD – 224 AD 184 AD ±49 149 AD – 313 AD^{S} 212 AD ±56
Est 5	GrA64253	1535 ±30	-28.23	150298, 429818	1.82-1.83	+0.73 to +0.72	3mg Leaf fragments; *Salix* bud 2x	First clastic input (possible reactivation)	1438 ±50 1467 ±44^{S}	432 AD – 570 AD 509 AD ±50 428 AD – 545 AD^{S} 483 AD ±44
Est 6***	GrA64254	1275 ±30	-28.28	150298, 429818	1.97-1.98	+0.58 to +0.57	3mg Leaf fragments	Start peat formation (time control) / minimum age residual channel	1228 ±38 1222 ±38^{S}	685 AD – 767 AD 727 AD ±38 685 AD – 767 AD^{S} 728 AD ±38

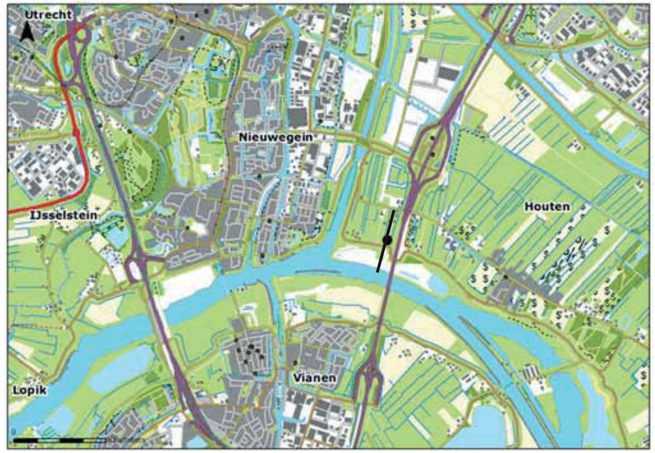
*** Monsters are presumably exchanged, sample names are linked to Groningen-numbers, in this report Est 4 and Est 6 dates are assumed to be exchanged. For sequence modeling dates Est 4 and Est 6 are turned in the sequence.

cross-section and coring location(s)



VIII| river Lek | NIEUWEGEIN

x = 136246, y = 446378, z = +0.77 NAP



dated intervals

Nieuwegein 1

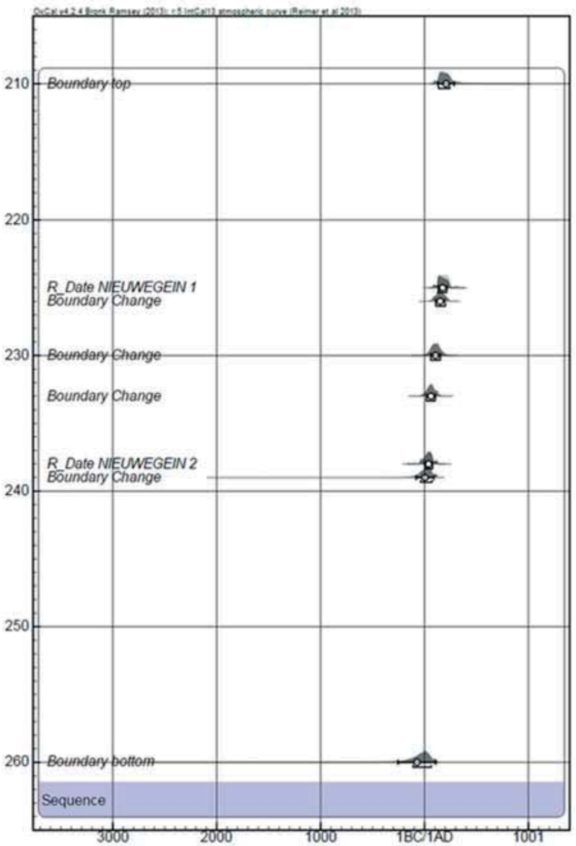
Nieuwgein 2

AD 900 levee map

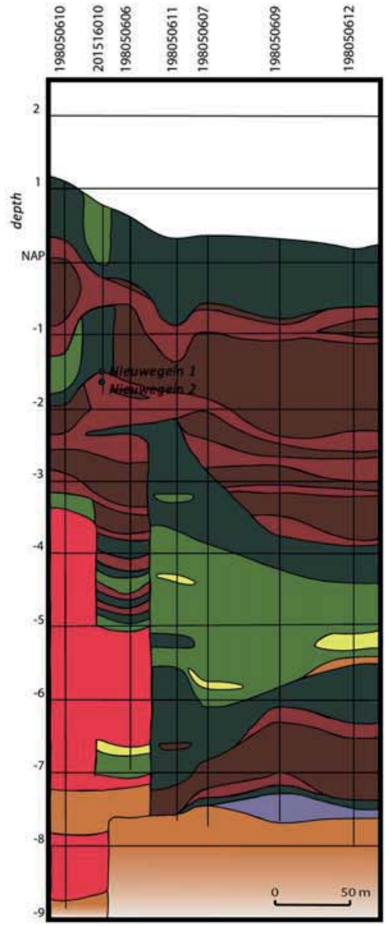
samples and C14-dates

Sample	Lab nr.	Lab age ±error	$\delta^{13}C$	Location (x,y) RD New-coordinates	Depth (m below surface)	Depth (to Dutch Ordnance Level, m)	Materials	Meaning	Calibrated age mean ±σ [cal yrs BP] [BB/R]	Historical age [yr BC/AD] [BB/R]
Nieuwegein 1	GrA64240	1830 ±30	-26.13	136246, 446378	2.25-2.26	-1.48 to -1.49	**3mg** *Alisma plantago-aquatica* 35x v +34x z; *Mentha aquatica* 25x; *Typha sp.* 10x; *Lythrum salicaria* 23x; *Apiaceae* 2x; *Carex sp.* 7x; *Ranunculus sp.* 8x; *Stellaria sp.* 2x	First fluvial input for river Lek	1768 ±43 1775 ±42[S]	137 AD – 220 AD 183 AD ±43 132 AD – 214 AD[S] 175 AD ±42
Nieuwegein 2	GrA64632	1965 ±35	-27.16	136246, 446378	2.36-2.40	-1.59 to -1.63	**3mg** *Alisma plantago-aquatica* 18x v +13x z; *Mentha aquatica* 12x; *Typha sp.* 15x+ *Lythrum salicaria* 17x; *Apiaceae* 2x; *Carex sp.* 7x; *Ranunculus sp.* 5x; *Stellaria sp.* 2x	Start peat formation (time control)	1916 ±40 1911±39[S]	1 AD – 75 AD 33 AD ±40 3 AD– 78 AD[S] 39 AD ±39[S]

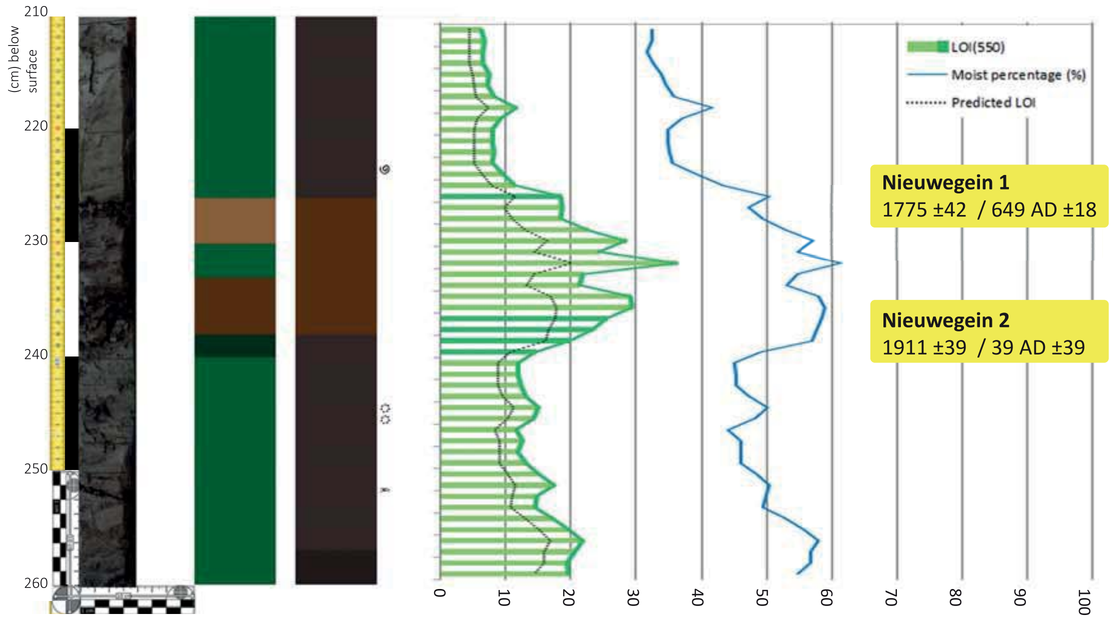
sequence dating model



cross-section and coring location(s)



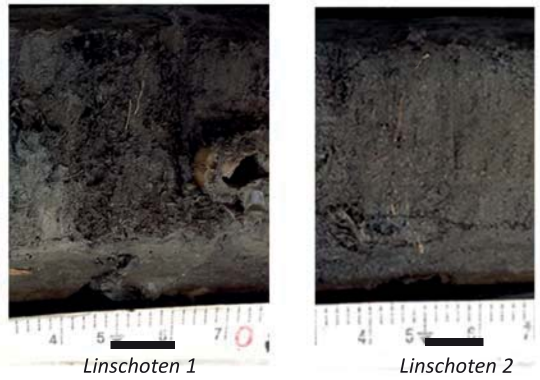
depth photo lithology colour remarks loss on ignition curve



IX| river Lange Linschoten | LINSCHOTEN

x = 121214, y = 453502, z = -0.35 NAP

dated intervals



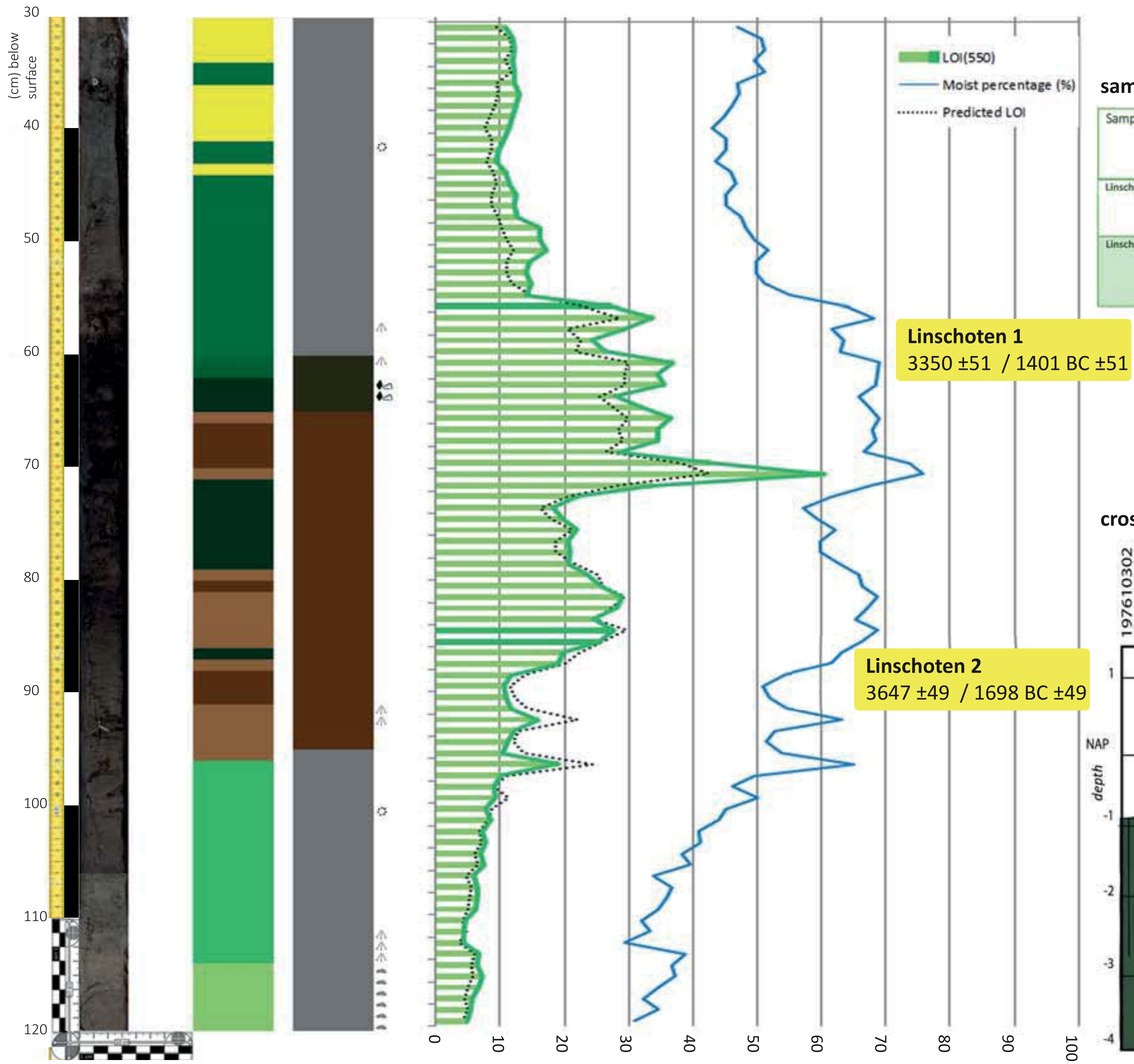
AD 900 levee map

sequence dating model

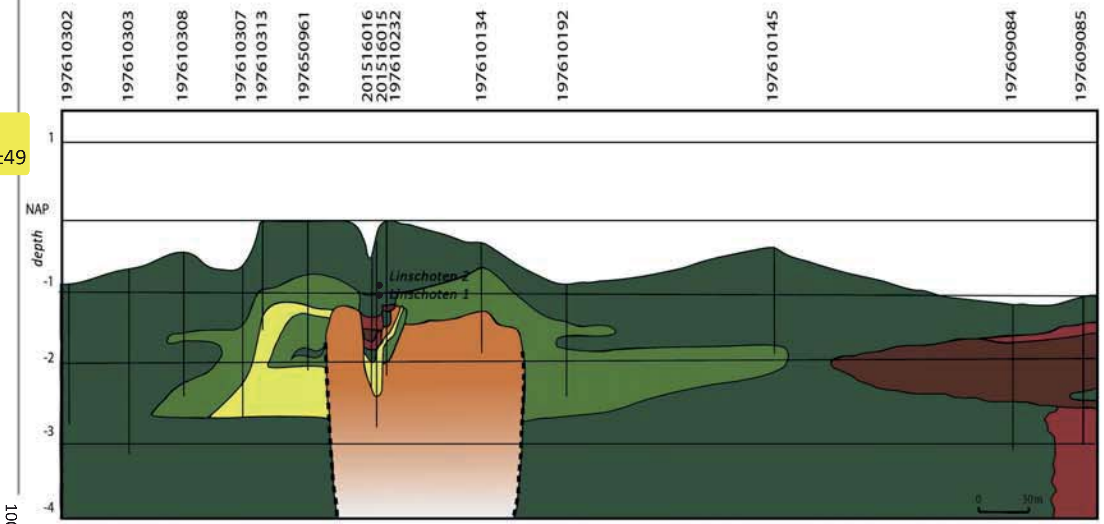
samples and C14-dates

Sample	Lab nr.	Lab age ±error	$\delta^{13}C$	Location (x,y) RD New-coordinates	Depth (m below surface)	Depth (to Dutch Ordnance Level, m)	Materials	Meaning	Calibrated age mean ±σ [cal yrs BP]	Historical age [yr BC/AD]
Linschoten 1	GrA64250	3130 ±35	-27.30	121214, 453502	0.55-0.56	-0.89 to -0.90	3mg *Alnus glutinosa* 5x v + 3x Catkin; Leaf fragment 1x	First clastic influx (re-)activation of residual channel Lange Linschoten	3353 ±52 3350 ±51	1443 BC – 1311 BC 1391 BC ±52 1448 BC – 1320 BC 1401 BC ±51
Linschoten 2	GrA64251	3405 ±35	-28.78	121214, 453502	0.85-0.86	-1.20 to -1.21	3mg *Alnus glutinosa* 24x v + 11 scales + 1 Catkin; *Urtica dioica* 1x; *Phragmites australis* 2x; *Poaceae* 1x; Leaf fragments	Start peat formation (time control) / minimum age residual channel	3652 ±52 3647 ±49	1746 BC – 1659 BC 1707 BC ±52 1741 BC – 1658 BC 1698 BC ±49

depth photo lithology colour remarks loss on ignition curve



cross-section and coring location(s)



River	Sample	Lab nr.	Lab age ±error	$\delta^{13}C$	Location (x,y) RD New-coordinates	Depth (m below surface)	Depth (to Dutch Ordnance Level, m)	Materials	Meaning	Calibrated age mean ±σ [cal yrs BP] [BR/R]	Historical age [yr BC/AD] [BR/R]
River Gelderse IJssel	**Vreugderijkerwaard 1**[*]	GrA62950	2665 ±30	-28.79	198968, 502969	1.40-1.41	-1.01 to -1.02	**4mg** *Alnus glutinosa* 1x *female catkin*, 2x *male catkin scale*, 8x *fruits*; 1x *Carex sp. fruit*; 2x *Alisma plantago-aquatica fruit*; 1x *Plantago major seed.*	Begin age of the river Gelderse IJssel, first large flood	**2779 ±26**	**836 BC – 801 BC** **830 BC ±26**
	Vreugderijkerwaard 2[*]	GrA63107	960 ±30	-29.64	198968, 502969	1.39	-1.00	**47mg** *charcoal*	first large scale floodings of the river Gelderse IJssel	**862 ±42**	**1024 AD – 1150 AD** **1088 AD ±42**
	Vreugderijkerwaard 3	GrA64249	1105 ±30	-27.23	198839, 502877	1.75-1.77	-1.19 to -1.21	**3mg** Leaf fragments 1x; *Carex sp.* frgm 7x; *Rumex sp.* 1x + 12x frgm; *Poaceae* 8x; *Mentha aquatica* 1x; *Lythrum salicaria* 4x	Begin age of the river Gelderse IJssel, start major river stage	1009 ±37 1014 ±35[S]	897 AD – 981 AD 938 AD ±37 895 AD – 976 AD[S] 936 AD ±35
	Vreugderijkerwaard 4	GrA64341	1210 ±35	-27.98	198839, 502877	1.95-2.00	-1.39 to -1.44	**3mg** *Carex sp.* 2x; *Urtica dioica* 2x; *Alisma plantago-aquatica* 1x; *Alnus glutinosa* 9x 2x scales	Begin age of the river Gelderse IJssel, first large clastic input	1135 ±55 1133 ±52[S]	770 AD – 878 AD 811 AD ±55 790 AD – 880 AD[S] 817 AD ±53
	Grafhorst 1	GrA64248	1345 ±35	-30.04	191512, 510417	1.51-1.55	-1.72 to -1.76	**3mg** *Alnus glutinosa* 8x; *Apoaceae* 1x + 1x frgm; *Carex sp.* 1x; *Persicaria sp.* 1x	Begin age of the river Gelderse IJssel, start major river stage	1280 ±35 1271 ±28[S]	647 AD – 758 AD 681 AD ±35 651 AD – 686 AD[S] 679 AD ±28[S]
	Grafhorst 2	GrA64338	1375 ±45	-29.37	191512, 510417	1.55-1.60	-1.76 to -1.81	**3mg** *Alnus glutinosa* 12x; *Typha sp.* 1x; *Persicaria sp.* 1x frgm; *cf. Ranunculus flammula* 2x; *Urtica dioica* 1x; *Carex sp.* 4x v + 1x *v+urn*; *Apiaceae* 4x	Begin age of the river Gelderse IJssel, first large clastic input	1297 ±38 1301 ±18[S]	618 AD – 677 AD 655 AD ±38 638 AD – 669 AD[S] 649 AD ±18[S]
River Lek	**Nieuwegein 1**	GrA64240	1830 ±30	-26.13	136246, 446378	2.25-2.26	-1.48 to -1.49	**3mg** *Alisma plantago-aquatica* 35x v +34x z; *Mentha aquatica* 25x; *Typha sp.* 10x; *Lythrum salicaria* 23x; *Apiaceae* 2x; *Carex sp.* 7x; *Ranunculus sp.* 8x; *Stellaria sp.* 2x	First fluvial input for river Lek	1768 ±43 1775 ±42[S]	137 AD – 220 AD 183 AD ±43 132 AD – 214 AD[S] 175 AD ±42
	Nieuwegein 2	GrA64632	1965 ±35	-27.16	136246, 446378	2.36-2.40	-1.59 to -1.63	**3mg** *Alisma plantago-aquatica* 18x v +13x z; *Mentha aquatica* 12x; *Typha sp.* 15x+ *Lythrum salicaria* 17x; *Apiaceae* 2x; *Carex sp.* 7x; *Ranunculus sp.* 5x; *Stellaria sp.* 2x	Start peat formation (time control)	1916 ±40 1911±39[S]	1 AD – 75 AD 33 AD ±40 3 AD– 78 AD[S] 39 AD ±39[S]
	Lexmond 1[**]	GrA64319	930 ±45	-29.04	131974, 442570	1.33-1.36	-0.13 to -0.16	**<1mg** 1x *Stellaria media seed*; 1x *Rorippa sylvestris seed*; 1x *Chenopodium album fruit*; 1x *Alisma plantago-aquatica fruit*; 2x *Ranunculus sceleratus fruit*; 3x *Mentha aquatica/arvensis fruit*; 1x *Sinapis arvensis fruit*; 1x cf. *Myosotis sp. fruit*; *1x Plantago major seed*	(re)Activation phase for river Lek; extra clastic input	846 ±50 851 ±49[S]	1040 AD – 1154 AD 1104 AD ±50 1033 AD – 1141 AD[S] 1099 AD ±49[S]
	Lexmond 2[**]	GrA64323	1515 ±40	-26.61	131974, 442570	1.45-1.49	-0.25 to -0.29	**10mg** 7x *Alnus glustinosa fruits*, 1x *female catkin; 1x Sonchus asper fruit*; 1x *Plantago*	First fluvial input for river Lek	1416 ±56 1409 ±55[S]	435 AD – 602 AD 534 AD ±56

								major seed		438 AD – 609 AD[S] 541 AD ±55[S]
	Ameide 1[**]	*failed sample analysis*	-	-	127453, 441165	0.75-0.77	-0.75 to -0.77	**4mg** 5x *Cicuta virosa,*; 8x *Carex cf. rostrata/vesicaria*; 1x *Alisma plantago-aquatica*; 6x *Mentha aquatica*; 2x *Typha sp.* 1,5x *Ranunculus flammula*; 3x *Mentha aquatica*; 2x *Lythrum salicaria*; 1,5x *Cicuta virosa,*; 1,5x *Carex cf. rostrata/vesicaria*; 3x *Carex sect. Acuta*; 1x *Typha sp.*	Begin age of the river Lek	-	-
	Ameide 2[**]	GrA62997	2160 ±30	-25.03	127453, 441165	0.97-1.03	-0.97 to -1.03	**3mg** 10x *Alisma plantago-aquatica fruits*; 20x *Rorippa sylvestris seeds*; 4 *Typha latifolia seeds*; 23x *Typha sp.*; 5x *Phragmites australis fruits*; 1x *Apium graveolens fruit*; 0.5x cf. *Apium fruit*; 1x *Apiaceae fruit*; 2x *Mentha aquatica fruits*; 1x *Carex cf. pseudocyperus fruit*; 1x *Carex acuta/nigra type fruit*; 2.5x *Carex sp. fruit*; 18x *cf. Capsella bursa-pastoris seeds*; 2x *Schoenoplectus sp. fruits*	First fluvial input for river Lek	2190 ±77 2160 ±77[S]	352 BC – 167 BC 241 BC ±77 348 BC – 115 BC[S] 213 BC ±77[S]
	Ameide 3A[**]	GrA64635	1975 ±30	-26.97	127453, 441165	0.79-0.82	-0.79 to -0.82	*Carex ssp.* 31x; *Typha sp.* 8x; *cf. Oenanthe aquatica* 2x frgm; *Alisma plantago-aquatica* 5x z + 2x v; *Mentha aquatica* 4x	Begin age of the river Lek	1926 ±34 1933 ±35[S]	18 BC – 65 AD 24 AD ±34 37 BC – 58 AD[S] 17 AD ±35[S]
	Schoonhoven[**]	GrA62968	1715 ±30	-27.04	120993, 439623	0.87-0.88	-1.57 to -1.58	**3mg** 6x *Alnus glutinosa fruits*, 1x *female catkin*; 26x *Alisma plantago-aquatica fruits*; 1x *Mentha aquatica fruit*; 3x *Berula erecta fruits*; 1x *Thalictrum sp. fruit*; 7x *cf. Oenanthe aquatica fruits*	Begin age of the river Lek	1626 ±44	259 AD – 384 AD 324 AD ±44
	Streefkerk 1[**]	GrA62966	2190 ±30	-28.14	112608, 436097	0.63-0.67	-1.93 to -1.97	**52mg** 3x *Urtica dioica seeds*; 5,5x *Alnus glutinosa fruits*, *3 male catkinscales*; *wood*	Begin age of the river Lek	2224 ±57	356 BC – 199 BC 275 BC ±57
	Nieuw Lekkerland 1[**]	GrA64317	2260 ±35	-29.02	107533, 433761	0.64-0.67	-2.44 to -2.47	**2mg** 8x *Alnus glutinosa fruits*; 1x *Bidens tripartita fruit*; 1x *bud indet.*; *leaf fragments*	Begin age of the river Lek	2254 ±59	390 BC – 234 BC 305 BC ±59
River Hollandse IJssel	**Snelrewaard**[*]	GrA64318	2650 ±45	-27.09	122464, 448834	0.67-0.71	-1.87 to -1.91	**1mg** *leaf fragments*; 3x *Alnus glutinosa* fruits; 12x *Alisma plantago-aquatica fruits*; 44x *Typha sp. seeds*; 2x *Carex sp. fruits*; 2x *Mentha aquatica fruits*; 10x *Berula erecta fruits*; 1x cf. *Oenanthe aquatica fruit*; 2x *Apiaceae fruits*	Begin age of the river Hollandse IJssel	2778 ±38	888 BC – 793 BC 829 BC ±38
	Oudekerk 1[**]	GrA64564	2390 ±30	-27.00	103618, 439348	0.56-0.60	-2.56 to -2.60	wood fragment	Begin age of the river Hollandse IJssel	2429 ±76 2423 ±64[S]	507 BC – 403 BC 480 BC ±76 490 BC – 404 BC[S] 474 BC ±64[S]
	Oudekerk 2[**]	GrA64321	2550 ±70	-27.49	103618, 439348	0.65-0.71	-2.65 to -2.71	**1mg** 22x *Alnus glustinosa fruits*, 1x *male catkin scale*; 3x *Carex sect. Paniculatae*; 2x *Urtica dioica seeds*; 4x *Lythrum salicaria seeds;*	Begin age of the river Hollandse IJssel	2608 ±105 2602 ±100[S]	803 BC – 547 BC 659 BC ±105 800 BC – 542 BC[S] 653 BC ±100[S]

	Gouderak 1[**]	GrA62970	1895 ±30	-27.99	107948, 445419	1.02-1.05	-2.92 to -2.95	**3mg** 17x *Alnus glutinosa fruits*, 1 *male catkin scale*, 1x *frgm male catkin*; 5x *Carex sp. fruits*; 1x *Bidens tripartitia fruit*; 3x *Ranunculus sp. fruits*; 1x Lythrum salicaria *seed*; 1x *Phragmites australis fruit*; 1 *nut fragment*	Begin age of the river Hollandse IJssel	1837 ±41	70 AD – 132 AD 113 ±41
River Waal	**Dreumel 6**	GrA64246	2285 ±30	-26.34	157764, 428471	2.28-2.32	+2.71 to +2.67	*Phragmites australis* 6x; *Mentha aquatica* 11x; *Ranunculus acris/repens* 1/2x; *Carex sp.* 1/2x; *Stachys sp.* 4x; *Alisma plantago-aquatica* 24x; Apiaceae 3x frgm; *Solanum dulcamara* 2x	Begin of clastic signal river Waal	2289 ±58	399 BC – 262 BC 340 BC ±58
	Venusweg 1	GrA64340	2310 ±40	-27.22	158392, 427943	1.07-1.12	+2.64 to +2.59	**3mg** Leaf fragments 1x; *Alisma plantago-aquatica* 2v + 35 z; *Carex* 1x frgm; *cf. Carex* 1x frgm; *Oenanthe aquatica* 1x; *cf. Oenanthe* 3x; *Typha sp.* 9x; *Mentha aquatica* 4x; *Poaceae* 1x; *Schoenoplectus* 1x	Begin of clastic signal river Waal	2331 ±65 2317±68[S]	408 BC – 262 BC 362 BC ±65 410 BC – 262 BC[S] 369 BC ±68
	Venusweg 2	GrA64337	2940 ±40	-27.23	158392, 427943	1.38-1.43	+2.33 to +2.28	**3mg** *Alisma plantago-aquatica* 18x; *Typha sp.* 27x; *Mentha aquatica* 7x; *Carex sp.* 1x; *Apium* 1x; leaf fragments +-	Begin of clastic signal river Waal	3095 ±64 3086±64[S]	1215 BC – 1059 BC 1143 BC ±64 1210 BC – 1057 BC[S] 1137 BC ±64
	Hellouw 1	GrA64244	2920 ±150	-28.89	140238, 425906	1.70-1.72	-0.17 to -0.19	**3mg** *Typha sp.* 14x; *Alisma plantago-aquatica* 7x v + 34x z; *Phragmites australis* 2x; *Rumex maritimus* 10x bd; *Rumex sp.* 2x; *Lythrum salicaria* 2x	Extra clastic input (LOI 10%>5%) of river Waal	3081 ±178	1367 BC – 926 BC 1138 BC ±178
	Hellouw 2	-	-	-	140238, 425906	1.80-1.83	-0.27 to -0.30	**1mg** *Typha sp. 65x; Alisma plantago-aquatica 26x z; Mentha aquatica 27x; Berula erecta 6x*	Begin of clastic signal river Waal	-	-
	Tuil 1	GrA64242	3070 ±35	-28.57	144798, 426257	2.05-2.06	+0.66 to +0.65	**3mg** Leaf fragments	Extra clastic input (LOI 10%>5%) of river Waal	3285 ±49 3336 ±37[S]	1394 BC – 1282 BC 1333 BC ±49 1429 BC - 1372 BC[S] 1387 BC ±37
	Tuil 2	GrA64243	3300 ±60	-29.40	144798, 426257	2.26-2.27	+0.45 to +0.44	**3mg** Leaf fragments; *Alnus glutinosa* 1x	Begin of clastic signal river Waal	3529 ±70 3379 ±30[S]	1639 BC – 1580 BC 1583 BC ±70 1457 BC - 1412 BC[S] 1430 BC ±30
	Tuil 3	GrA64633	3170 ±35	-29.02	144798, 426257	2.54-2.56	+0.17 to +0.15	**5mg** Leaf fragments 3x; *Alnus glutinosa 6x v + 1x catkin*; *Persicaria minor/mitis* 1x; *Urtica dioica* 1x; *Lythrum salicaria* 1x	Start peat formation (time control)	3397 ±40 3424 ±32[S]	1496 BC – 1416 BC 1447 BC ±40 1501 BC - 1444 BC[S] 1475 BC ±32
River Lange Linschoten	**Linschoten**[**]	GrA62969	2000 ±30	-27.57	120848, 450247	0.96-0.97	-1.86 to -1.87	**4mg** 11x *Urtica dioica fruits*; 1x *Alisma plantago-aquatica fruits.*	Begin age of the river Lange Linschoten	1949 ±36	40 BC – 47 AD 1 AD ±36
	Linschoten 1	GrA64250	3130 ±35	-27.30	121214, 453502	0.55-0.56	-0.89 to -0.90	**3mg** *Alnus glutinosa* 5x v + 3x Catkin; Leaf fragment 1x	First clastic influx, (re-)activation of residual channel Lange Linschoten	3353 ±52 3350 ±51	1443 BC – 1311 BC 1391 BC ±52 1448 BC – 1320 BC 1401 BC ±51

	Linschoten 2	GrA64251	3405 ±35	-28.78	121214, 453502	0.85-0.86	-1.20 to -1.21	**3mg** *Alnus glutinosa* 24x v + 11 scales + 1 Catkin; *Urtica dioica* 1x*; Phragmites australis* 2x; *Poaceae* 1x; Leaf fragments	Start peat formation (time control) / minimum age residual channel	3652 ±52 3647 ±49	1746 BC – 1659 BC 1707 BC ±52 1741 BC – 1658 BC 1698 BC ±49
	Est 4***	GrA64252	1830 ±35	-28.75	150298, 429818	1.37-1.41	+1.18 to +1.14	**3mg** *Poaceae* 1x; *Mentha aquatica* 3x; *Apiaceae* 2x + 1x frgm; *Cyperaceae* urn 1x frgm; *Rumex maritimus/palustris* bd 2x; *Chenopodium sp*. 1x frgm; *Atriplex patula/prostrata* 1x; *Berula erecta* 1x; *Oenanthe aquatica* 3x + 5 frgm; *Cirsium/Carduus* 1x; *Persicaria sp.* 1x; *Ranunculus acris/repens* 2x, *Stellaria media* 1x; Leaf fragments 1x	Second clastic input (possible reactivation)	1767 ±49 1740 ±55[S]	135 AD – 224 AD 184 AD ±49 149 AD – 313 AD[S] 212 AD ±56
	Est 5	GrA64253	1535 ±30	-28.23	150298, 429818	1.82-1.83	+0.73 to +0.72	**3mg** Leaf fragments; *Salix* bud 2x	First clastic input (possible reactivation)	1438 ±50 1467 ±44[S]	432 AD – 570 AD 509 AD ±50 428 AD – 545 AD[S] 483 AD ±44
	Est 6***	GrA64254	1275 ±30	-28.28	150298, 429818	1.97-1.98	+0.58 to +0.57	**3mg** Leaf fragments	Start peat formation (time control) / minimum age residual channel	1228 ±38 1222 ±38[S]	685 AD – 767 AD 727 AD ±38 685 AD – 767 AD[S] 728 AD ±38

BR/R Calibrated ages calculated with OxCal 4.2 (Bronk Ramsey, 2009) and the IntCa23 reference dataset (Reimer et al., 2013).

* lab-analyses carried out by Harm Jan Pierik

** fieldwork and lab-analysis carried out by Harm Jan Pierik.

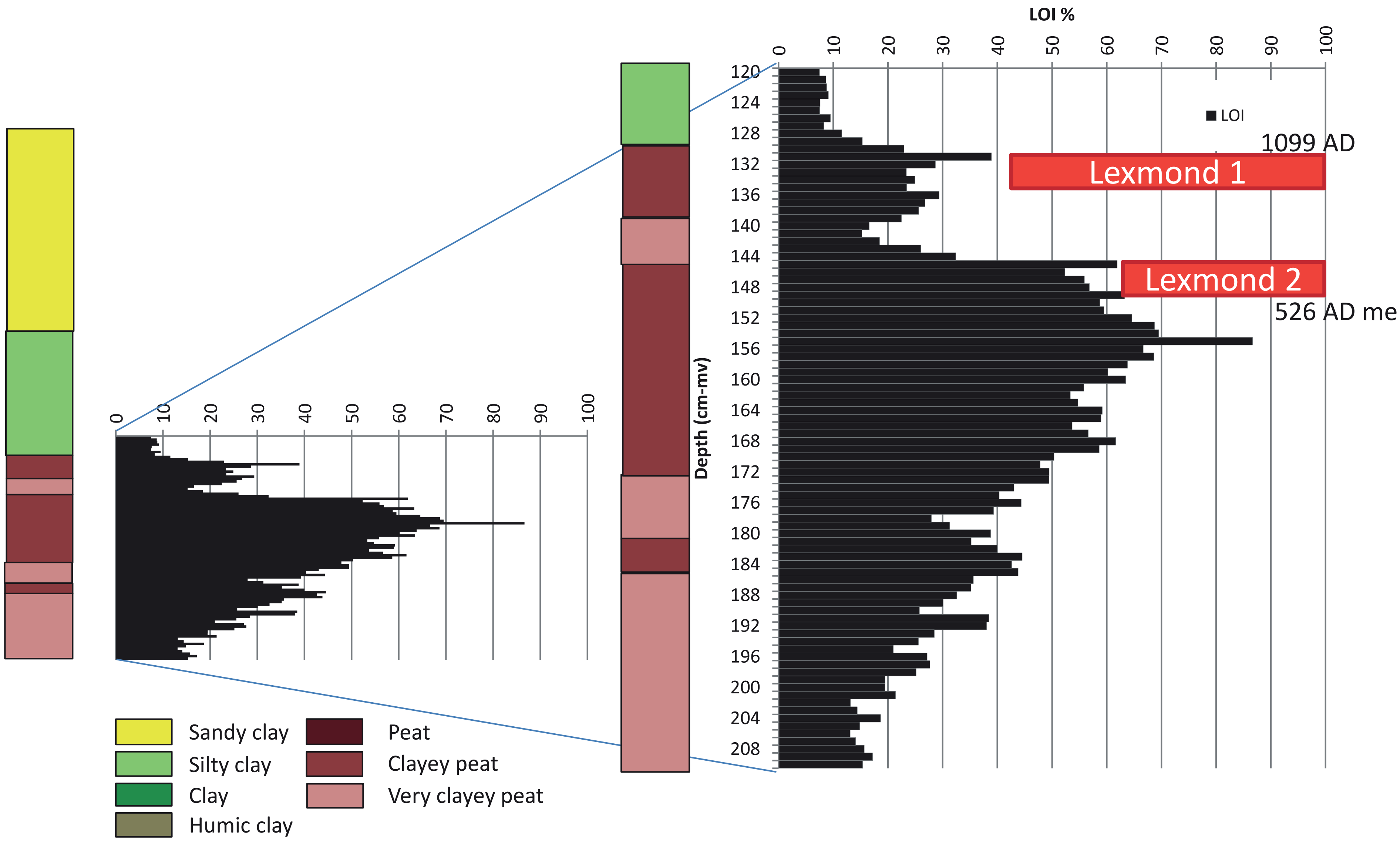
*** Monsters are presumably exchanged, sample names are linked to Groningen-numbers, in this report Est 4 and Est 6 dates are assumed to be exchanged. For sequence modeling dates Est 4 and Est 6 are turned in the sequence.

S calibrated using sequence modeling with Oxcal 4.2 (Bronk Ramsey, 2009)

Sample	River	Type of Dating	Lab nr	x	y	z	MEAS	d Distance	Lab age ±error	δ13C	±σ [cal yrs BP] BCAD _TS	±σ [cal yrs BP] BCAD _TS	Calibrated age range BCAD MINIMUM _TS	Calibrated age range BCAD MAXIMUM _TS	River Phase	Remarks	Meaning
Est 4***	Est	C14	GrA-64252	150298	429818	-			1830 ±35	-28,75	56	56	149	313	P2	good	Second clastic input (possible reactivation)
Est 5	Est	C14	GrA-64253	150298	429818	-			1535 ±30	-28,23	44	44	428	545	P2	good	First clastic input (possible reactivation)
Est 6***	Est	C14	GrA-64254	150298	429818	-			1275 ±30	-28,28	38	38	685	767	P5	good	Start peat formation (time control) / minimum age residual channel
Vreugderijkerwaard 1*	Gelderse IJssel	C14	GrA-62950	198968	502969	-	85844,98	551	2665 ±30	-28,79	26	26	-836	-801	N.A.	too old	Begin age of the river Gelderse IJssel, first large flood
Vorchten M3a	Gelderse IJssel	C14	GrA-44632	204818	490348	2,8	70182,97	666	2105 ±35		59	59	-176	-59	P0	macrofossils (shallowing waterdepth	Begin of peat formation in proto-IJssel brook valley system; peat (Vb) onder Bo
Herxen M2a	Gelderse IJssel	C14	GrA-42398	206234	491925	-	71946,81	508	1930 ±165		202	202	-160	314	P0		peat-filling brook valley, covered by Gelderse Ijssel overbank
Herxen M3-2	Gelderse IJssel	C14	GrA-42516	206234	491925	3,05	71946,81	508	2235 ±40		56	56	-377	-211	P0		peat under crevasse Bc; peat Vb base Gelderse IJssel
B01-1194.6	Gelderse IJssel	C14	GrA-38085	199394	500034	0,44	82355,35	1548	1535 ±30		50	50	432	570	P0	change in peat	basis van veen
Westenholte ADC 67-1	Gelderse IJssel	C14	KIA 38639	199738	502228	1,015	84484,23	201	2020 ±30	-29,04	41	41	-50	22	P0	basis of peat	smaal fruits and other plant material; 6 fruits of Alnus Glutinosa; 3,5 pieces of buds
Westenholte ADC 67-2	Gelderse IJssel	C14	KIA 38640	199738	502228	1,015	84484,23	201	3020 ±30	-28,24	58	58	-1372	-1217	P0	gyttja on eaolian sand	small fruits and seeds ; 11 fruits of Alnus glutinosa; 1 fruit of Polygonum aviculare; 1 fruit of Carex sp.; 1 fruit of Oenanthe aquatica
Westenholte ADC 68-1	Gelderse IJssel	C14	KIA 38641	199578	502280	0,903	84627,34	203	3620 ±20	-29,62	33	33	-2021	-1948	P0		small fruits; 2 female catkin pieces of Alnus glutinosa
Westenholte ADC 68-2	Gelderse IJssel	C14	KIA 38642	199578	502280	0,903	84627,34	203	3615 ±30	-27,37	46	46	-2023	-1939	P0		small fruits; 4,5 fruits of Alnus glutinosa; 1 fruit of Carex sp.; 1 fruit of Urtica dioica; 2 buds of Salix sp.; 1 fruit of Oenanthe aquatica
Westenholte ADC 70-4	Gelderse IJssel	C14	KIA 38646	198598	502892	0,752	85986,69	201	2250 ±35	-27,7	57	57	-386	-231	P0		small fruits; 3 fruits of Alnus glutinosa; 1 fruit of Carex hirta/riparia; 1 fruit of Urtica dioica; 1 fruit of Galeopsis sp.
Zwolle II	Gelderse IJssel	C14	GrN-27025	200256	506212	-0,16	87779,52	3147	1950 ±40		46	46	3	115	P0		peat (bulk), not IJSSEL, but lacustrine?
Vorchten M2a	Gelderse IJssel	C14	GrA-44639	204818	490348	2,8	70182,97	666	1295 ±35		38	38	670	766	P2	end of peat in proto-IJssel	
B01-1194.4	Gelderse IJssel	C14	GrA-38096	199394	500034	0,44	82355,35	1548	1115 ±25		33	33	895	971	P2		top veen overgang naar venige klei
Vondstnummer 54 31-32	Gelderse IJssel	C14	Poz-20198	198725	500125	0,48	83763,39	1999	1125 ±35		52	52	889	972	P2		donderbruik veen; (0.30-0.37); .037-0.48 grijze klei, licht vertikaal doorworteld. P2B
Vondstnummer 54 18	Gelderse IJssel	C14	Poz-20197	198725	500125	0,48	83763,39	1999	1350 ±30		28	28	650	680	P2	change in peat	darkrown peat; P2A
Vreugderijkerwaard 4	Gelderse IJssel	C14	GrA-64341	198839	502877	-	85840,23	393	1210 ±35	-27,98	53	53	790	880	P2	good	Begin age of the river Gelderse IJssel, first large clastic input
Westenholte ADC 70-2	Gelderse IJssel	C14	KIA 38644	198598	502892	0,752	85986,69	201	1605 ±25	-28,26	43	43	407	532	P2	too old, reworked material?	small fruits and other plant material; 1,5 fruits of Ranunculus lingua; 5 fruits of Ranunculus acris/repens; 2 fruits of Rumex acetosella; 1 fruit of Alnus glutinosa; 1 budof Salix sp.; 3 buds
Westenholte ADC 70-3	Gelderse IJssel	C14	KIA 38645	198598	502892	0,752	85986,69	201	1375 ±20	-25,57	10	10	647	664	P2		small fruits; 1 bud; 6 fruits of Alnus glutinosa; 2,5 fruits of Ranunculus lingua; 2 stones of Rubus sp.
Westenholte WH-I-1	Gelderse IJssel	C14	UtC-14771	199162	503853	0,07	86734,26	1156	1142 ±55		71	71	778	975	P2	maturisation of IJssel	Maturisation of Gelderse IJssel: Begin sedimentation at distance from channel axis
Westenholte WH-I-2	Gelderse IJssel	C14	UtC-14772	199162	503853	0,07	86734,26	1156	1143 ±55		71	71	778	974	P2	maturisation of IJssel	Maturisation of Gelderse IJssel: Begin sedimentation at distance from channel axis
Zwolle I	Gelderse IJssel	C14	GrN-27024	200256	506212	-0,16	87779,52	3147	1540 ±30		48	48	431	565	P2	hydrological change	peat (bulk), not IJSSEL, but lacustrine?
De Enk Zuid	Gelderse IJssel	C14	GrA-34964	191833	503967	-0,48	95146,75	1913	980 ±35		48	48	1016	1150	P2		
De Slaper B4-2	Gelderse IJssel	C14	GrA-34961	188919	505005	-0,03	95651,34	3290	780 ±35		24	24	1224		P2	was 1247	veen tussen zandlaagjes
Grafhorst 1	Gelderse IJssel	C14	GrA-64248	191512	510417	-	99148,72	1668	1345 ±35	-30,04	28	28	651	686	P2	good	Begin age of the river Gelderse IJssel, start major river stage
Grafhorst 2	Gelderse IJssel	C14	GrA-64338	191512	510417	-	99148,72	1668	1375 ±45	-29,37	18	18	638	669	P2	good	Begin age of the river Gelderse IJssel, first large clastic input
WAP-1	Gelderse IJssel	C14	UtC-14774	203397	492597	1,43	74225,91	2035	1026 ±43		55	55	969	1040	P3		very top of peat; shallowing waterdepth; Maturisation of Gelderse IJssel: begin sedimentation at distance from channel axis
Vreugderijkerwaard 3	Gelderse IJssel	C14	GrA-64249	198839	502877	-	85840,23	393	1105 ±30	-27,23	35	35	895	976	P3	good	Begin age of the river Gelderse IJssel, start major river stage
Vreugderijkerwaard 2*	Gelderse IJssel	C14	GrA-63107	198968	502969	-	85844,98	551	960 ±30	-29,64	42	42	1024	1150	P3		first large scale floodings of the river Gelderse IJssel
Westenholte ADC 70-1	Gelderse IJssel	C14	KIA 38643	198598	502892	0,752	85986,69	201	1140 ±25	-24,55	49	49	882	968	P3		small fruits; 10 fruits of Ranunculus acris/repens; 3 fruits of Ranunculus lingua
Westenholte ADC 66-1	Gelderse IJssel	C14	KIA 38638	199768	502270	1,066	84484,23	251	1900 ±25	-26,81	92	92	1665	1950	P5	too young, recent fill	small fruits and seeds; 2 Ranunculus acris/repens; 1 Ranunculus lingua; 2 Persicaria minor; 3 Eleocharis palustris / uniglumis; 3 Carex sp.; 2 cf.Glyceria sp.; 1 Persicaria mitis
Westenholte ADC 66-1	Gelderse IJssel	C14	KIA 38638	199768	502270	1,066	84484,23	251	1900 ±25	-26,81	92	92	1665	1950	P5	too young, recent fill	small fruits and seeds; 2 Ranunculus acris/repens; 1 Ranunculus lingua; 2 Persicaria minor; 3 Eleocharis palustris / uniglumis; 3 Carex sp.; 2 cf.Glyceria sp.; 1 Persicaria mitis
Veeneiken groep I	Gelderse IJssel	dendro		198839	502877		85840,23	393					120	230	P3		
Veeneiken groep II	Gelderse IJssel	dendro		198839	502877		85840,23	393					510	525	P3		
Snelrewaard *	Hollandse IJssel	C14	GrA-64318	122464	448834	-	18556,86	148	2650 ±45	-27,09	38	38	-888	-793	P2	too old, oxidation	Begin age of the river Hollandse IJssel
Kleidek Hollandse Ijssel	Hollandse IJssel	C14	GrN-7577	120702	448637	-0,90	20447,69	190	1805 ±50		69	69	133	316	P2	good	peat, #68
Gouderak 1	Hollandse IJssel	C14	GrA-62970	107948	445419	-	35353,94	402	1895 ±30	-27,99	41	41	70	132	P2	good	Begin age of the river Hollandse IJssel
Linschoten**	Hollandse IJssel	C14	GrA-62969	107948	445419	-			2000 ±30	-27,57	36	36	-40	47	P2	good	Begin age of the river Lange Linschoten
Oudekerk 1**	Hollandse IJssel	C14	GrA-64564	103618	439348	-	45413,68	323	2390 ±30	-27	64	64	-490	-440	P2	too old, oxidation	Begin age of the river Hollandse IJssel
Oudekerk 2**	Hollandse IJssel	C14	GrA-64321	103618	439348	-	45413,68	323	2550 ±70	-27,49	100	100	-800	-542	P2	too old, oxidation	Begin age of the river Hollandse IJssel
Meijerbergse Ijssel	Hollandse IJssel	C14	GrN-7580	126350	452640	-0,50	12981,72	589	760 ±45		33	33	1224	1280	P3	good	The meander was probably cut off (naturally?) just before the embankment of the Hollandse IJssel.
Linschoten 1	Lange Linschoten	C14	GrA-64250	121214	453502	-			3130 ±35	-27,3	51	51	-1448	-1320	P2	not reactivation phase	First clastic influx, (re-)activation of residual channel Lange Linschoten
Linschoten 2	Lange Linschoten	C14	GrA-64251	121214	453502	-			3405 ±35	-28,78	49	49	-1741	-1658	P5	not reactivation phase	Start peat formation (time control) / minimum age residual channel
Nieuwegein 2	Lek	C14	GrA-64632	136246	446378	-	2808,35	568	1965 ±35	-27,16	39	39	3	78	P0	good	Start peat formation (time control)
Nieuwegein 1	Lek	C14	GrA-64240	136246	446378	-	2808,35	568	1830 ±30	-26,13	42	42	132	214	P2	good	First fluvial input for river Lek
Lek	Lek	C14	GrN-8707	136212	446375	0,3	2841,752	561	1950 ±30		35	35	17	81	P2		clayey peat, Berendsen 1982 136,185
Willige Langerak	Lek	C14	GrN-8708	122402	439900	-0,3	19698,9	354	2220 ±35		53	53	-361	-209	P2		peaty clay, Brerense 1982 136;185
Nieuw Lekkerland 1**	Lek	C14	GrA-64317	107533	433761	-	36943,95	664	2260 ±35	-29,02	59	59	-390	-237	P2	too old, oxidation	Begin age of the river Lek
Ameide 1**	Lek	C14	failed sample analysis	127453	441165	-	14252,65	771	-	-	-	-	-	-	-	-	Begin age of the river Lek
Lexmond 1**	Lek	C14	GrA-64319	131974	442570	-	8818,28	785	930 ±45	-29,04	49	49	1033	1141	3b	too young, fresh roots	(re)Activation phase for river Lek; extra clastic input
Lexmond 2**	Lek	C14	GrA-64323	131974	442570	-	8818,28	785	1515 ±40	-26,61	55	55	438	609	P2	too young, fresh roots	First fluvial input for river Lek
Ameide 2**	Lek	C14	GrA-62997	127453	441165	-	14252,65	771	2160 ±30	-25,03	77	77	-384	-115	P2	older layer	First fluvial input for river Lek
Ameide 3A**	Lek	C14	GrA-64635	127453	441165	-	14252,65	771	1975 ±30	-26,97	35	35	-37	58	P2	good	Begin age of the river Lek
Schoonhoven**	Lek	C14	GrA-62968	120993	439623	-	21345,11	650	1715 ±30	-27,04	44	44	259	384	P2	good	Begin age of the river Lek
Streefkerk 1**	Lek	C14	GrA-62966	112608	436097	-	30932,32	500	2190 ±30	-28,14	57	57	-356	-199	P2	too old, oxidation	Begin age of the river Lek
	Nederrijn	C14	GrN-16819						2540 ±100		UNCALIBR	UNCALIBR	UNCALIBR	UNCALIBRATED			
	Nederrijn	C14	GrN-7266						1585 ±50		UNCALIBR	UNCALIBR	UNCALIBR	UNCALIBRATED			
Hellouw 2	Waal	C14	-	140238	425906	-	35697,95	471	-	-	-	-	-	-	-		Begin of clastic signal river Waal
Loefkamp-01	Waal	C14	UtC-11136	153372	426739	3,62	18987,70	2162	2238 ±32		54	54	-378	-212	P2		seeds (peaty clay)
Dreumel II	Waal	C14	GrN-6994	158475	428170	3,70	15119,31	1793	2560 ±50		91	91	-804	-564	P0		Vegetaion horizon; gyttja; Bruchem / Oevershof (soil formation)
Waal II	Waal	C14	GrN-12457	132900	425000	1,20	43932,69	772	2315 ±35		53	53	-406	-366	P0		clayey peat Gameren?
Waal II alkali	Waal	C14	GrN-13505	132900	425000	1,20	43932,69	772	2150 ±50		89	89	-352	-111	P0		clayey peat alkali extract
Dalem II-2	Waal	C14	UtC-1896	130015	426315	0,10	46701,04	682	2810 ±190		235	235	-1257	-801	P0		spagnum sp. Fruit; Gameren #48?
Dreumel I	Waal	C14	GrN-6993	158475	428170	3,70	15119,31	1793	1815 ±50		67	67	130	252	P2	low organic content	Vegetation Horizon; Waal soilformation
Dreumel 6	Waal	C14	GrA-64246	157764	428471	-	15149,86	1021	2285 ±30	-26,34	58	58	-399	-262	P2	older layer	Begin of clastic signal river Waal
Venusweg 1	Waal	C14	GrA-64340	158392	427943	-	15380,87	1812	2310 ±40	-27,22	68	68	-410	-262	P2	too old, reworked material	Begin of clastic signal river Waal
Venusweg 2	Waal	C14	GrA-64337	158392	427943	-	15380,87	1812	2940 ±40	-27,23	64	64	-1210	-1057	P2	too old, reworked material	Begin of clastic signal river Waal
Tuil 2	Waal	C14	GrA-64243	144798	426257	-	30597,39	949	3300 ±60	-29,4	70	70	-1457	-1412	P2	too old, reworked material	Begin of clastic signal river Waal
Tuil 3	Waal	C14	GrA-64633	144798	426257	-	30597,39	949	3170 ±35	-29,02	40	40	-1501	-1444	P2	too old, reworked material	Start peat formation (time control)
Waal I	Waal	C14	GrN-12456	132900	425000	1,20	43932,69	772	1795 ±30		55	55	143	318	P2	low organic content	humic clay (thin layer); in clastic bed
Waal I alkali	Waal	C14	GrN-13504	132900	425000	1,20	43932,69	772	1655 ±50		71	71	265	527	P2	most reliable	alkali extract of humic clay
Dalem II-1	Waal	C14	UtC-1899	130015	426315	0,10	46701,04	682	1600 ±50		58	58	407	536	P2	most reliable	fragment of cf Salix wood (thin peat layer); Waal P2?
Tuil 1	Waal	C14	GrA-64242	144798	426257	-	30597,39	949	3070 ±35	-28,57	49	49	-1429	-1372	P3b	too old, reworked material	Extra clastic input (LOI 10%>5%) of river Waal
Hellouw 1	Waal	C14	GrA-64244	140238	425906	-	35697,95	471	2920 ±150	-28,89	175	175	-1367	-926	P3b	too old, reworked material	Extra clastic input (LOI 10%>5%) of river Waal

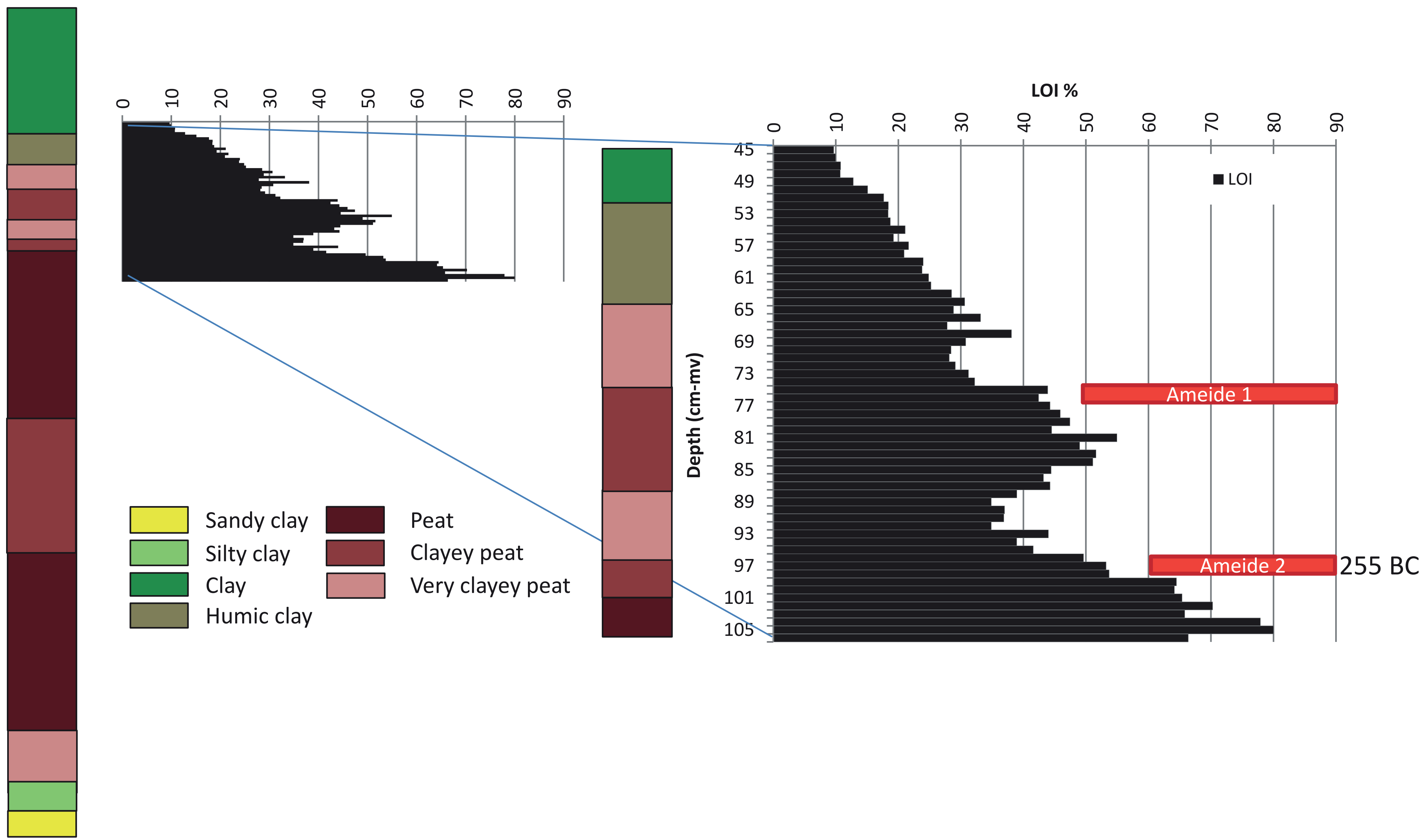
Lek 02 Lexmond

x = 131974 y = 442570



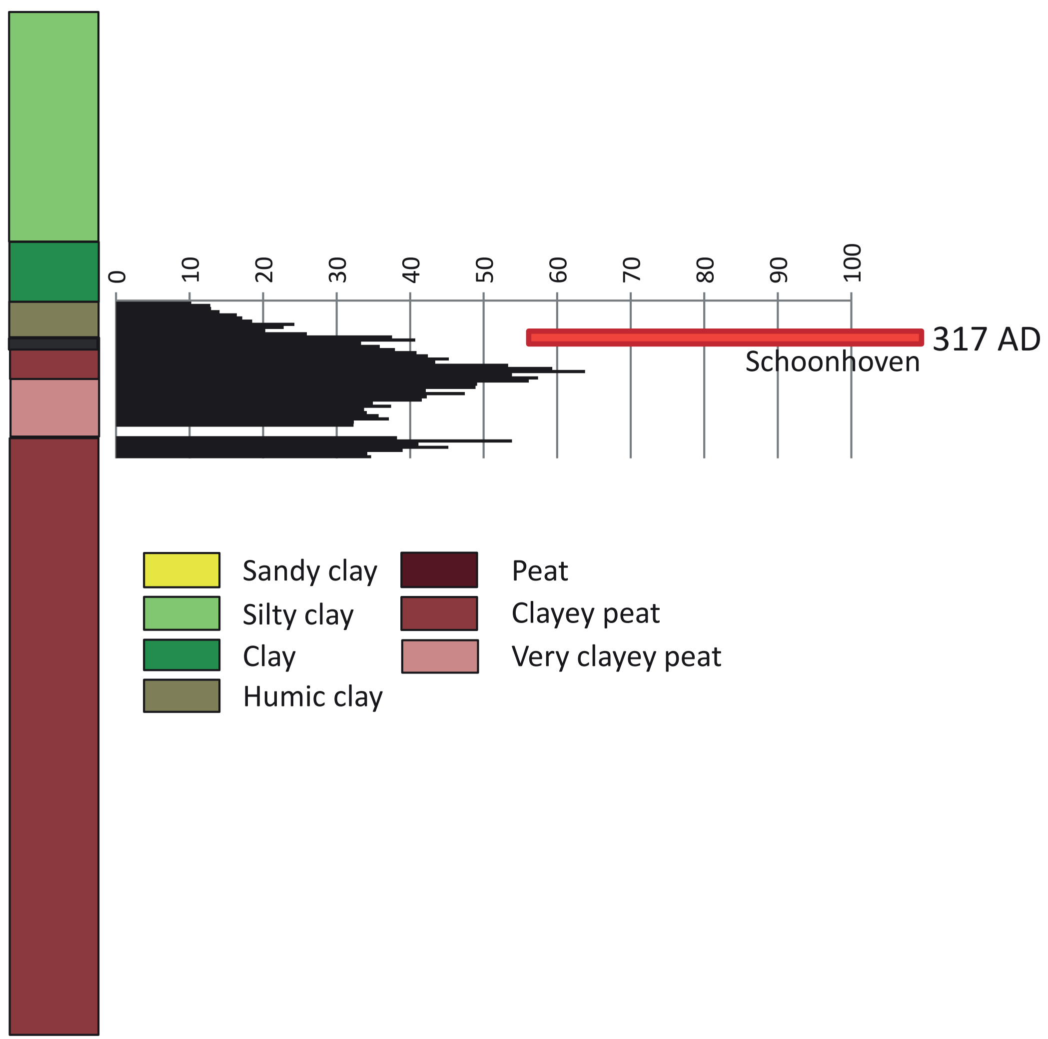
Lek 03 Ameide

x = 127453 y = 441165



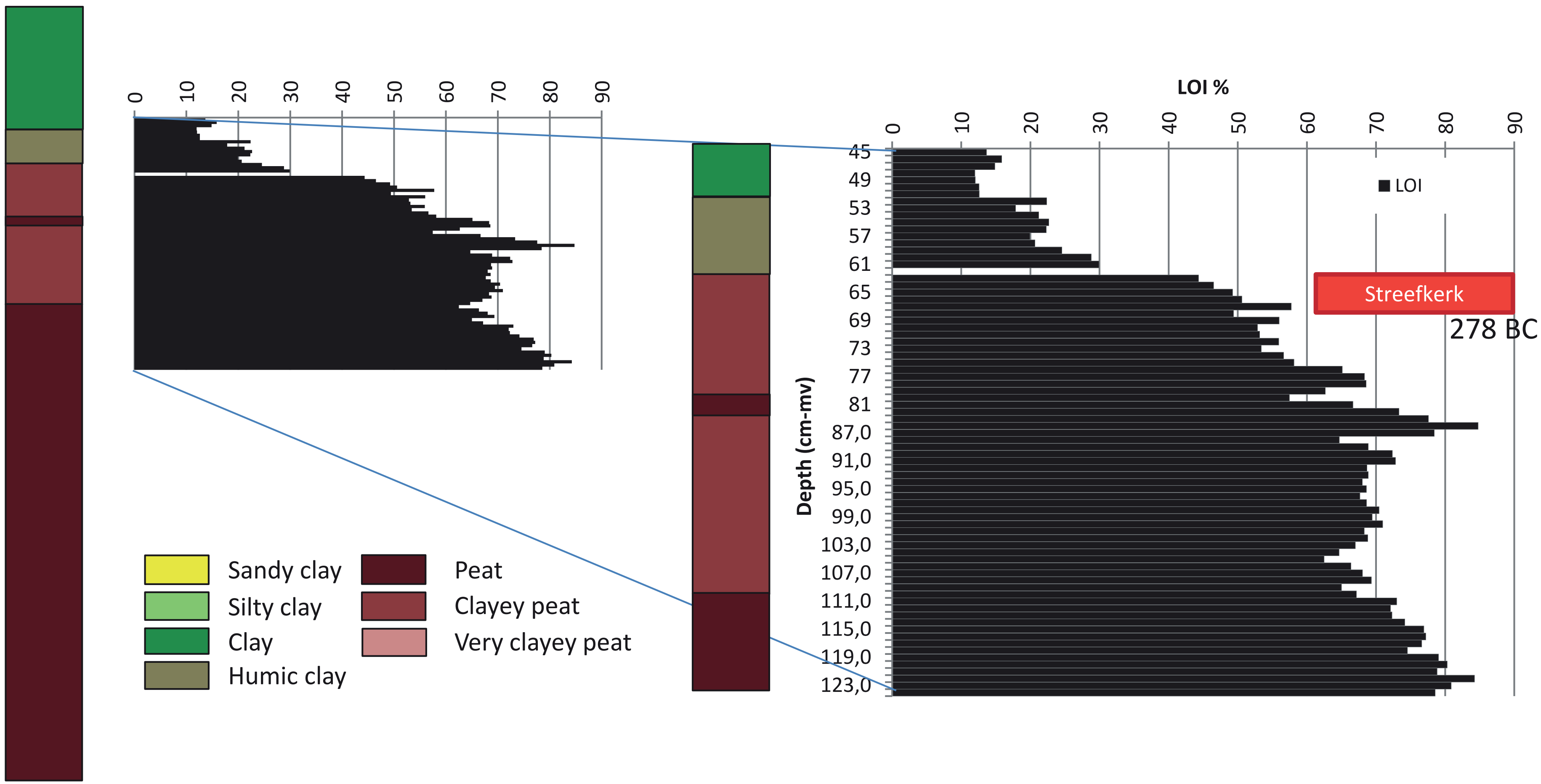
Lek 10 Schoonhoven

x = 120993 y = 439623



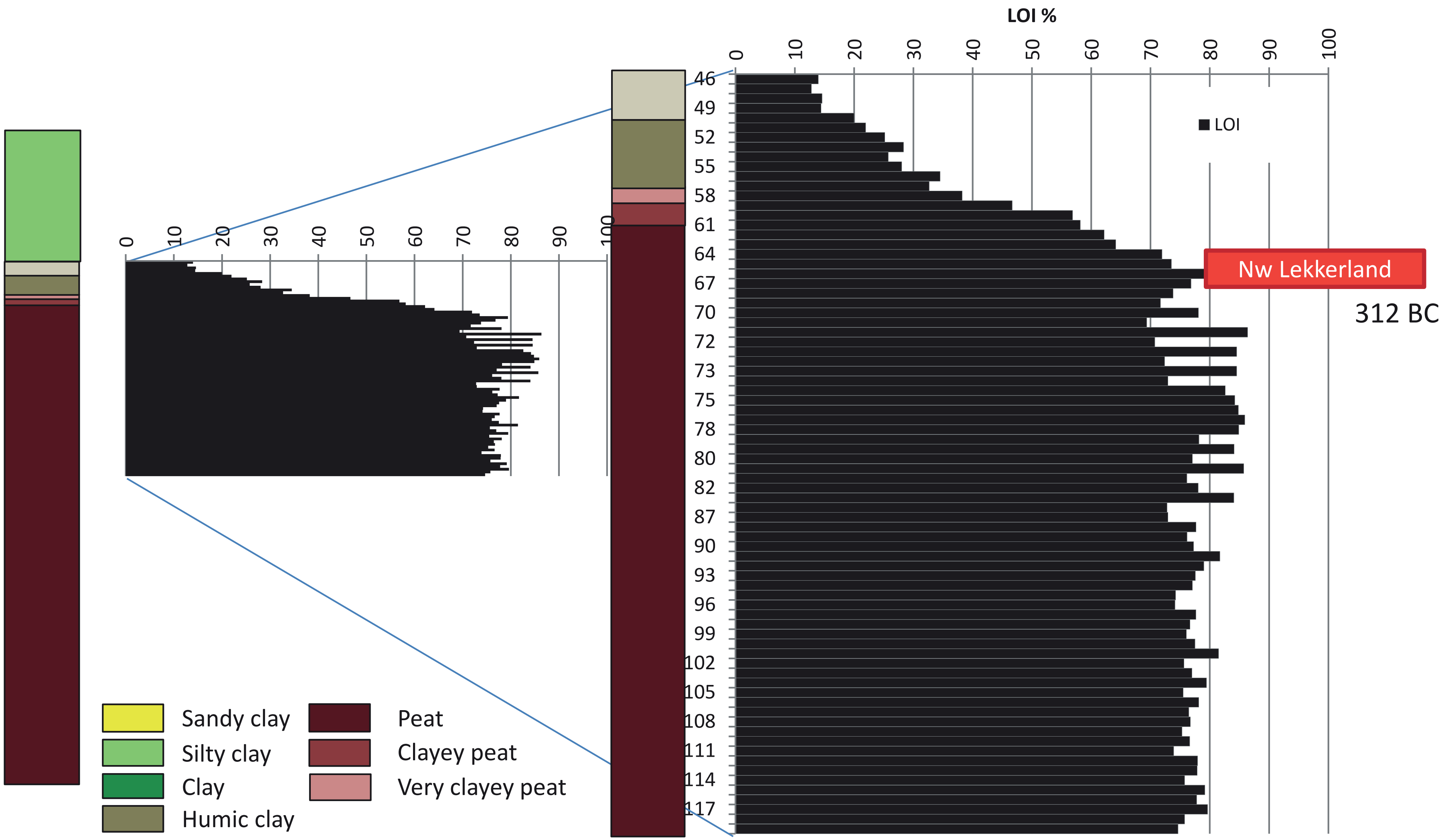
Lek 04 Streefkerk

x = 112608 y = 436097



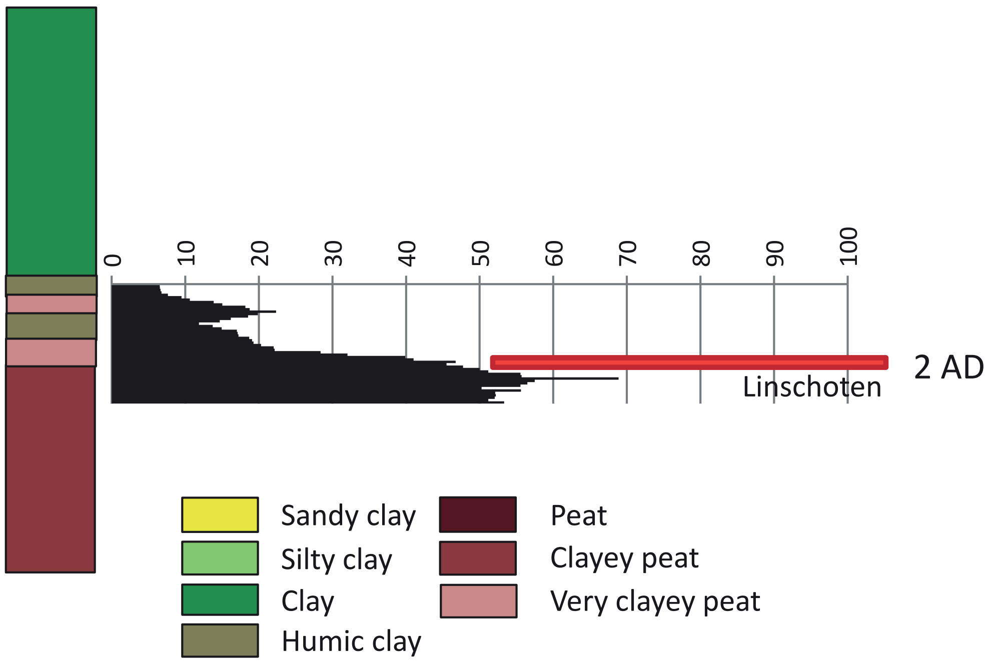
Lek 05 Nieuw Lekkerland

x = 107533 y = 433761



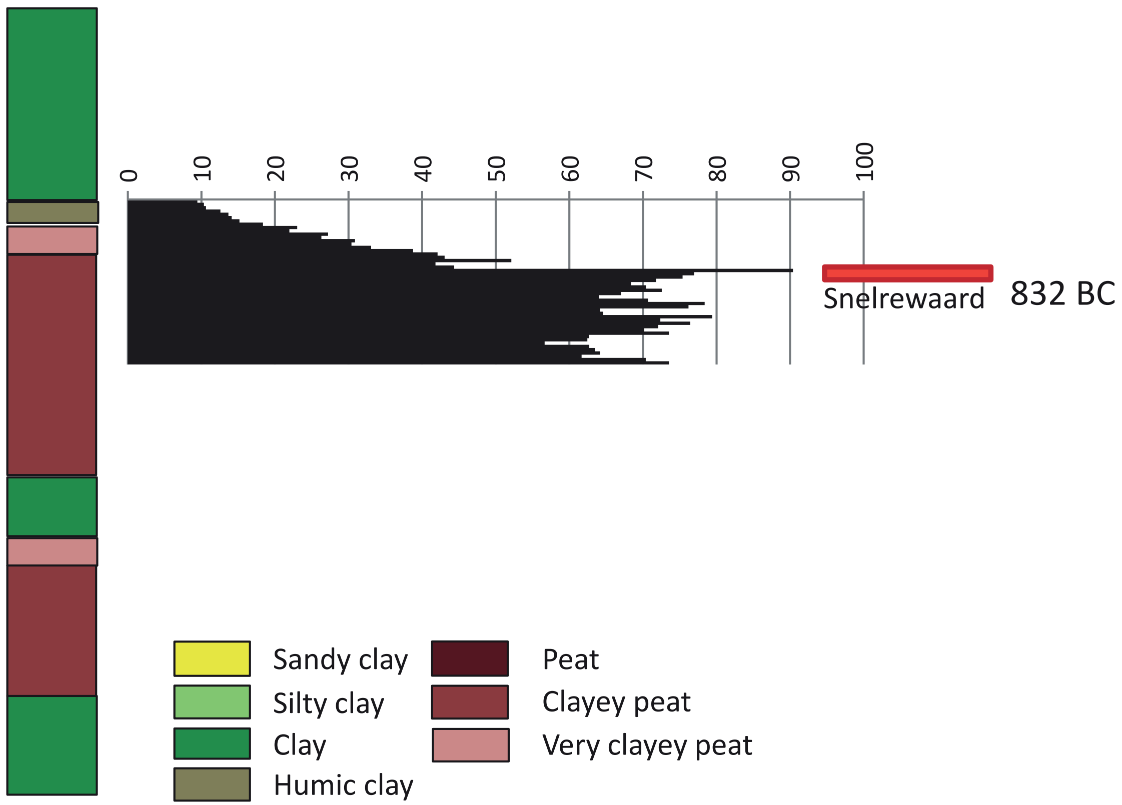
Hollandse IJssel 15 Linschoten

x = 107948 y = 445419



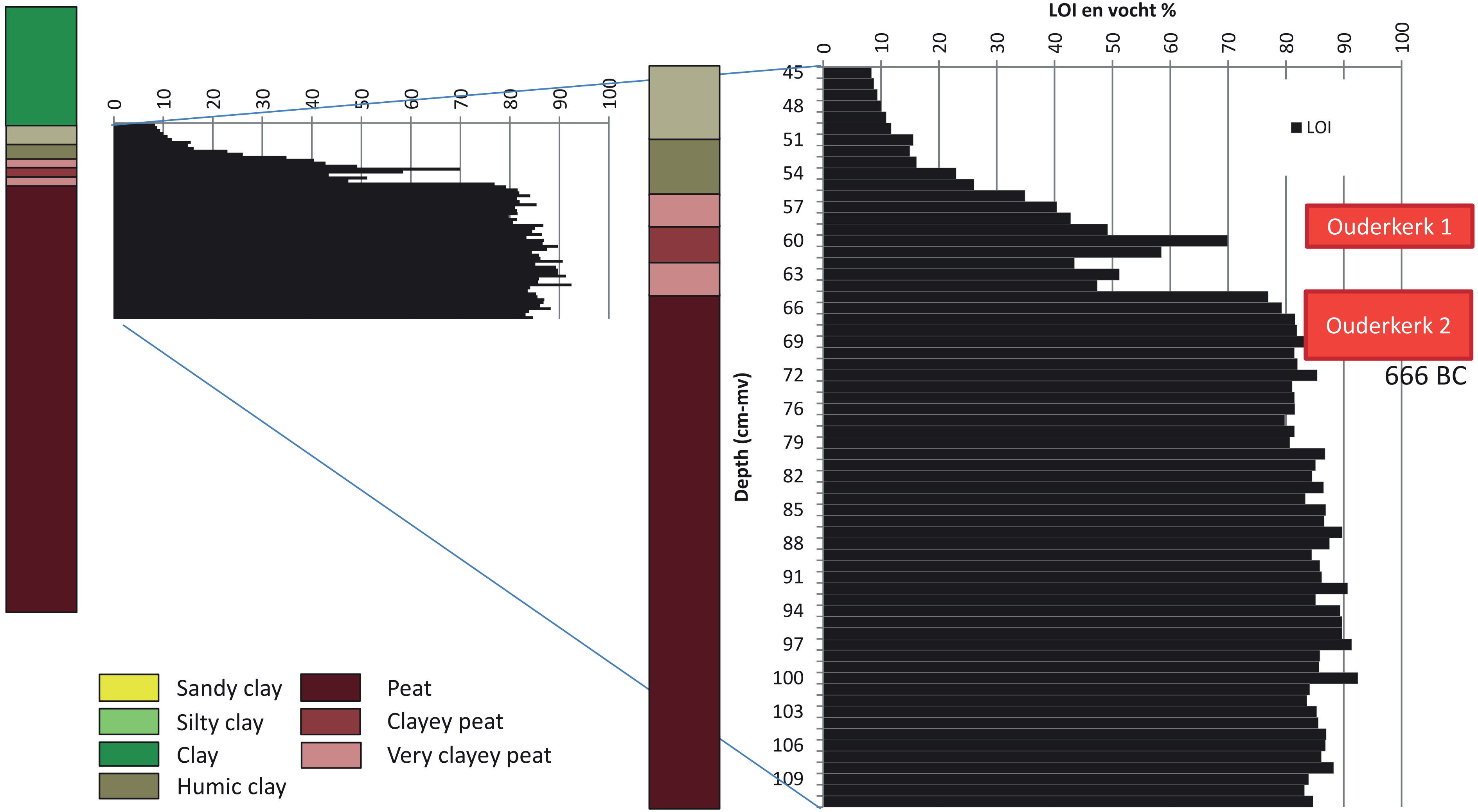
Hollandse IJssel 16 Snelrewaard

x = 122464 y = 448834



Hollandse IJssel 06 Ouderkerk

x = 103618 y = 439348



Hollandse IJssel 07 Gouderak

x = 107948 y = 445419