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Chrono- and archaeostratigraphy and development of the River Amstel: results of the North/South underground line excavations, Amsterdam, the Netherlands

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Abstract

Since 2003 extensive archaeological research has been conducted in Amsterdam, the Netherlands, connected with the initial phase of the new underground system (Noord/Zuidlijn). Research has mainly focused on two locations, Damrak and Rokin, in the centre of Medieval Amsterdam. Both sites are situated around the (former) River Amstel, which is of vital importance for the origin and development of the city of Amsterdam. Information on the Holocene evolution of the river, however, is relatively sparse. This project has provided new evidence combining archaeological and geological data, and allowed the reconstruction of six consecutive landscape phases associated with the development of the River Amstel. The course of the present-day Amstel is the result of a complex interaction of processes that started with an early prehistoric tidal gully within the Wormer Member of the Naaldwijk Formation, including Late Neolithic (2400–2000 BC) occupation debris in its fill that was subsequently eroded. Next, this system developed into a later prehistoric Amstel river course that was part of the Angstel–Vecht–Oer-IJ system (1020–350 BC), meandering through a peat-dominated landscape. Later on the processes included intensive reclamation of land, drainage and canalisation, although the Amstel was also strongly influenced by natural storm tides. After intense land reclamation, starting around 1200 AD, the meandering Amstel from Nes to Kalverstraat, which was originally 150 m wide, became the rather straight 20–50 m wide tamed, canalised river of today.

Keywords: River Amstel, tidal gullies, sedimentary and chronostratigraphical history, archaeology, North/South line, archaeostratigraphy, Late Neolithic occupation, Bell Beaker, Amsterdam

Introduction

The origin and development of the city of Amsterdam is directly related to flowing water, more specifically to its position near the River Amstel and the IJ, the southernmost part of the former Zuiderzee. Because of severe storm tides during the 12th century large parts of the peatland in and around the former Zuiderzee (the present IJsselmeer) were eroded, creating an open, easily navigable connection between the Waddenzee/North Sea in the north and waterways such as the Overijsselse IJssel, the Eem, the Hollandse Vecht, Amstel and the IJ (Wiggers, 1955; Ente, 1971; Vos et al., 2011). Around the middle of the 13th century AD a dam was constructed in the Amstel situated at the location of the present Dam Square. According to historical sources, the dam was built around 1264 AD (e.g. Gawronski et al., 2012).

Thanks to its location at the mouth of the River Amstel, the access to the North Sea and its strategic position at the borders of the counties of Holland and Utrecht, Amsterdam developed into a flourishing trading centre. The Damrak was a secluded harbour for international sailors, in particular for the states bordering the Baltic Sea. From here, trading goods

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Fig. 1. Part of the map of Amsterdam by Cornelis Anthoniszn (1544) with the location of the two main research sites Damrak and Rokin discussed in this paper marked.

(in the Late Middle Ages mainly grain, beer, textiles, wood and fish) could be shipped along the River Amstel and/or IJ into the hinterland or via safe waterways, even to Flanders in Belgium.

During the past 50 years the remains of dwellings with dateable finds and evidence of land reclamation by means of anthropogenic filling of the riverbanks have been excavated along the east and west banks of the river, parallel to the Nes and Warmoesstraat to the east and the Kalverstraat and Nieuwendijk to the west (e.g. Gawronski et al., 2012; Toebosch, 2011). The oldest discovered remains of habitation at the mouth of the Amstel date to the beginning of the 13th century AD (Gawronski et al., 2012). Subsequently, this small hamlet grew rapidly, becoming one of the world's main trading and economic centres in the 17th century (Gawronski et al., 2012).

Although archaeological research during the past 40 years has provided a wealth of information on the history of Amsterdam, relatively little is known about the development and role of its main artery, the River Amstel, in its growth. In the early 1990s the city council of Amsterdam approved the plans for the construction of an underground metro-system, the Noord/Zuidlijn (North/South line). The project involved large-scale construction sites, excavated to a depth of 33 m –NAP (at De Pijp). Based on a study of the Archaeological Department of the city of Amsterdam (now the Bureau Monumenten en Archeologie of the city council of Amsterdam; Veerkamp, 1997, 1998a,b) to assess the archaeological importance of the scheme and the necessity of research, a multidisciplinary archaeological project plan was created (Kranendonk, 2003). Archaeological research was integrated in the civil engineering process and undertaken between 2005 and 2012 by a team directed by city archaeologist J. Gawronski. The main focus of research was two sites along the former River Amstel, i.e. Damrak, as part of the old sea port, and Rokin, as part of the old inner harbour; these sites correspond to metro stations in the oldest, medieval part of Amsterdam (Fig. 1).

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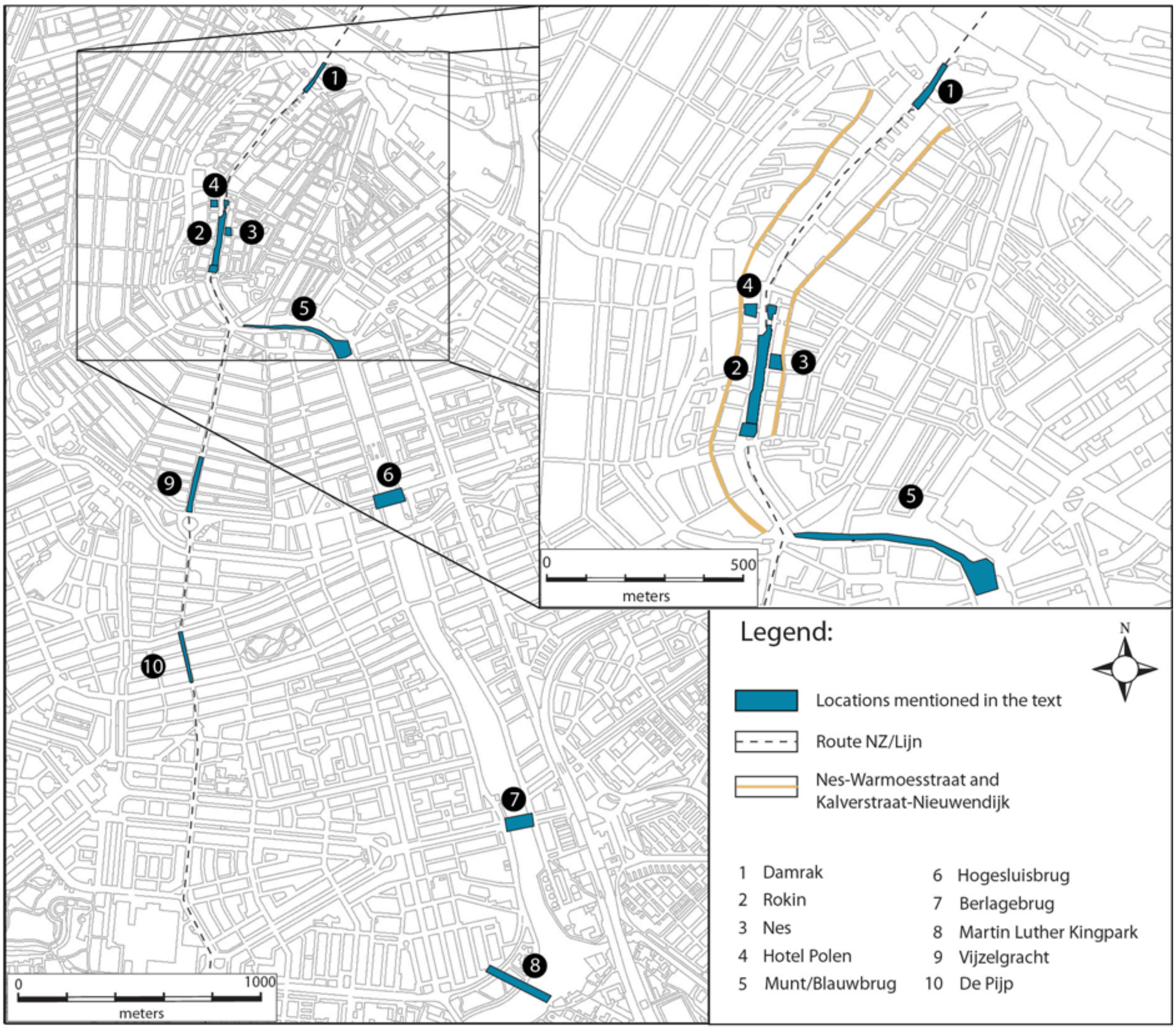

Fig. 2. Overview of the study locations on a map of Amsterdam (Damrak, Rokin, Hotel Polen, NES, core/cone descriptions Munt/Blauwbrug, Hogesluisbrug, Berlagebrug and Martin Luther King Park).

Finds from both the Damrak and Rokin sites were investigated to analyse the origins and social-cultural development of this part of the city. Moreover, it was expected that the sites would yield more detailed information, based on refuse patterns, on the cultural development on a parcel's surface. The geological history of the River Amstel, the main artery of Amsterdam, was a second focal point of the project plan because of the unprecedented deep exposures in the subsurface stratigraphy (Damrak: approximately 25m –NAP; Rokin: 27m –NAP), providing an opportunity to add significantly to the sparse knowledge of the river's Holocene development prior to the project.

In this paper we present new sedimentological, faunal and archaeological data concerning the River Amstel through time within the city limits of Amsterdam and present a new chronostratigraphical model of its evolution. In archaeological terms, these models will provide a better understanding of the development of the River Amstel and its role in the city's history.

Methods

Sampling

This research is focused on the data retrieved from the key sites of Damrak and Rokin. These sites were excavated to a depth of approximately 25–27 m –NAP, well below the Holocene–Pleistocene boundary transition. During this work, an emphasis was placed on the different and complex fills of the River Amstel and its possible precursors. In addition to the studies at Damrak and Rokin, Pleistocene deposits have also been documented at locations at Vijzelgracht and 'de Pijp' (Fig. 2).

Civil engineering constraints resulted in a site-specific adapted archaeological research programme. At Damrak three caissons were sunk to 25 m –NAP, of which caisson 1 was the largest (60 × 20 m) and the main focus of investigation. Caisson 1 is situated over the former 'Nieuwe Brug', directly in the centre of the entrance to Amsterdam's late-medieval

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international harbour. The sediments underneath the caisson were loosened by means of high-pressure water cannons and removed by pumping of the sludge. Finds were mainly retrieved by an industrial sieving machine, specifically made for archaeological purposes. Archaeological investigation was mainly conducted from August 2005 to January 2006. Wherever and whenever possible and necessary, small cross-sections through the underlying sediments were recorded.

In contrast to the rather harsh archaeological circumstances at the Damrak location, the other sites offered much better conditions for collecting archaeological and geological data. Before removing the superficial sediments, deep walls (up to 40 m –NAP) were constructed, a floor was injected and a roof was built, thus creating a semi-closed box. Subsequently this box was excavated in five or more phases, each approximately 5 m deep. Excavation was conducted simultaneously with the archaeological research. During the period 2006–2011, the main part of Station Rokin (c. 190 × 25 m) was excavated to a depth of about 27 m –NAP. Archaeological finds were retrieved before removal and transportation of the sediments away from the site. Archaeological excavations were undertaken using a grid system, allowing the finds to be collected (and recorded) per strata/layer/feature and per defined square. In the first two phases of excavation (to a depth of about 11 m –NAP) most of the 90 cross-sections (west to east) were documented, the last section reaching a maximum depth of about 27 m –NAP.

Because of the civil engineering work schedule, the time pressures made it impossible to describe in detail all the different layers *in situ*, therefore the sediments were sampled by means of sediment trays, which were used to provide detailed sedimentological descriptions and for micropalaeontological sampling. In total, more than 150 trays from the main four sites have been described in detail (Kluiving et al., 2006, 2008; Kluiving, 2007). For the sedimentological analysis of the Holocene sediments in the Rokin station excavations, ten trays were selected, from each of which five samples at 10 cm intervals were examined for grain size and thermogravimetric analysis (TGA) (Kluiving & Troelstra, 2012). From the Damrak location 64 samples were selected for similar sedimentological analyses (Kluiving, 2011).

Additional data

Alongside the newly acquired datasets associated with these geotechnical investigations, a number of other additional datasets have been used: (a) descriptions of cores in the current bed of the River Amstel held by the city's archive (Stads Archief Amsterdam), (b) pre-existing soil cores and cone penetration data from the Project Bureau North/South subway and from a few other locations from Amsterdam, and (c) cores and cone-penetration data retrieved from the DINO database (Dinoloket, 2013). Information from two previously investigated archaeological sites adjoining the Rokin location were also included (Fig. 2).

Laboratory analyses

For grain size distribution, all samples were analysed using a Fritsch laser particle sizer. Organic carbon and carbonate content ($CaCO_3$) were measured in a LECO TGA analyser. Both facilities are located in the laboratories of the Faculty of Earth and Life Sciences, VU University, Amsterdam. For micropaleontological analysis, part of each sample was washed over a >63 micron sieve and dried on a hotplate. The residues were analysed under a binocular microscope; all microfaunal/floral and lithological elements were identified and listed.

Dating

Inherent to fluvial sediments is the process of sedimentation, reworking and erosion of material. Younger organic material can therefore easily be mixed with older organic debris, either locally sourced or far travelled (e.g. locally grown plants and/or carbon derived from older rocks). Through these processes old carbon can be introduced and stored in the depositional environment, and can result in the contamination of radiocarbon dates producing erroneous results (Bowman, 1995). Also freshwater shells have reservoir correction problems since some molluscs live on older plant remains, therefore consuming older carbon, again producing erroneous older age estimates (the so-called reservoir effect). For these reasons, in all cases of the AMS^{14}C, ^{13}C samples on shells in this paper, dates should be regarded as maximum ages of the sampled units.

In an attempt to gain more information about absolute dates of the sediments, some remains of plants have been dated by means of AMS^{14}C, ^{13}C and dendrochronology. In relation to the depositional reconstruction these dates can be regarded as maximum age estimates. Combined with the stratigraphical position of sediments and archaeological remains a chrono- and archaeo-stratigraphical model is created. For comparisons of age results from various sources, ages expressed in AMS^{14}C, ^{13}C years and calendar years BP are also given in calendar years AD and/or BC.

Results

Location Damrak

Based on sedimentological, faunal and archaeological data, the sequence at Damrak can be divided into five units, D1–D5, which are described in the following sections from the oldest to the youngest deposits (Fig. 3).

Unit D1 consists of olive green silty calcareous clays alternating with sandy layers, with climbing ripples and flaser bedding.

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Table 1. AMS^{14}C, ^{13}C dating results of botanical data at Damrak

Layer depth	Calendar age	Material	Remarks	Institute number	Unit
10.87–10.73 m –NAP	352–95 Cal BC, 2Σ 2151 ± 24 BP CALIB rev 4.3	*Alnus* (catkin)	Higher (Easter) level of oldest riverfill	KIA33973	D2
10.87–10.73 m –NAP	1207–1045 Cal BC, 1Σ 2919 ± 49 BP INTCAL04	*Alnus* (catkin)		UtC-15077	D2
10.87–10.73 m –NAP	3939–3858, 3814–3783 Cal BC, 1Σ 5037 ± 36 BP INTCAL04	*Menyanthes trifoliate*		UtC-15110	D2
10.87–10.73 m –NAP	895–866, 858–806 Cal BC, 1Σ 2685 ± 55 BP INTCAL04	*Ranunculus*		UtC-15109	D2
9.51–9.47 m –NAP	1679–1311 Cal BC, 2Σ 3196 ± 68 BP CALIB rev 4.3	*Sphagnum*	Peaty layer (storm tide)	KIA33972	D4.1
9.51–9.47 m –NAP	1873–1842, 1817–1797, 1778–1617 Cal BC, 1Σ 3410 ± 80 BP INTCAL04	*Sphagnum*		UtC-15079	D4.1
8.09–8.06 m –NAP	1618–1428 Cal BC, 2Σ 3242 ± 40 BP CALIB rev 4.3	*Carex paniculata*	Washed away (storm tide) material	KIA33971	D4.3
8.09–8.06 m –NAP	1743–1606, 1566–1560, 1546–1538 Cal BC, 1Σ 3370 ± 60 BP INTCAL04	*Urtica dioica*		UtC-15078	D4.3

Table 2. AMS^{14}C, ^{13}C dating results of foraminifera and wood at Rokin

Layer depth	Calendar age	Material	Remarks	Institute number	Unit
11.5–11.4 m –NAP	5320–5210 and 5140–5140 Cal BC, 2Σ Cal BP 7270–7160 and 7100–7090 INTCAL09	*Scrobicularia*	Section R2, layer 61	Beta-336505	R2
11.5–11.4 m –NAP	5040–4840 Cal BC, 2Σ Cal BP 6990–6790 INTCAL09	*Cardium*	Unit R2, layer 61	Beta-336507	R2
11.5–11.4 m –NAP	2900–2870 and 2800–2780 Cal BC, 2Σ Cal BP 4850–4820 and 4750–4730 INTCAL09	*Unio*	Unit R2, layer 61	Beta-336506	R2
10.25–10.15 m –NAP	770–410 Cal BC 2470 ± 45 BP OxCal v3.10		Treetrunk at base of layer 60 Unit R3 and the transition to the underlying layer 61 Unit R2	Kiev 1475 and 1479	R2 – R3
c. (9.60 m —NAP)	390–200 Cal BC, 2Σ Cal BP 2340–2150 INTCAL09	*Valvata piscinalis*	From a pocket within layer 60 Unit R3	Beta-336504	R3

All dates should be regarded as maximum ages of the sampled units.

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Table 3. Dendro-chronological date results of (worked) wood at Rokin

Depth	Calendar age	Material	Remarks	Institute number	Unit
c. 7 m –NAP	1319 AD ± outside sapwood	Alder	Northeastern part of Rokin	DAI 53518	
c. 9.5–10 m –NAP	1319 AD (outside sapwood)	Alder	Southwestern part of Rokin	DAI 53528	R4
c. 10–10.5 m –NAP	± or shortly after 1316 AD	Oak	Southwestern part of Rokin (at the base of layer 59 Unit R4)	DAI60521	R4
c. 10–10.5 m –NAP	± or shortly after 1317 AD	Oak	Southwestern part of Rokin (at the base of layer 59 Unit R4)	DAI60522	R4

$CaCO_3$ content is around 12%. The unit is rich in calcareous benthic foraminifera, mainly *Ammonia beccarii* and *Elphidium* sp., indicative of brackish water (inner estuarine) conditions. Archaeological finds are scarce and include sherds dating from the Bell Beaker period (c. 2400–2000 BC) between 12.40 and 12.85 m –NAP, together with a grinding stone dated at 2800–0 BC. Below the analysed unit, two stone hammer axes were found between 17.32 and 18.30 m, respectively 15.17 and 16.18 m –NAP; typologically, both are dateable to the Late Neolithic (Bell Beaker). Unit D1 is assigned to the upper part of the Holocene Wormer Member of the Naaldwijk Formation (Oer-IJ).

The grey-green silty clays unconformably overlying this deposit constitute Unit D2 (11.70–11.40 m –NAP). However, Unit D2 is quite variable in composition and also includes dark brown humic silty clays, eroded peat, intact peat layers, discontinuous sand laminae, slumps and pockets of sand. $CaCO_3$ values are around 19%. Molluscs are common and include *Littorina* sp., *Cardium* sp., *Mytilus* sp., *Hydrobia* sp. and opercula of *Bithynia* sp. In addition, abundant fish remains, ostracods and the foraminifera *Ammonia* sp., *Elphidium* sp. and *Nonion* sp. occur throughout. The unit is interpreted as a high-energy estuarine environment, with reworked material from brackish and freshwater environments. The erosional base of Unit D2 is associated with the development of a large-scale transverse gully. At the eastern (higher) part of the oldest fill of Unit D2 four samples of plant remains were AMS^{14}C, ^{13}C dated, showing an age range from c. 3939 to 95 BC, results that suggest considerable reworking of the material (Table 1). The youngest age, 352–95 BC at 10.87–10.73 m –NAP provides a maximum age for the sediments at that depth (Table 1). The section of D2 contains only a few archaeological finds, assigned to a general age of Bronze Age to Late Medieval.

Diatom analysis (De Wolf & Cleveringa, 2009) revealed the presence of *Synedra berolinensis* and *Stephanodiscus hantzschii* in the deepest palaeochannel fill (Unit D2). These diatoms characterise freshwater, eutrophic to hyper-eutrophic environments. *Synedra berolinensus* has been interpreted as a pollution marker and associated with Late Medieval (15th century AD) events, thus suggesting a considerably younger age for the oldest palaeochanel fill (De Wolf & Cleveringa, 1999, 2009). However, elsewhere the species has also been regarded as indicative for natural eutrophic conditions (Arvola & Tulonen, 1998; Burgis et al., 1973; Reynolds et al., 2002; Swale, 1963), which would suggest that it cannot be used as an age marker for the sediments.

Separated by an erosional boundary from Unit D2, Unit D3 (11.40–10.40 m –NAP) consists of brown-grey, organic rich silty clays alternating with light grey calcareous silty clays and rhythmic laminations of silty sand. Overall sand and $CaCO_3$ percentages decrease sharply from the lower boundary upwards while organic carbon percentages increase. All three parameters fluctuate significantly within Unit D3 (Fig. 3). The unit contains sparse microfauna; some wood and shell fragments are present. The erosional contact with the underlying unit suggests a younger gully fill. Based on the presence of fresh and brackish water diatoms, its microfauna and lithology, Unit D3 is interpreted as a fluvial sediment, with brackish water and storm influence.

Conformably overlying Unit D3 is a sequence of silty clays assigned to Unit D4 (10.40–7.60 m –NAP). The $CaCO_3$ and sand percentages remain low, C^{org} values are constant. The unit is divided into four sub-units (Fig. 3). D4.1 (10.40–8.60 m –NAP) consists of finely laminated clays, with occasional washed-in black peat, sparse ostracods, shell fragments and a *Valvata* layer at 8.85 m –NAP. It is interpreted as deposition in a quiet fluvial environment, but with short phases of brackish influence associated with offshore storm activity.

Sub-units D4.2 (8.60–8.17 m –NAP) and D4.3 (8.17–8.07m –NAP) are thin horizons consisting of laminated humic silty clays. The deposits are increasingly more calcareous vertically upwards. The diatoms are defined as freshwater with some marine influence. Unit D4.2 is interpreted as the product of an alternating fresh and brackish water environment based on its lithology and diatom content. D4.3 contains a layer comprising clasts of peat. Unit D4.3 is interpreted as a high-energy storm or flood deposit. A protected freshwater sequence D4.4 (8.07–7.60 m –NAP) marks the termination of Unit D4 and contains common ostracods, often in doublets, indicating *in situ* preservation.

Unit D5 (7.60–5.85 m –NAP) consists of (dark) grey-brown strongly silty clays, with less sand and slightly higher $CaCO_3$ values than the underlying D4 units. Intervals with rich molluscan

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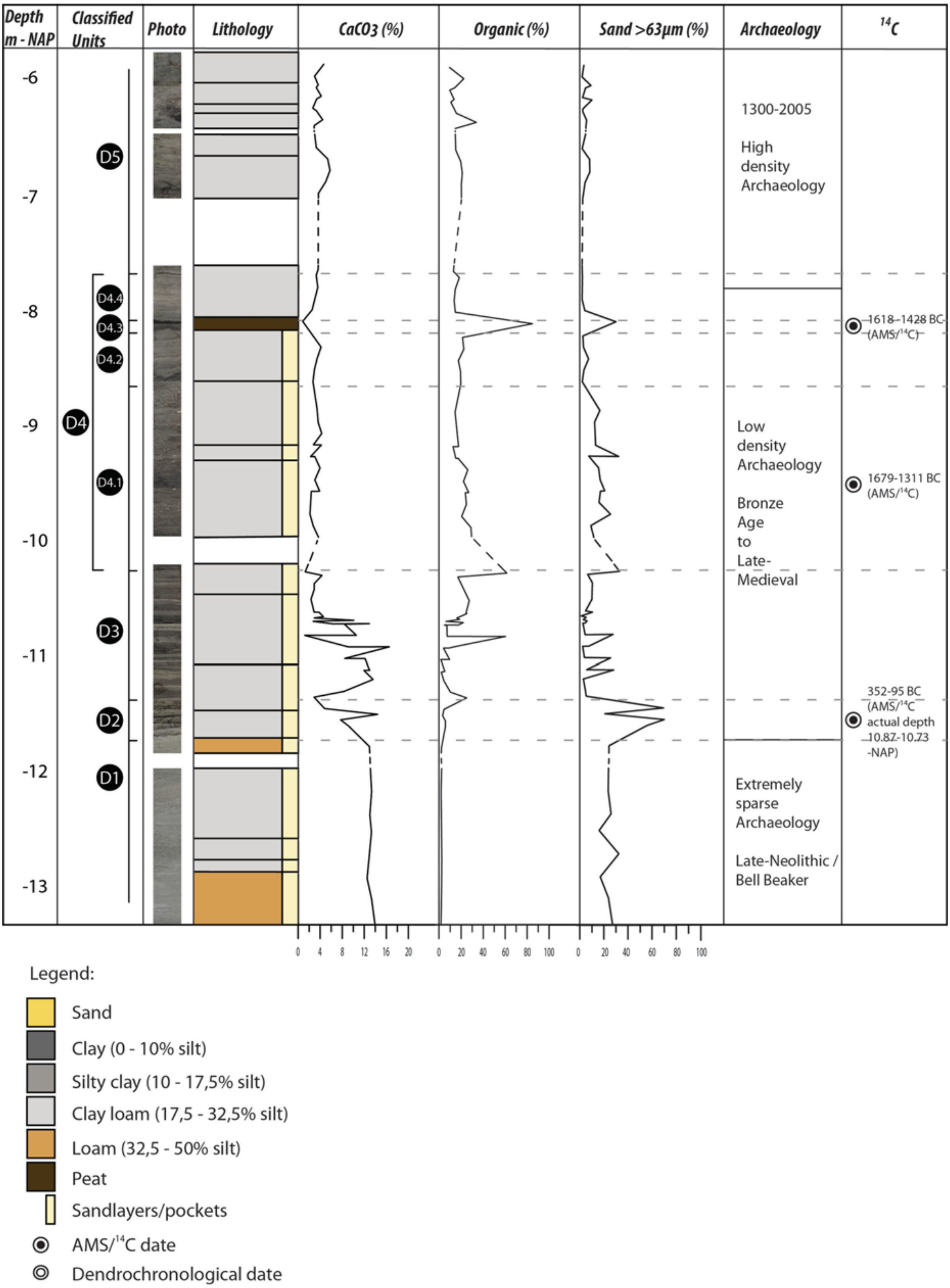

Fig. 3. Composed section on basis of photographed soil trays at the Damrak, including the archao-geological data. The AMS^{14}C, ^{13}C date 352–95 BC in Unit D2 is projected at this depth and is actually located in a higher non-erosive position.

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faunas are present, including the brackish water species *Mytilus edulis*, *Cerastoderma glaucum*, *Littorina* sp., *Macoma balthica* and *Hydrobia* sp., and occasional benthic foraminifera such as *Ammonia beccarii* and *Jadammina macrescens*. Freshwater elements are characterised by smooth ostracods and the gastropods *Valvata piscinalis* and *Bithynia* sp. This unit is especially notable for the high density of archaeological finds, consisting of hundreds of thousands of a.o. ceramic sherds, bones, and metal and leather (fragments of) objects. The sequence is interpreted as freshwater deposits with a strong brackish influence and on the basis of archaeological finds an age of 1300 AD and younger is suggested.

A sample from the reworked peat layer of Unit D4.1 was AMS^{14}C, ^{13}C dated within a range of 1873 to 1311 BC, whereas the peaty layer of Unit D4.3 yielded ages of between 1743 and 1428 BC (Table 1). These rather similar ages suggest the peats derive from a geographically comparable source and constitute storm deposits eroded from an older peat bed. Archaeological finds from Unit D4.4 and upwards (Unit D5) indicate ages from the 14th century onwards.

The youngest sediments recorded down to a depth of c. 7.60 m –NAP are strongly mixed. At c. 7.30 m –NAP the base of an abutment and vertically upwards to c. 6 m –NAP (or even higher), they comprise midden deposits from the first half of the 16th century. The origin of this material accounts for the very substantial number of finds present, which is stratigraphically in general good sequential order.

Location Rokin

Based on lithology, sedimentary characteristics and archaeological finds, the sequence at Rokin can be sub-divided into six units, R1–R6 (Fig. 4a–c). Pleistocene sands, capped by a thin layer of compacted peat (the Basal Peat layer of the Nieuwkoop Formation) are present below 12.72 m –NAP.

Unit R1.1 (12.70–12.37 m –NAP) consists of grey silty clays with discontinuous sand layers and doublets of the brackish water bivalve *Cerastoderma glaucum* in the deeper part of the sequence. This section is assigned to the Wormer Member (Naaldwijk Formation), an Early–Mid-Holocene marine deposit found throughout the western Netherlands. The sediments of Unit R1.2 can be studied west and east of the central gully. Its base contains chunks of slightly brownish-grey clay, sandy clays and peat, with some pottery sherds, a worked bone awl and bones of domestic animals (cow, sheep/goat and pigs) as well as of game (red deer, wild boar, beaver and bear). A number of bones show cut marks as a result of butchering activities. The bone material is well preserved and the sherds show only slight abrasion, indicating quick burial in an aqueous environment. The sherds, including a rim sherd of a Veluwe-type Bell Beaker, can be dated to the Late Neolithic, c. 2400–2000 BC. As a whole, the finds are interpreted as the partial remains of a Late Neolithic settlement situated near this site, which has been subsequently washed away. The age of the sediments in R1.2 must be younger than 2000 BC.

Unit R2 (12.37–10.40 m –NAP) is composed of sandy clays with shell material and fragments of macroscopic plant remains. Reconstruction of the depth and morphology of this unit on basis of the archaeological documentation (drawn sections and surfaces) indicates a slight meandering of the river from southwest to northeast along the Rokin (Fig. 5a and b). Mollusc shells from the base of this unit yielded ages of 5320–5140 BC (*Scrobicularia*), 5040–4840 BC (*Cardium*) and 2900–2780 BC (*Unio*) (Table 2). The ages of the two brackish water molluscs (*Scrobicularia*, *Cardium*) are indicative of the older part of the Wormer Formation and suggest reworking of older material, while the date of the *Unio* has to be considered a maximum age. Since Unit R2 erodes into Units R1.1 and R1.2, it is stratigraphically younger than those units, and thus younger than the Bell Beaker period.

The boundary between Unit R2 and the overlying Unit R3 (10.40–8.86 m –NAP) is clear-cut, indicative of intrinsic river behaviour or an erosive phase. At the transition from Unit R2 to Unit R3 several tree trunks were found. One of them was C^{14} dated, yielding an age of 770–410 BC (Table 2). Densely laminated sediments of silty clay intercalated with thin calcareous clayey layers with much organic material are present throughout the Rokin site and are interpreted as freshwater river sediments, with some intercalated marine phases, evidenced by the calcareous clay layers. In addition, shells of the freshwater gastropod *Valvata piscinalis* from a 10-cm thick shell-pocket at 9.60 m –NAP within Unit R3 were dated, yielding a maximum age of 390–200 BC, thus in general agreement with or even younger than the age of the trunks. *Valvata piscinalis* is a characteristic species for stagnant to very slow-moving freshwater with dense vegetation.

The sediments of Unit R4 (8.86–6.43 m –NAP) consist of dark brown organic silty clays. The base is characterised by silty sand, peat and clayey peat, often in chunks, interpreted as relic storm tide deposits. The base often shows a jagged outline while shell fragments indicate a marine incursion. The stratigraphic position of Unit R4 varies considerably over the Rokin transect and can even reach a depth of c. 10.00 m –NAP (Fig. 6). The overall depositional interpretation of the unit is of freshwater river sediments with a few marine phases near its base denoting the influence of storm tides.

In a smaller trench at the northeast of the main Rokin trench, excavated to a depth of c. 8 m –NAP, a trunk of alder was found at a depth of about 7 m –NAP and dated dendrochronologically to about 1319 AD (Table 3). The archaeological investigation and comparison with the data from the main Rokin trench suggests that this context can be assigned to Unit R4. Another alder trunk was found at the southwest of the main Rokin trench, at a depth of about 9.50–10.00 m –NAP (the base of Unit R4) and dated at 1319 AD. In the same layer and close

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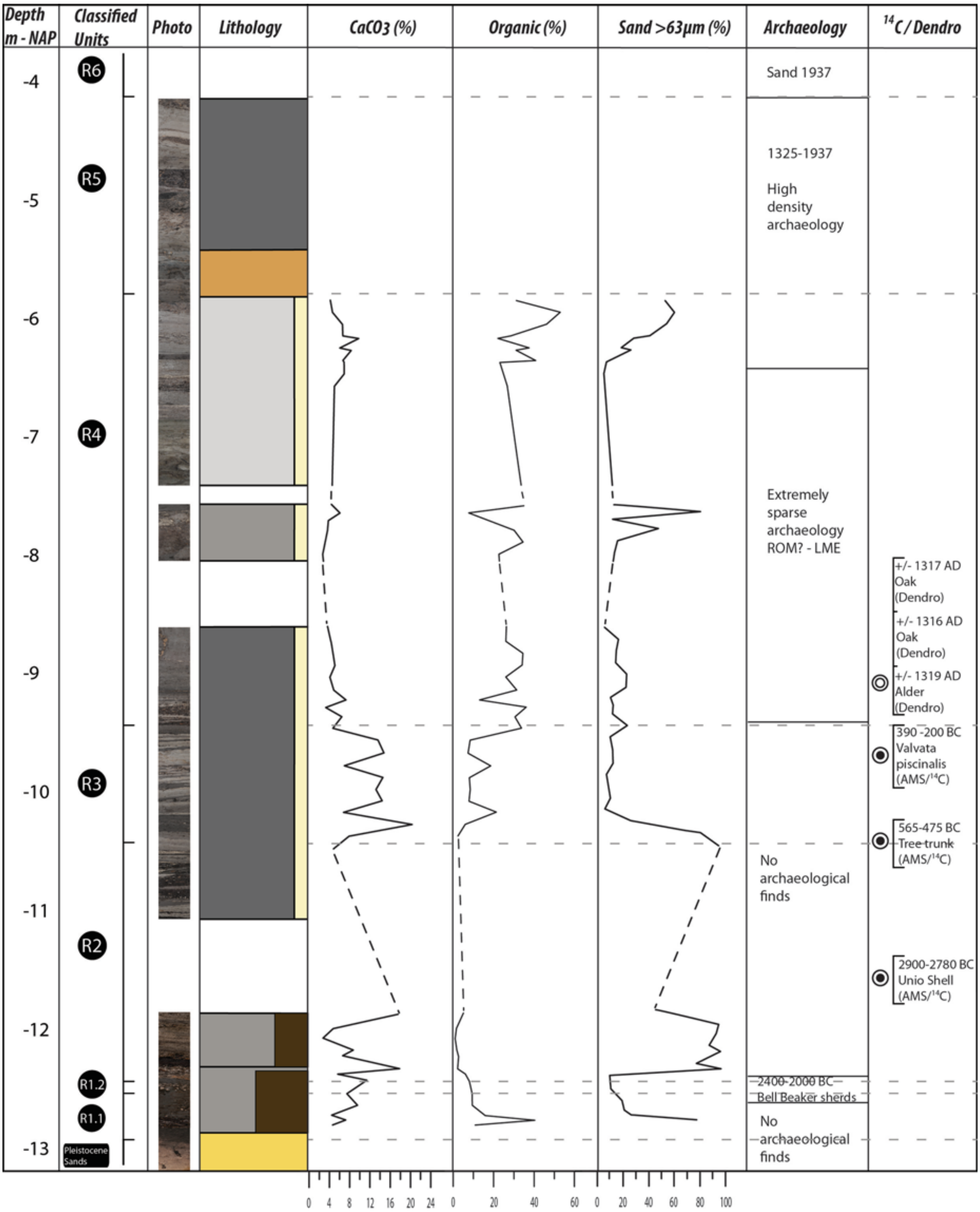

Fig. 4. (a) Composed section on basis of photographed soil trays at the Rokin, including the archaeo-geological data. See for legend Fig. 3. The AMS^{14}C, ^{13}C date of the Unio *is located at the same elevation at approx. 50–100 m lateral of the current section. (b) Photographed section (facing north) at the Rokin through the deeper sediments between c. 7 and 11 m –NAP. (c) Schematic section (facing north) at the Rokin.*

by, two worked fragments of oak (possibly parts of a ship) were found at c. 10.00–10.50 m –NAP and dated at or shortly after 1316 and 1317 AD. Based on these dates the boundary between Units R3 and R4 is postulated at 1319/1320 AD. This is well after the founding of the Dam in the Amstel, dated to around 1264 AD. These data suggest that storm tides could have had an erosive effect on the Amstel sediments behind the Dam. Storm tides and spring tides often lead to flooding on the streets of Amsterdam. Furthermore, there are several accounts concerning the breaching of a dyke during Late Medieval times with

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Fig. 4. Continued.

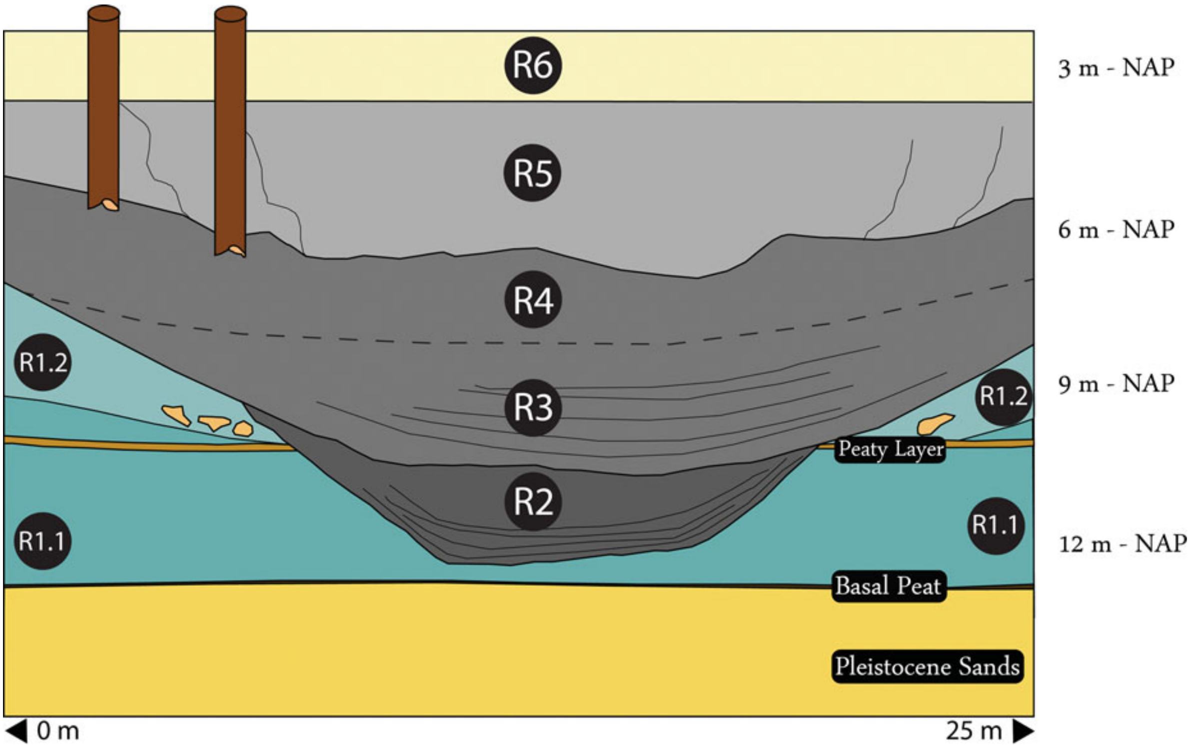

Fig. 4. Continued.

disastrous consequences for the landscape and its population, for example the flooding of the Watergraafsmeer. High water then could reach the Rokin from the hinterland, flooding via the Watergraafsmeer through the Amstel to the Rokin. Water, tree trunks, peat and other materials would have affected the sedimentation pattern of the Amstel, particularly south of the Dam (in the Rokin area). The differences in depth of both alder trunks does indicate rapid natural silting up of the northern part of the Rokin after the Dam was built and/or following (some) storm event(s).

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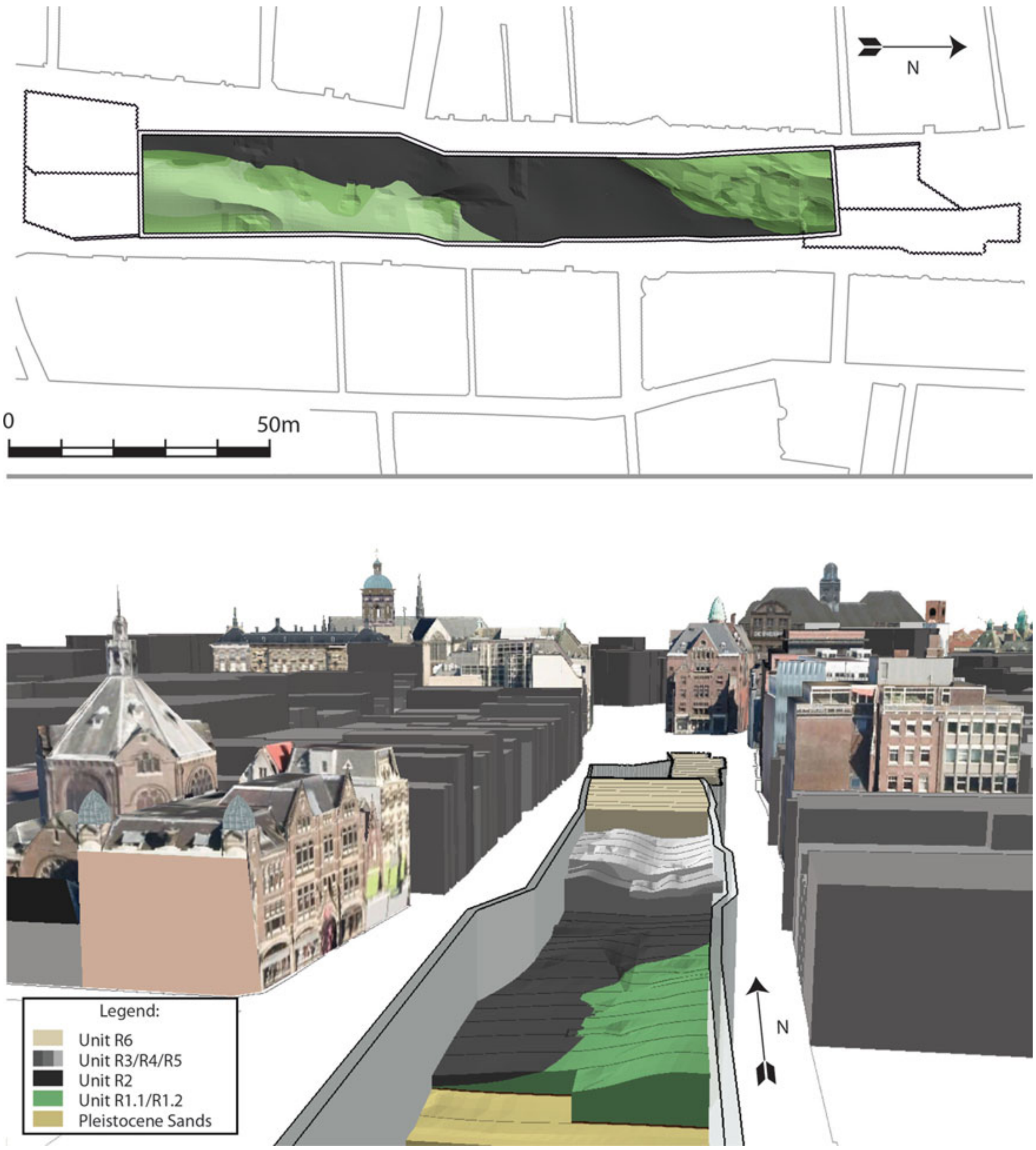

Fig. 5. (a) 3D-model of the oldest meandering riverfill (dark-grey) eroded in the Wormer sediments (green) at the Rokin. (b) Length and cross-sections at the Rokin.

The transition between Units R3 and R4 probably marks the difference between sedimentation before and after the construction of the Dam in the River Amstel. The exact depth and/or transition layer is hard to define due to the erosive activities of storm tides sometime in the first quarter of the 14th century, during which former deposits were (partly) eroded (Fig. 6).

The boundary between Units R4 and R5 (6.43 to c. 3.00 m –NAP) is marked by the transition to grey-brown silty clays, with a high organic content, including wood and plant remains. Unit R5 is interpreted as freshwater river sediments, with no marine influence. It contains several layers with a high density of cultural material (objects of wood, metal, ceramics, leather, glass, bone etc.). The finds extend down to about 6.50 m –NAP, thus incorporating the top of Unit R4. The oldest find layers are situated in the north and contain large quantities of Siegburg jar fragments mainly dating from c. 1325 AD onwards. The youngest material is found in the centre of the riverbed. From c. 1600 AD onwards the layers often are quite jagged, a result of dredging the waterways in order to retain sufficient water depth (Fig. 7). These younger layers are bordered and penetrated by the piles of the quay foundations. The flat-cut bases of those piles are driven into the top of the Pleistocene sands at about 12–13 m –NAP.

The uppermost fill (Unit R6) of the Rokin location is anthropogenic and consists of greyish-beige sand. This sand, which

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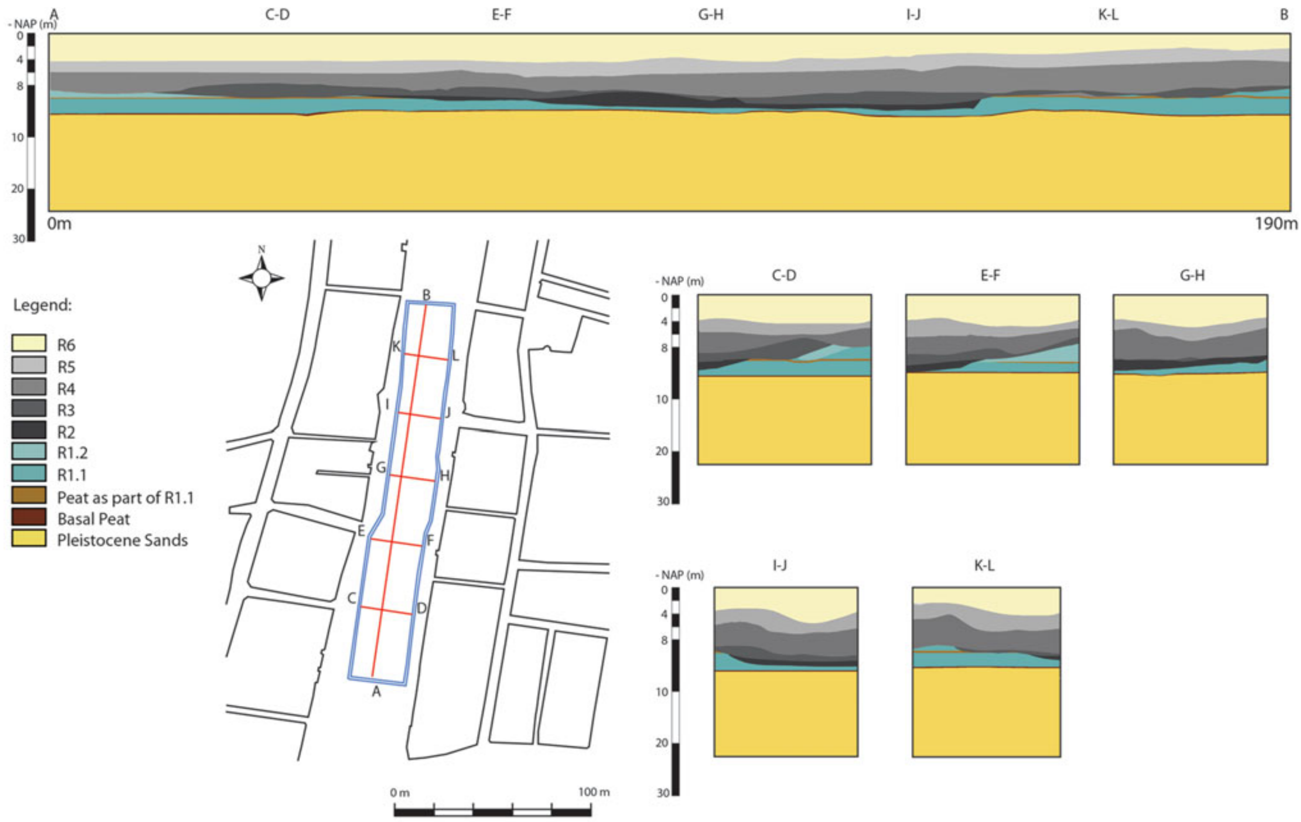

Fig. 5. Continued.

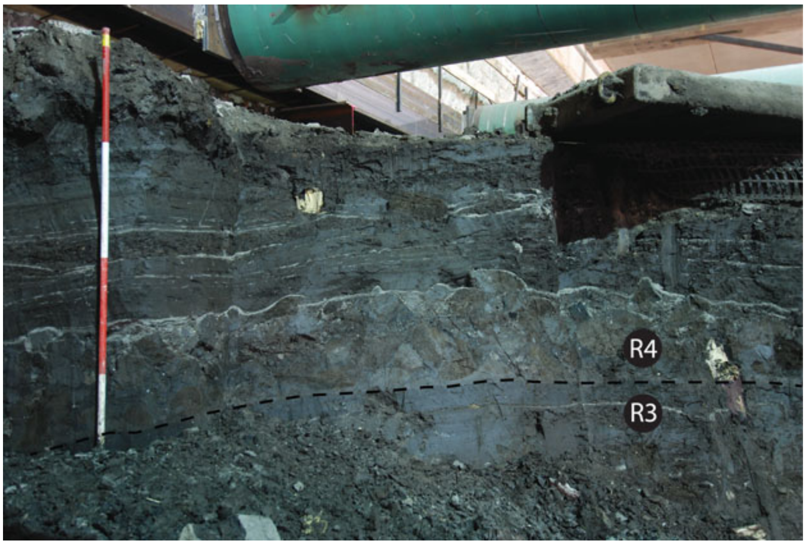

Fig. 6. Sharp boundary between Units R3 and R4, the medieval Amstel with indications of storm tides.

locally extends to a depth of up to 4 m –NAP, was used to infill the remainder of the stream in 1936/1937 AD.

In summary, the oldest recognisable structure is interpreted as a tidal gully carrying fresh water (Unit R1.2); it contains Late Neolithic material and is cut into the Holocene (Wormer) deposits (Unit R1.1), which rest on top of the Pleistocene sand (Fig. 4b and c). The subsequent Units R2–R6 chart the evolution of the River Amstel. Incised through the gully deposits of Unit R1.2 are the remnants of a deeply cut palaeochannel (Unit R2), which is interpreted as the Prehistoric Amstel. This freshwater system was active until at least younger Iron Age times. Younger palaeochannel sediments dated to the Late Medieval (Units R3 and R4) and late- and post-Medieval (Unit R5) are recorded higher in the section. The transition between Units R3 and R4 is dated to around 1319/1320 AD, just post-dating the construction of the dam in the Amstel. From that time

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Fig. 7. Part of the section at the Rokin with visible jagged outlines (especially at the base of the dark-grey 19th century layer) due to dredging.

onwards, huge amounts of cultural debris were recovered, dating the younger sediments (Units R4 and R5) to the second quarter of the 14th century and later. The final fill of the River Amstel (Unit R6) took place in 1936/1937 AD.

Additional observations

Nes and Hotel Polen Two excavations at locations parallel to the River Amstel, Nes (Nes, BMA code NES 009) and Kalverstraat (Hotel Polen, BMA code KA 004), show land reclamation in western and eastern directions, respectively, from approximately 1225 AD onwards (Figs 8 and 9). The base of the river sediments is (steeply) sloping towards the middle of the Rokin (former river), with a minimum depth of 9.50 m –NAP. Material culture was emplaced by the dumping of rubbish into the river in order to create habitable plots, and can be found to a depth of c. 6.50 m –NAP. The oldest cultural material is found along the banks on both sides of the River Amstel. It has been observed that towards the centre of the Rokin (i.e. the deeper part of the river), increasingly younger archaeological material is found. This is illustrated by the section at Hotel Polen (Fig. 9), where from c. 1325 AD onwards dumped material culture can be found at the Rokin, while older cultural deposits can be found under the building plots between the Kalverstraat and the Rokin.

Sediment core and cone penetration data from the Amstel Preceding some past urban construction works at various locations in the Amstel area, sediment cores and cone penetrations were taken from the Martin Luther King Park to the Munt/Blauwbrug (Stads Archief Amsterdam; Fig. 2). A general lithostratigraphy of the subsurface of Amsterdam comprising Holocene clay and sand on top of Pleistocene sand is shown in Table 4. The depth of the top of the Pleistocene sands varies but in the centre of Amsterdam it is between c. 11 and 13 m –NAP.

The deepest recognition of fluvial sediments in the Martin Luther King Park is at a depth of c. 9.5 m –NAP; here, the younger (Holland) peat is absent within these cores. Core 1 at the Berlagebrug shows a lower boundary of organic brown clay with peat remains, which is interpreted as fluvial sediments at a maximum depth of 10.05 m –NAP (Table 4).

Two cross-sections across the Amstel at the Hogesluisbrug were generated by cone penetration (Fig. 10). Here, fluvial sediments (a river fill) reach a depth of about 10 m –NAP, although the exact transition from the Wormer deposits to the organic silty and sandy clays of the palaeochannel sediments is often gradual. The deepest erosional base of the fluvial sediments is situated in the western part of the present-day Amstel streambed (Fig. 10). Furthermore, a slight bend of the river course is suggested (Fig. 10) comparable to the reconstruction of the oldest meandering fill detected at the Rokin (see above and Fig. 5a).

Based on the description of eight sediment cores between the Blauwbrug and the Munt, an erosive river deposit is postulated. In one core at the southwest of the Blauwbrug a relatively thin peat layer between 3.90 and 4.85 m –NAP is present, interpreted as a remnant of the Holland peat (Holland peat on top of the expected sequence of Wormer Member, Basal Peat

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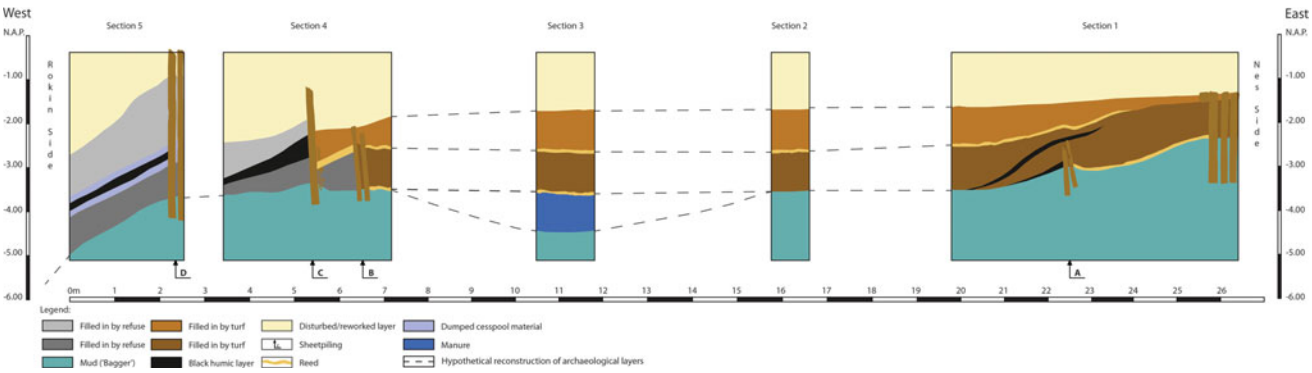

Fig. 8. Composed section of the Nes excavation (BMA code NES 009) (reworked on the basis of the original data of BMA, after Veerkamp, 1998b, p. 64).

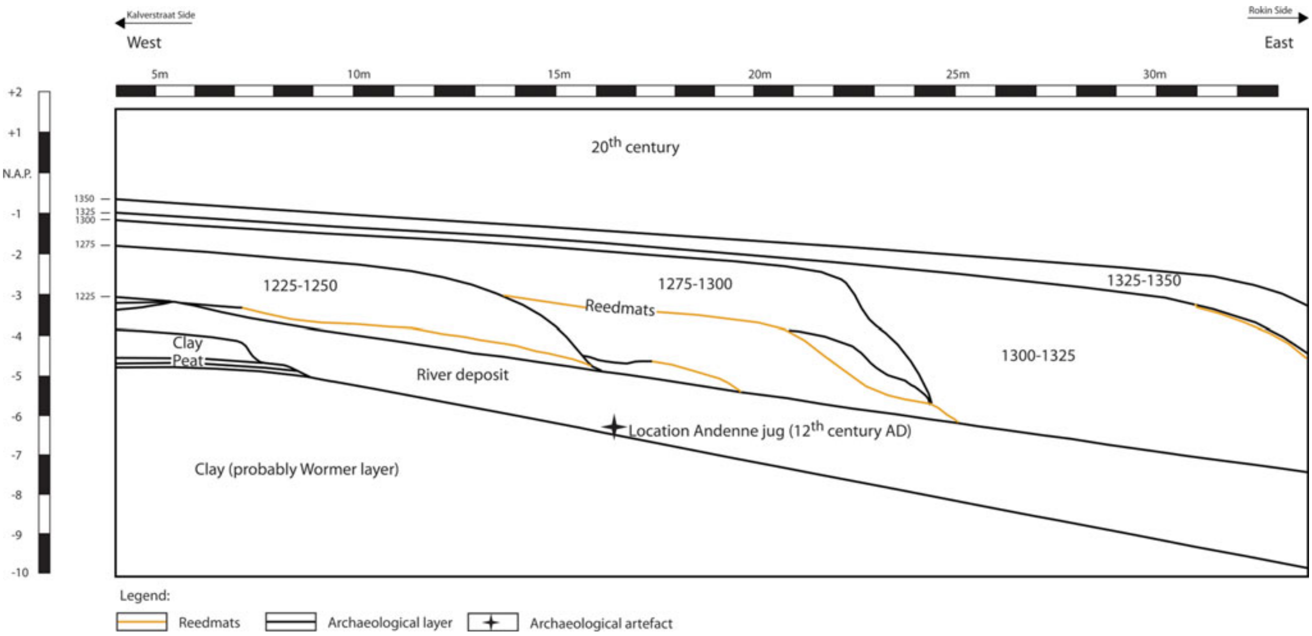

Fig. 9. Composed section of Hotel Polen excavation (BMA code KA 004) (reworked on the basis of the original data of BMA, after Veerkamp, 1998b, p. 60).

and Pleistocene sands). Apparently the Amstel reached to a depth of 3.90 m –NAP, but only at this location, which is about the maximum depth of the main canals in Amsterdam. At this location, the original riverbed appears to have a bend that is directed more to the northeast compared to its present course.

In summary, sediment core and cone data from the Amstel south of the Rokin indicate an erosive river or large gully to a depth of at least 10 m –NAP. According to the data from the Hogesluisbrug, a meandering channel is suggested (Fig. 10).

Discussion

The archaeological and geological research undertaken on key locations at Rokin and Damrak has resulted in new data on the chrono-archaeostratigraphy and development of the River Amstel. Analyses of the sedimentary sequences at both locations combined with archaeological findings allow a correlation of the two sites as well as a reconstruction of the evolution of the River Amstel within the city limits through time (Fig. 11).

The basal units at Rokin (R1.1 and R1.2) of Wormer Member sediments correlate with Unit D1 at Damrak at a comparable depth –NAP, both consisting of calcareous clays with sand laminae, containing characteristic benthic foraminifera, indicative of an intertidal marine (estuarine) environment. The deepest part of the Wormer Member sediments (Unit R1.1) at Rokin shows the Velsen Layer, which marks the gradual drowning of the coastal region by rising sea levels, dated approximately 5000–6000 BP (3050–4050 BC; Westerhoff et al., 1987). The presence of a complex Wormer Member gully system at the Damrak prevents the recognition of the Velsen Layer.

Already during Bell Beaker times, about 2400–2000 BC, the region of Amsterdam appears to have been inhabited

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Table 4. (Colour online) Lithostratigraphy of cores at Martin Luther Kingpark and Berlagebrug as well as 'Standard' Amsterdam sediment stratigraphy

Martin Luther King Park		
Depth −NAP (m)	*Material*	*Interpretation*
0.4–2.8	Water	Amstel river water
2.8–4.4	Slightly silty, humic, peat, mud, some sand	Fluvial sediments
4.4–5.3	Slightly silty clay, very humic, peat	Fluvial sediments
5.3–10.4	Slightly silty clay, lightly humic, some sand and peat	Fluvial sediments
10.4–10.6	Peat, clay, shell and some sand layers	Wormer layer, Naaldwijk Formation or fluvial sediments
10.6–11.0	Sand, slightly silty, some clay layers and shell	Holocene Wormer layer, Naaldwijk Formation
11.0–11.4	Slight silty clay	Wormer layer, Naaldwijk Formation
11.4–11.9	Peat, clayey	Basal peat of the Nieuwkoop Formation
11.9–16.0*	Sands, with some clayey layers	Pleistocene sands and clay (Boxtel Formation)
Berlagebrug, core 1		
Depth −NAP (m)	*Material*	*Interpretation*
−0.40–3.20	Water	Amstel river water
3.20–5.10	Mud, peat, clayey, organic/humic	Fluvial sediments
5.10–10.05	(Weak) brown clay, humic, some peat and shell	Fluvial sediments?
10.05–11.70	Grey clay, some shell	Holocene Wormer layer, Naaldwijk Formation
11.70–11.80	Peat, clayey	Basal peat of the Nieuwkoop formation
11.80–20.65*	Sand, clay	Pleistocene sands and clay (Boxtel Formation)
'Standard' sediment stratigraphy within the research area		
Depth −NAP (m)	*Material*	*Interpretation*
+1–2.5	Clay, sand, turfs, refuse etc.	Anthropogenic layers
2.5–5.5	Peat	Younger peat (Holland peat)
5.5–11/13	Grey silty clay and silty sand	Holocene Wormer layer, Naaldwijk Formation
c. 10–10.2	Clay layer, very humus rich to clayey peat	Velsen phase of Holocene Wormer
11–13, layer of a few decimetres	Peat	Basal peat of the Nieuwkoop Formation
11–13, and deeper	Sand and clay	Pleistocene sands and clay (Boxtel Formation)

*Maximum depth of core.

and/or visited by small groups of people; this is indicated by the finds of cultural material at the base of a tidal gully (Unit R1.2). This and similar gullies in Amsterdam's subsurface are assigned to the Wormer Member of the Naaldwijk Formation.

The archaeological finds from Unit R1.2 at the Rokin site show that during the late Neolithic, the river was in a peat-rich landscape, with locations suitable for (semi)permanent settlement. Habitable lands are preferably situated in eco-systems offering direct proximity to drinkable water, dry land and good possibilities for hunting game, fishing and (in this period) agriculture (e.g. Van Ginkel & Hogestijn, 1997). Higher areas of river banks and former streams would offer such circumstances, and near the Rokin site, these favourable conditions apparently were present during Late Neolithic times. Some remarkable finds also occur in the deeper parts of the excavation in Unit D1 at the Damrak, which could be related to the prehistoric finds of Unit R1.2 at the Rokin. It thus appears that Late Neolithic material was present in the layers of the Wormer Member at the Damrak, which are similar to the finds of (Late Neolithic) Bell Beaker material at the Rokin in one of the oldest river courses in the region of Amsterdam documented so far. Apparently this Neolithic gully drained into the estuary below the Damrak location, which explains the deeper occurrence of contemporary

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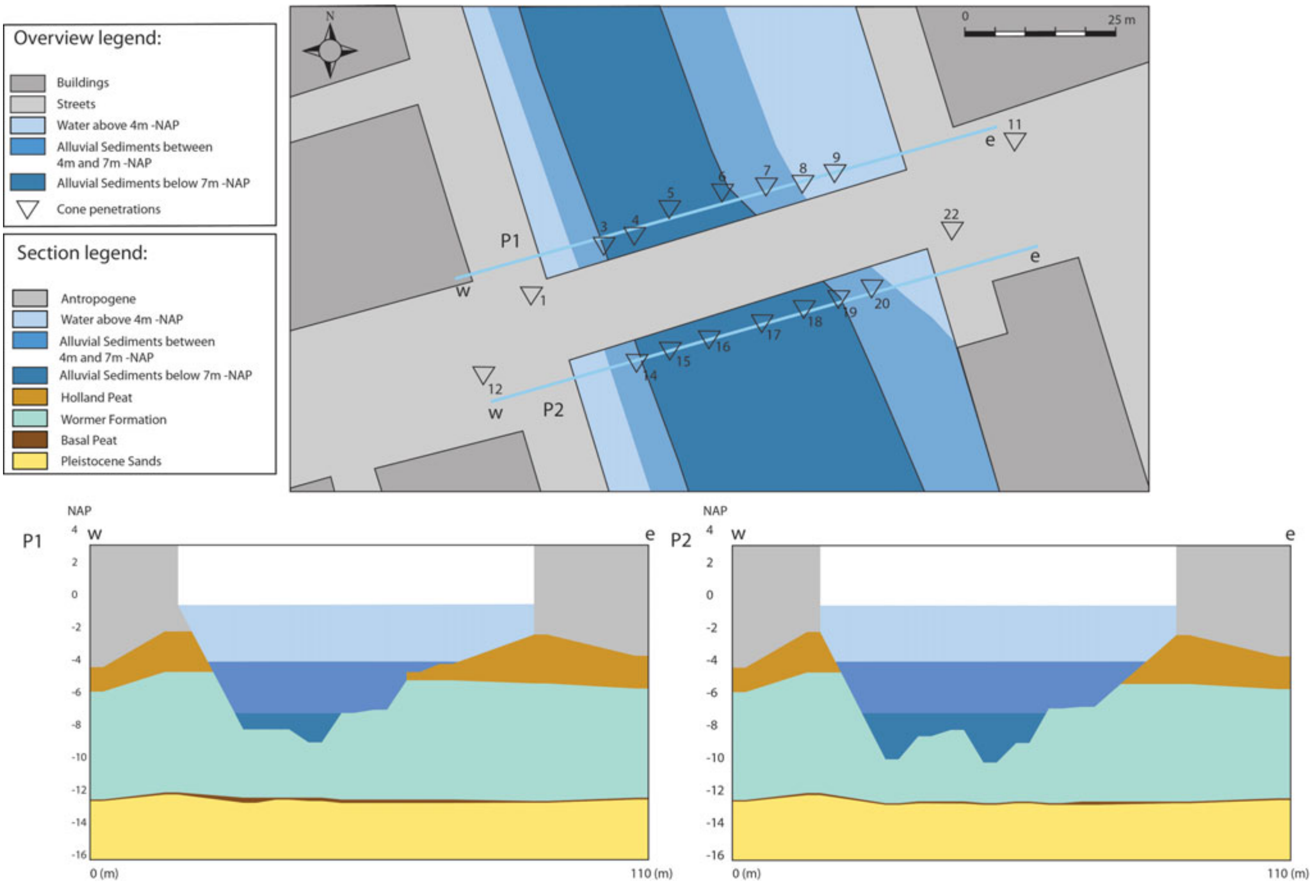

Fig. 10. Overview of the cone penetrations and two interpreted cross-sections at the Hogesluisbrug. Cone penetration data were derived from MOS Grondmechanica (C. Hogenes, pers. comm.).

archaeological finds at that location. Based on all observations and recorded dates for Unit R1.1 an age of 4050–2000 BC is suggested, while Unit R1.2 is interpreted as being deposited in 2000–1020 BC. For Unit D1 an approximate age of 4050–1020 is suggested (Fig. 11).

The course of this older gully R1.2 was used by the Prehistoric Amstel (Units R2 and D2), which shows a completely different fill compared to the underlying sequence. The clear resemblance in lithology of sand, with wood, plant remains and shell material of both fills of Rokin and Damrak suggests a direct relationship between the two. This unit was cut into the gully and shows a rather fast-flowing riverbed, filled with sand and plant remains. The environment is interpreted as freshwater with some phases of brackish influence, with indications of storm tides at Rokin and with a high-energy estuarine environment at Damrak. This oldest river phase of activity at Damrak (Unit D2) is dated as (late) Iron Age or younger, based on the maximum AMS^{14}C, ^{13}C ages of 352–95 BC. Unit R2 has, on the basis of the Bell Beaker finds of Unit R1.2, to be dated to around 2400 BC or later. Depth–time correlation between Units R2 and D2 may even suggest multiple phases of activity in this Prehistoric channel of the Amstel (Fig. 11).

Clastic sedimentation due to river activity, such as that recorded in the Angstel–Vecht area, started after 2970 BP (1020 BC) and strongly decreased around 2300 BP (350 BC) (Bos et al., 2009). The continued river activity was much decreased in the Angstel–Vecht lake area until 1470 BP (480 AD) (Bos et al., 2009). The period of river activity in the Angstel–Vecht area extends for 1500 years, although the greater part of the deposits formed during the first 670 years of that episode (Bos, 2010). It seems that the fluvial activity in the Angstel–Vecht system more or less coincides with the initial phases of the Prehistoric River Amstel in this study. The interpreted basal age of Unit R2/D2 is therefore 1020 BC (Fig. 11). The transition from the correlated Units R2/D2 to the fine-grained laminated Units of R3/D3 may very well correspond to the demise of the Angstel–Vecht system around 2300 BP (350 BC) and with the closure of the Oer-IJ (300 BC). At the northern side it is known that the Oer-IJ estuary, which connected the late Prehistoric Amstel and its precursors with the Angstel–Vecht system, eventually shut down in the years 500–100 BC (Vos, 2008; Vos et al., 2010).

This implies that the Prehistoric Amstel, Oer-IJ estuary and Angstel–Vecht system were all part of a single interconnected waterway, which stopped functioning around 300 BC. The start

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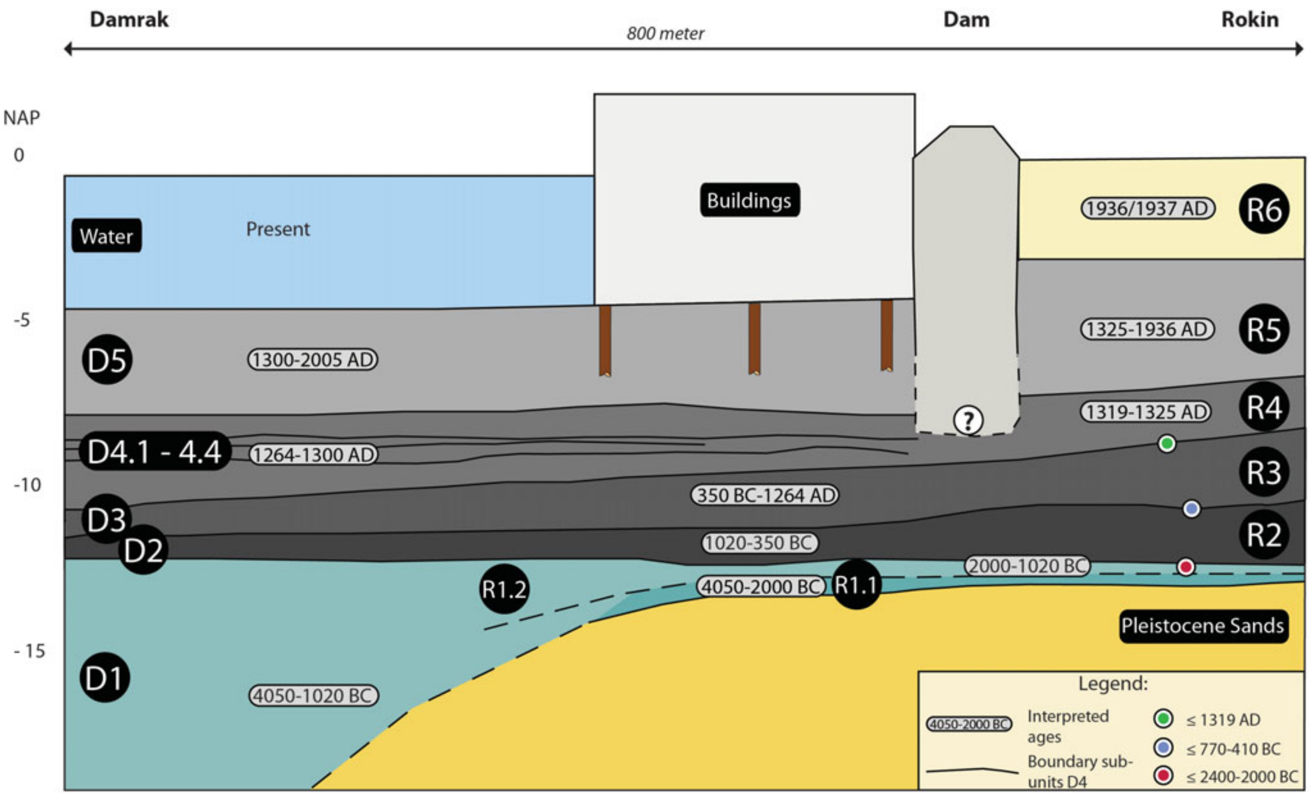

Fig. 11. Correlation and chronostratigraphical interpretation of the schematic sections at the Damrak and Rokin locations. For explanation of interpreted ages see Discussion section.

of this inter-regional waterway is at least younger than 2400 BC, and most likely coincides with the 3000 BP (approximately 1020 BC) start of the Vecht–Rhine connection (see Bos et al., 2009; Vos et al., 2010; De Gans, 2014).Within Unit D3 a sharp decrease in sand content upwards associated with increased organic sedimentation, implying reduced energy conditions, could record the assumed shutdown of the Angstel–Vecht system and associated Oer-IJ estuary in this estuary–river environment between Dam and Rokin. The 390–200 BC date on the *Valvata piscinalis* shells at Rokin, which themselves are indicative of stagnant to very slow moving freshwater, fits the suggested date of 2300 BP (350 BC) for the demise of the Angstel–Vecht system. The reduced activity of the river is then recorded in Units R3/D3, which is characteristic of a freshwater environment, with slight brackish influence derived from the Zuiderzee.

At the Rokin site, this palaeochannel fill is covered by younger deposits. These Younger Amstel sediments (Unit R3) are characterised by a laminated structure. At the base of this fill a few tree trunks were present, one of which yielded an AMS^{14}C, ^{13}C age of 770–410 BC. This unit also shows remarkable similarities with that from the Damrak site (Unit D3), also overlying the oldest Amstel fill. These sediments are therefore assigned a period of pre-Dam construction (before 1264 AD) as well.

Eventually the threat of the opening of the Zuiderzee increased, causing tidal storms to penetrate into the Amstel river mouth in the 12th century AD (e.g. Buisman, 1995) and also in the 13th century AD (Buisman, 1995). In response to these events, the authorities ordered the building of a dam in the Amstel around 1264 to prevent storms and flooding causing future disasters (e.g. Gawronski et al., 2012). Despite the dam and dykes, (tidal) storm periods could still have disastrous consequences, which are recorded in the sedimentological record, for example the early 14th century storm evidence that is preserved in Units D4/R4 described in this study.

The overlying sediments of Unit R4 at the Rokin site differ from those (Units D4.1–D4.4) at Damrak. At Rokin, the base of Unit R4 (at about 9.5 m –NAP) shows clear influence of erosion due to storm tides, but is essentially defined as the product of deposition in a freshwater environment. In contrast, at the Damrak site, brackish water influence in Unit D4 continues. This contrast can be explained by the construction of the Dam in the Amstel in the mid-13th century AD, leading to a drastic decrease in salt water influence at the Rokin location. Archaeological finds and dendrochronologically-dated tree trunks and processed wood date the boundary between Units R3 and R4 at the Rokin site to the first quarter of the 14th century AD. The interpreted age for Unit D4 is therefore 1264–1300 AD, while the age of Unit R4 is interpreted to be 1319–1325 AD (Fig. 11).

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Unit R5 at the Rokin site shows a freshwater environment. This fill commenced in the second quarter of the 14th century AD and yielded huge amounts of archaeological debris. At Damrak, at a depth of c. 8.20–8.07 m –NAP, evidence for storm tides is also present (Unit D4.3). Younger layers from Damrak (Unit D5), from a depth of 7.60 m –NAP upwards, are defined as a mainly freshwater environment with brackish influence. Here also, large amounts of archaeological material dating from the 14th century AD onwards are encountered. The construction and sheltering of the Dam has increased different sedimentation patterns in Damrak and Rokin, notably the four phases of D4, which have not been observed at Rokin. Because of different 20th century developments at Damrak and Rokin the interpreted ages of D5 and R5 are c. 1300–2005 AD and c. 1325–1936 AD, respectively (Fig. 11).

The sparse information on Amstel sediments south of Rokin, to approximately the Martin Luther King Park, suggests a river eroding into the Wormer Member sediments to a depth of at least 10 m –NAP. Detailed information on the sedimentary sequence in this part of the river fill is lacking, preventing direct correlation to the Rokin and Damrak data. However, several phases in the river fill at these locations are clearly also present. Interpretation of the deepest riverbed at the Martin Luther King Park, the Hogesluisbrug and the Blauwbrug suggests a rather meandering river compared to its present-day course, comparable to the meandering riverbed observed in the Rokin excavation. The rather straight and canalised Amstel of today was obviously a more meandering river in earlier times.

Conclusions

On the basis of archaeological and geological research at the Damrak and Rokin locations, as part of a much wider archaeological research programme preceding the construction of the new North/South subway line, a new chrono- and archaeostratigraphy has been established for the development of the River Amstel (Fig. 11). This research documents the evolution of the River Amstel in Amsterdam from a tidal gully system occupied by Neolithic peoples to the erection of the Dam in the mid-13th century; the development can be summarised in six chronological phases:

1. In the early to middle Holocene the western Netherlands were exposed to an open coast line, and around 5500 yr BP (3500 yr BC) the first stable sand barrier gave way to an inland lagoon, in which the Oer-IJ tidal channel was formed (Vos et al., 2010); tidal channels were present as part of the Wormer Member of the Naaldwijk Formation in the subsurface of Amsterdam. One of these old tidal channels, which existed between 4050 and 2000 BC, is described in this study at the Rokin site.
2. The remains of an eroded occupation layer of Late Neolithic Bell Beaker cultural material dating to 2400–2000 BC (4350–3950 BP) suggests that there was habitation along a tidal gully of the Oer-IJ system, which incised through a well-vegetated peat landscape. Humic material present in the sediments suggests a connection of the tidal gully with a peat-bog drainage system. This system most likely was the precursor of the later River Amstel (see also De Gans, 2014), and may have therefore been active between 2000 and 1020 BC (3000 BP).
3. The River Amstel started to flow around 3000 BP (1020 BC) when the Rhine system debouched in the Angstel–Vecht area and formed a regional waterway, the Amstel–Oer-IJ, which in turn drained into the North Sea. This was the main course of the Angstel–Vecht system until the River Vecht took over the drainage from the River Amstel around 2300 BP (350 BC). The end of this phase coincides with the closure of the Oer-IJ tidal gully at Bergen near the North Sea coast (Vos et al., 2010).
4. This river phase starts with the demise of river activity from the Vecht to the Amstel around 2300 BP (350 BC), with the Amstel getting only episodic drainage during times of high discharge from the Rhine distributaries in the Angstel–Vecht system (Bos et al., 2009). After 2050 BP (100 BC) the Amstel drains into the IJ, which gradually erodes the large peat bog in the later Zuiderzee area. The Angstel–Vecht system stopped being active around 1470 BP (480 AD), while the River Amstel continued to drain as a peat-bog drainage river into the expanding Zuiderzee; in this study this phase of activity is recorded at Rokin until 1319 AD.
5. From about 1225 AD onwards, extensive land reclamation was undertaken around the River Amstel to assist in the creation of building plots. Furthermore, the construction of quays in the centre of Amsterdam led to a development of a rather narrow and straightened River Amstel, essentially the river as it is today. Late-Medieval storm activities originating from the expanding and opening Zuiderzee forced the authorities to build a dam in the Amstel in the mid-13th century AD to prevent future disasters caused by high water events. At Damrak and Rokin only storm deposits of the early 14th century are preserved since high sedimentation events that overprint previous flooding phases have removed all sedimentary traces.
6. This major and final Amstel phase comprises sediments containing huge amounts of material culture, which is dated from c. 1325 AD onwards. After the erection of the dam and associated storm episodes, low fluvial sedimentation rates were recorded at Rokin with few marine incursions during storms, while brackish sedimentation continued at the Damrak site. At Rokin, sedimentation ends in 1937, when this part of the river was finally infilled by the city authorities. At Damrak, after some years of building activities between 2003 and 2012, water is again flowing in this part of the Amstel.

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To conclude, this paper has demonstrated that the River Amstel was more than a peat-bog drainage system. In prehistoric times at least one tidal gully system preceded the development of the river and was part of the Angstel–Vecht–Oer-IJ system. Once developed, the river meandered through a well-vegetated peat landscape until land reclamation and the building of quays in Late- and Post-Medieval times let to a narrower and much more tamed River Amstel as it appears nowadays.

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