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SOIL Discussions

Soil archives of a Fluvisol: subsurface analysis and soil history of the medieval city centre of Vlaardingen, the Netherlands – an integral approach

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Abstract

In Medieval times the city of Vlaardingen (the Netherlands) was strategically located on the confluence of three rivers, the Meuse, the Merwede and the Vlaarding. A church of early 8th century was already located here. In a short period of time Vlaardingen developed into an international trading place, the most important place in the former county of Holland. Starting from the 11th century the river Meuse threatened to flood the settlement. These floods have been registered in the archives of the fluvisol and were recognised in a multidisciplinary sedimentary analysis of these archives.

To secure the future of this vulnerable soil archive currently an extensive interdisciplinary research (76 mechanical drill holes, grain size analysis (GSA), thermogravimetric analysis (TGA), archaeological remains, soil analysis, dating methods, micromorphology, and microfauna has started in 2011 to gain knowledge on the sedimentological and pedological subsurface of the mound as well as on the well-preserved nature of the archaeological evidence. Pedogenic features are recorded with soil descriptive, micromorphological and geochemical (XRF) analysis. The soil sequence of 5 meters thickness exhibits a complex mix of "natural" as well as "anthropogenic layering" and initial soil formation that enables to make a distinction for relatively stable periods between periods with active sedimentation. In this paper the results of this large-scale project are demonstrated in a number of cross-sections with interrelated geological, pedological and archaeological stratification. Distinction between natural and anthropogenic layering is made on the occurrence of chemical elements phosphor and potassium.

A series of four stratigraphic/sedimentary units record the period before and after the flooding disaster. Given the many archaeological remnants and features present in the lower units, we assume that the medieval landscape was drowned while it was inhabited in the 12th century AD. After a final drowning phase in the 13th century, as a reaction to it, inhabitants started to raise the surface.

1 Introduction

Since the fifties of the last century archaeological excavations in the city centre of Vlaardingen started to turn the view on Vlaardingen's history at first adopted by 17th and 18th century history writers that the old medieval city was flooded by the river Meuse (Fig. 1; De Ridder, 2002). Archaeological finds in the research area are dated to the Middle Ages (AD 500–1500), while archaeological excavations in the city centre south of the old church revealed a medieval cemetery that has been in use between AD 1000 and 1050. This discovery comprised a more complete story of the medieval structure of Vlaardingen and made clear that today's position of the church was also the position at AD 1000. Assuming that there have been no other reasons to move the church it must have been the same position in AD 726/727 (anonymous quote).

Despite a long period of archaeological research combined with soil observations a number of research questions regarding the landscape and soil development still exist. Based on previous research a number of fluvial channels are assumed to date from the Iron Age, Roman Age and Middle Ages spanning a period of almost 2000 years of dynamic landscape and soil development (De Ridder and van Loon, 2007; Kluiving and Vorenhout, 2010, 2011). It is still unknown what the exact location, age of initiation and cessation of river gullies is. Also the extent, nature and stratification of the thick anthropogenic cover layer that underlies the old town has not been systematically researched in the past. In general the complex interrelation between natural processes like river flow, sea level rise and flooding with the cultural history of Vlaardingen and initial soil development will be addressed in this paper.

Archaeological research in nature is dedicated to small-scale excavations or limited coring campaigns that do not always address such complex interactions of dynamic landscape development and cultural habitation. This is further enhanced by the covered and protected nature in the old city of Vlaardingen, because the narrow streets and old infrastructure do not allow large scale excavations or intensive coring campaigns to take place. In addition currently rarely developments take place that make

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archaeological research necessary. The general problem centred in this paper is the combination and collaboration of multiple research methodologies and correlations of heterogeneous results that is paramount in geoarchaeological research. Standard descriptions of mechanical drill holes, grain size analysis (GSA), thermo-gravimetric analysis (TGA), dating of archaeological remains, soil analysis, C14 dating methods, micromorphology, and microfauna are combined in this paper. The approach is carried out in this paper in order to reconstruct the fluvial history and deposition of the past 3000 years of this region in combination with the formation of fluvisols[1] combined with the archaeological and settlement history.

2 Previous research

The location of Vlaardingen in the Early Holocene, around 7500 years BP, was in a tidal basin that was influenced by river drainage. Around 6300 years BP, the location changed into a wetland environment with swamps and small lakes (Hijma, 2009). Between 6300 and 5000 years BP the area was transformed into a peat growing environment, locally first alternating with silty clay of estuarine deposits (Echteld Formation), secondly alternating with shallow marine deposits of the Wormer Layer of the Naaldwijk Formation: clay with very fine sand layers (salt marshes). Due to these dynamic processes the Holland Peat layer is not continuous, unlike classical Dutch Holocene stratigraphy, so that in some locations the Late Holocene Walcheren layer of the Naaldwijk Formation, deposited in the last 2500 years, is directly on top of the Wormer layer, while in other locations the Holland Peat layer is in between these two marine layers of the Naaldwijk Formation (Hijma, 2009). In Vlaardingen many cultural traces of the Iron Age and Roman Period (2750–2000 BP) have been retrieved in this landscape, such as west of Vlaardingen (Vos and Eijskoot, 2009). Generally the Wormer layer can

[1] A fluvisol is a soil that is present in temperate climates as the Netherlands, may occur on flat areas and are characterised by clay illuviation horizons as well as by a high cation exchange capacity (FAO, 2007).

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be found below −3 m NAP, while the Walcheren layer is located above −3 m NAP. In the late Middle Ages the actual surface was at +1 m NAP, right before the significant surface lowering due to the peat exploitation. Currently that surface is indeed lowered locally to −2 m NAP (Vos and Eijskoot, 2009), although that surface may be higher above old gully complexes that have become inversion ridges.

Around 1300 years BP located on the point bar ridge of the "Vlaarding" creek a church was founded, that was given by Heribald to the well-known missionary Willibrord. North of it, and in a later stage also around the church a settlement is originating that has been called Vlaardingen (van Loon and de Ridder, 2006). Vlaardingen is one of the oldest settlement nuclei of the Western Netherlands, and grows in the 11th and 12th century into one of the most important settlements in the county Holland. From the count's court the systematic peat exploitation around the settlement has been coordinated. In this count's capital in the second half of the 11th century for the first time coins have been produced on which counts titles appear. In the year AD 1163 Vlaardingen is struck by a severe flooding disaster, which had serious consequences for the settlement. Large pieces of domesticated land were lost and had to be exploited again. Vlaardingen received city rights early 13th century that were confirmed on paper at AD 1273. On the other hand the importance of the city decreased relative to other cities in Holland in the 13th and 14th centuries. The settlement grows around the church and terp, but the expansion is limited due to the dikes, a situation that continues until the Industrial Revolution in the 19th century (Torremans and de Ridder, 2007).

The actual centre of the city is located on a medieval terp around the old church. This resulted eventually in a mound, surface: 200 by 250 m, built up in a 4–5 m thick sequence of clay and manure in which organic rests of former occupation are extremely well preserved, e.g. wooden posts, mesh walls, but also leather objects. Recently, graves were found in the city centre, dating AD 1000–1050, in which not only the wooden coffins, but also the straw that covered the deceased. In human teeth DNA appeared to be well preserved, classified as the oldest in the nation, turning the church hill into a large database of human DNA (De Ridder et al., 2008).

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3 Material and methods

In order to address complex research questions around the history of the city of Vlaardingen in relation to the changing landscapes and soil profiles in this once flooded area, as well as to overcome logistical problems of access to the old city, a systematic mechanical coring campaign (Macro-Core) was carried out ($n = 76$), with core diameter 5 cm. The location of cores was planned to draw specific profiles and has taken place in the streets and places that were accessible (Fig. 2). Special permission has been granted by the city council to lift the street bricks and to employ the coring device. Core depth was ranging between 6 and 9 m below street level (Table 1).

All cores have been transported to the laboratory, where they have been cut, for standard sediment description (Bosch, 2008), sampling and further laboratory analysis.

Mechanical coring has delivered samples of the subsurface in a metre scale. Mechanical coring has caused hiatuses in coring sequence, in profile sequences these hiatuses are depicted, and in layer and unit correlations the deposit above the hiatus is assumed to be maximised to the meter scale.

A total of 211 sediment samples were used for grain size analysis and determination of organic and calcareous content. Sediment analysis was performed at the Sediment Analysis Laboratory of the VU University Amsterdam. Grain size analysis with a Sympatec HELOS KR laser-diffraction particle sizer was applied in order to quantify grain size distributions and make statistical comparisons and analyses. The latter was achieved through end-member analysis (cf. Weltje and Prins, 2003), which aims at unmixing the varying grain size distributions and identify a limited number of end-members that best represent the dataset. The results can be used to distinguish between lithological units, related to sediment sources or depositional mechanisms. Furthermore, thermo-gravimetric analysis with a Leco TGA 701 was applied to quantify the organic matter and carbonate content of the sediment samples. Results of TGA and GSA analyses as well as extensive description have already been published elsewhere (Kluiving et al., 2014).

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Micromorphology was described on 21 thin sections of 15 × 3 cm of 13 mechanical cores. Undisturbed samples have been air dried before being impregnated with a colourless unsaturated polyester resin. After vaporisation of the main part of the acetone samples have been hardened by gamma radiation. Thin sections have been prepared from the blocks (cf. Jongerius and Heintzberger, 1975), which have been analysed with polarising microscope with enlargements 200× (cf. Bullock et al., 1985; Courty et al., 1989). Results of these analyses as well as extensive description have already been published (Kluiving et al., 2014).

Small volumes of sediment have been sieved on a sieve with 2mm width on multiple intervals from 28 cores ($n = 67$). Based on combinations of species as well as conservation status, it is assumed that freshwater and land animals had their habitat in local-regional areas, while the saltwater specimens have their provenance in the North Sea and Wadden Sea. Shells and shell rests have been analysed by expert knowledge which has been reported on in Kluiving et al. (2014).

XRF values have been sampled on 10 cores through measurements with a handheld Thermo Scientific Field Mate Niton XRF analyser.

Radiocarbon AMS dating is carried out in Poznańskim Laboratorium Radiowęglowym in Pozan, Poland in 23 dates where 21 samples are dated on bulk organic material and wood, while two samples are dated on human bone material (Fig. 3).

4 Results

4.1 Lithofacies, sediment composition and soil characteristics

Eight main lithofacies units can be distinguished within the studied cores based on macroscopic core description (colour, sedimentary structures, texture; Table 2).

The results of grain size analyses were subjected to end-member analysis, through which four end-members could be distinguished (Fig. 4, Table 3). All end-members have an unimodal grain size distribution. End-members can be related to governing

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factors such as sediment source or depositional mechanism. However, it is difficult to identify anthropogenic actions as a depositional mechanism, although the provenance of specific end members may be interpreted in these units. The combined % of EM1 and EM2 appears to be high (> 50 %) in units 4, 7-2, 7-3, and 7-1, corresponding with the interpretation of gully deposits from the lithology where energy levels are apparently sustainable high to carry such bedload (Table 3).

Unit 4 consists of a rather coarse clayey sand with an EM1+2 sum of more than 50 %. The unit occurs in the higher part of the terp in elongated lenses that reflect a cultural induced depositional mechanism (system 6). But also a few isolated lenses of unit 4 occur, which based on this association this unit can have a natural as well as a cultural origin.

Unit 5 is a layer with a large component of peat, described as dark (black) with natural stones, shell rests, sandy and loose in packing. Various organic remains like wood and plant rests occur. Usually this unit is intermixed with unit 6. The unit is also sandy in nature expressed by EM1+2 % of 33 %, and is interpreted as a cultural layer, meant to artificially raise the surface (cf. van Dasselaar, 2011).

Unit 6 consists of black silty and sandy clay layers with a large humic content, mixed with bones and other archaeological remains and occurs in association with unit 5, and is interpreted as a cultural layer (cf. van Dasselaar, 2011).

Unit 7 is a sandy clay to silt poor sand, in which three sub facies have been recognised. The first subfacies (7-1) has an EM1+2 proportion of 37 % and a relative large proportion of EM3 of 45 %. The other two sub facies (7-2 and 7-3) have significantly coarser signatures with EM1+2 % 56–61. This facies is associated with gully deposits with a natural origin in the first while the upper two sub facies appear to be culturally influenced, because of the coarser nature as well as the presence of a.

Unit 8 is a clay with sand lamination interpreted as point bar deposits with a high proportion of fine end members 3 and 4.

Unit 9-1 is a silt poor clay interpreted as low energy flood-basin deposits dominated by EM 3 and 4 of more than 90 %, and EM1+2 % of 9 %.

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Unit 9-2 has a similar lithology but with a slightly higher EM1+2 sum of 12 %, and is interpreted as a cultural deposit.

Unit 10-1 is an organic silt poor clay interpreted as low energy flood-basin deposits and interpreted as flood basin deposits, the two sub facies distinguish a natural facies with an EM1+2 sum of 13 % and a potential more culturally influenced sub facies 10-2 with an EM1+2 sum of 22 %. Within the top parts of unit 10-1 at core 29 brown colours and the presence of humus staining are indicative of soil formation processes. Also the top of 10-1 in core 39 shows similar characteristics indicative of soil processes.

Unit 11-1 is a natural peat layer, interpreted as the Hollandveen layer of the Nieuwkoop Formation, while the subfacies 11-2 has a relatively higher clastic content, and occurs in higher stratigraphic contexts, and is therefore interpreted as redeposited peat deposits.

The grain size of the sediments present in the units varies over units but also reveals patterns that confirm the unit subdivision. Large differences exist between the content of coarse components (EM1 + 2 %) within units 4, 5, 7-2 and 7-3. In all of these units the sum of EM1 and 2 is very high (45–90 %) for system 6 and significantly lower (2–30 %) for system 3.1 (Table 3). The peaty cultural layer of unit 5 differs with a 10 % EM 1+2 proportion in system 3.1, while the system 6 shows a 45 % proportion. Unit 7-1 varies over systems 1, 4, and 5 reflecting gully deposits with variable flow energy, with system 1 the lowest and system 4 the highest energy.

4.1.1 Thin section analysis

In several cores to the west of the mound in the top of system 1 vegetated point bar deposits with charcoal remains have been interpreted that have been regularly burned (Kluiving et al., 2014). Also in the top of system 3 (in core 15) evidence of well-conserved plant rests with artefacts show human presence in combination with a C-14 date on bone of AD 936–1015 (no. 23; Fig. 3). In core 28 in the top of system 1 micro-evidence of cooking rests relating to slags and hearth slags (Kluiving et al., 2014).

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Artefacts disturbing the top of the peat layer in cores 30 and 55 show the presence of an old surface on top of system 1 that correlates with other cores (Fig. 6a).

4.1.2 XRF results

Since XRF values have been measured every 40 cm in core sections (see methods), results can best be incorporated by comparing with the sedimentary log (Kluiving et al., 2012). Based on this comparison a number of transitions in the occurence of chemical elements have been established (Table 5).

First results show that there appears a correlation between phosphor (P) and the archeological sequence. All cores show in general a significant drop in P in the measured samples going downcore. In cores 1, 10, 25, 30 and 35 this relation is specifically clear. In cores 1, 5 and 30 it is also observed that in their basal parts these cores show a slight increase in P.

Secondly it is observed that copper (Cu) and lead (Pb) are increased as well in the upper part of the cores corresponding with the P trend in the sequence.

Lastly it appears that the potassium (K) values have more constant levels through all layers (at 0.2 %), a trend which does not correlate with P, Cu or Pb.

Based on the observed trends boundaries have been drawn that separate naturally deposited layers from archaeological deposits/cultural layers. In most cores more than one transition in P, Cu and/or Pb values is present, only two cores have a single transition from high elevated values in P, Cu and/or Pb from low to zero values (cores 14 and 35; Table 5). At three cores Cu, P and/or Pb values are still slightly elevated below the basal transitions (cores 1, 5 and 30; Table 5). The basal XRF transition depth, from an elevated chemical element value to absence, is in most cases at the top of system 1 or the basal occurrence of system 3.

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4.1.3 Results of shell analysis

Shell rests can after analysis been split up into three categories: freshwater, saltwater and continental. Results indicate that we can specify two groups within the analysed shell rests: Group A shows exclusively freshwatershells or shell rests, with some continental shell rests ($n = 17$). Group B shows an alternation between salt water and freshwater rests, alternating with continental rests ($n = 12$; Table 6). Within group B salt water shells and rests often occur higher in the profile above freshwater and continental rests (Figs. 5a, 6a).

4.1.4 Radiocarbon dating

Results of the radiocarbon dating program show a two-part division in the spread of radiocarbon dates (Fig. 3). There is a concentration of dates in the AD 900–1000 and one in the AD 1050–1200 periods.

All radiocarbon dates are plotted in the cross sections (Figs. 5, 6).

4.2 Sedimentary and (partly) anthropogenic systems

Incorporating the results from the field description and laboratory sediment analyses, the lithological facies of the natural deposits and cultural layers were clustered into seven lithogenetic sedimentary and (partly) anthropogenic systems (Table 4).

All systems have a range of lithological units and contain gully, point-bar, floodbasin and floodbasin, organic deposits, based on their lithological characteristics (Table 3). Below these units peat and clay deposits are observed that belong, based on their lithology and positional depth, to the Holland Peat layer of the Nieuwkoop Formation (top 4.80–5.50 m – NAP) and the Wormer Layer of the Naaldwijk Formation (top 5.70–6.40 m – NAP).

All natural and anthropogenic systems contain a range of lithological units (Table 2). These units within the systems are also depicted in the cross-sections in Figs. 5 and 6.

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In overview it is observed that the combined number of EM1 and EM2, the coarsest fraction, coarse and medium sand is more prominent in the higher and younger systems, e.g. systems 3.1 and 6. In system 1 it is striking that the interpreted flood basin clays to be deposited in medium to deep water contain the highest proportion coarse sediment in relation to the gully and point bar deposits (Table 3). In general carbonate contents of sediments analysed are relatively elevated, with higher values (up till 20 %) in the systems 1 and 4 (Table 4). The lowest values (below 10 %) occur in system 6.

System 1 sediments consist of grey to grey brown sandy clay that is interpreted as gully (unit 8) and point bar deposits (unit 7) that have a dominance of EM3, where the point bar deposits have sand layers and a significantly higher finer proportion of EM4. Grey to light grey silty clays (unit 9) are interpreted as medium-deep water floodbasin deposits with an equal dominance of EM3 and 4 and a relatively low sum EM1 + 2. Organic shallow water floodbasin deposits are interpreted from grey to dark grey silty clay with similar endmember properties as unit 9.

System 1 is the basal unit everywhere located on top of the Holland Peat or, if eroded, directly on top of the Wormer layer (Fig. 5). The top of the gully deposits is most likely eroded by younger systems. The gully deposits of system 1 are located in the centre of Figure 5 between cores 7 and 53 flanked on the west by flood basin deposits between cores 8 and 14. In the north-south profile system 1 gully (channel and point bar deposits) is located from core 53 southward to where it is cut off by system 4 (Fig. 6). To the north the gully deposits are bounded by flood basin deposits in core 002. In core 58 channel deposits are observed also bounded by flood basin deposits to the north. At cores 28–55 system 1 flood basin and peat deposits also occur at higher levels, with the top between −0.25 m NAP and −1, 5 m NAP, confirmed by AMS C14 and archaeological dating (Fig. 3; van Dasselaar, 2011). In cores 29 and 30 the combined data of archaeological dating and C-14 analysis (1130 ± 35 BP, core 29, Fig. 3) as well as the observation of a soil profile in unit 10 below the peat in core 29 (Fig. 6a).

In system 1 TGA data of sediments show patterns of relatively high amounts of "old carbon" in flood basin deposits (units 9 and 10), while carbonate content is increased in

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the “gully” deposits (units 7 and 8; Table 4). The latter high value of carbonate content in conjunction with the presence of freshwater and continental shell rests points to a provenance of detrital carbonates transported with the Maas river to this region.

System 2 interpreted as gully sediments (unit 8) are grey silty clay deposits with sand layering, a dominance in EM3, marine shells and a relatively high proportion of EM1 +2 (∼ 10 %). Flood basin deposits in this system consist of grey silty clay with continental shell material with dominant EM3 and relatively low EM 1+2 proportions. Light brown silty clay with detritus and peat layering is interpreted as shallow water flood basin deposits.

System 2 is much more confined and is located in the east-west profile only in the centre part, eroded by younger systems elsewhere (Fig. 5). Also in the north-south profile system 2 is confined to the city heart of Vlaardingen and is eroded on the south side by the Maas river, and potentially in the north side by younger incisions of systems 3 and 3.1 (Fig. 6). The top of system 2 is between 1.00 and 0.50 m – NAP, dated AD 1100–1200 bracketed by dating all archaeological remains in that system (Kluiving et al., 2014; Dasselaar, 2011).

System 3 gully deposits (unit 8) consist of a grey sandy to silty clay with sand banding with a dominance of EM3 and a relatively high proportion of EM1+2 (> 10 %). The gully sediments contain continental and freshwater shell rests. (Dark) grey to (light) brown silty clay (10) is interpreted as organic floodbasin deposits with double the amount of EM3 vs EM4. The dark-coloured sediment with the humus/detritus banding and staining is interpreted as shallow water floodbasin deposits that are in this stratigraphic position often disturbed by human influence.

System 3 with associated gully and floodplain sediments has a rather continuous presence in the east-west profile (Fig. 5), while in the north-south profile the system appears to be dissected by younger systems as well as by non-deposition due to relatively high (non-eroded) remnants of systems 1 and 2 (Fig. 6). Two of the system 3 gullies are located within 10 to 25 m of the old church. The top of system 3 is between 0 and 0.20 m – NAP in north–south profile B–B’ and even between 0.20 and 0.50 m +

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NAP in the east–west profile A–A. System 3 is dated AD 1200–1300 by AMS C14 and relative dating (Figs. 3, 5a, 6a).

System 3.1 gully deposits of sandy clay to clayey sand appear in the top of the system and are sparsely sampled. The dark grey to grey brown silty clay with humus staining are interpreted as shallow water floodbasin deposits. The EM4 endmember is slightly dominating over the EM3 fraction, while the anthropogenic influence is reflected in the high proportion of EM1+2 (> 20 %). Dark grey silty clay has a similar EM3/EM4 relation but has a lower proportion of EM1+2 of almost 10 %. These sediments are interpreted as medium-deep water flood basin deposits. System 3.1 also has a significant high amount of archaeological remains.

System 3.1 has in both profiles a more continuous cover of which the top occurs between 1.20 and 0 m + NAP in the city heart, and between 0 and 2.5 m – NAP on the west side of the city heart (Fig. 5). System 3.1 is dated AD 1200–1300 by relative dating (Figs. 5a, 6a).

System 4 gully deposits (unit 7-1) are grey silty sands and have a 60 % of EM1+2. Grey to light brown silty clay with silt/sand banding is interpreted as point bar deposits has a dominant EM3 and an almost 20 % of EM1+2. Flood basin deposits of system 4 have similar characteristics as other systems.

System 4 only occurs in the southern part and incises in systems 1 and 2 as well as potentially in system 3 (not observed). System 4 is covered by systems 3.1 and 6; the top of this system is at 1.0 m – NAP, and is relatively dated older than AD 1200 (stratigraphically below system 3.1). System 4 correlates with Maas river deposits, Echteld Formation (Fig. 6).

System 5 gully deposits (8) are grey silty clay, sand and humus banding with a dominant EM3 and with a < 10 % EM1+2. Grey sandy clay has a 33 % of sum EM1 + 2 with a slightly dominant EM3 over EM4, interpreted as point bar deposits. Grey to grey brown silty clay has a dominant EM4 proportion.

System 5 only occurs in the eastern part of the research area (Fig. 5), note also the deep occurrences of these sediments in the northern part of the north-south profile

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(Fig. 6). System 5 incises deeply even into system 1 sediments and is covered by systems 3 (although barely) and 3.1. The stratigraphic top of system 5 is at 0.50 m – NAP while the system is dated AD 1100–1200, confirmed by AMS C14 and archaeological dating.

System 6: The (dark) grey to grey black silty clay with peat banding and humus staining which resembles similar interpreted shallow water flood basin deposits in previous systems has a significantly higher proportion of EM1+2 (~ 27 %). EM 3 and EM 4 are almost similar in this anthropogenically influenced deposit. Grey silty clay resembles deeper flood basin deposits with a dominant EM3 proportion, and with a ~ 19 % proportion of EM 1+2 %. Especially the remaining deposits of sand, (humic) sandy clay, clayey sand and silty sand have grey to various colours, and extremely high proportions of EM1 +2 of 60 to 90 % (Tables 3, 4). Observations of the carbonate content and comparisons with lower systems show that system 6 has significantly lower carbonate values (Table 4). This may be due to the fact that soil forming processes have been going on when this material was exposed after it was piled up. An alternative option would be that the material from system 6 is transported from elsewhere with a substrate with a lower carbonate value. The very coarse nature of the grain size may support the latter explanation.

System 6 is the topmost layer and covers all lower systems with a 2.5 m thickness in the city heart in an elongated shape while at the eastern and western margins of that centre the thickness of system 6 is only 1 m (Fig. 5). The relative age of this system is determined at AD 1400 at the base until the present at the surface, interpreted as an entirely cultural system, caused by human interference, as opposed to the other systems (1, 2, 3, 3.1, 4 and 5) that are interpreted as naturally deposited, although systems 3, 3.1 and 5 are minor to major influenced by human's actions.

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5 Discussion

The natural subsurface of the "Stadshart Vlaardingen" consists of an inversion relief of a number of river systems with sandy gully deposits in a chronological sequence. These river systems are underlain by the silt-poor calcareous clay of the Wormer layer of the Naaldwijk Formation (8000–5500 years BP), and the Holland Peat layer of the Nieuwkoop Formation (5500–3000 BP). The oldest (river) system 1 in this study is incised in both of these two formations to a depth of at least 6 m – NAP (Fig. 5).

Micromorphological evidence has demonstrated evidence of burning (micro-charcoal remains) as well as slags in flood basin deposits in the top of this system between 300 and 350 cm – NAP, while also a few archaeological traces have been found at a deeper level in gully deposits of this system (van Dasselaar, 2011).

The settling traces that have been found in the flood basin deposits belong to the oldest gully in the subsurface of Vlaardingen. System 1 correlates to the "Hoogstad" creek system of the Vlaardingen system (De Ridder and van Loon, 2007) and has a minimum date of Roman Age. Considering the fact that there appears to be a hiatus in deposition after system 1 of approximately 1000 years, soil development, i.c. fluvisols may be expected on such a surface. In general these soils are only present on stable surfaces, which indicate that the top of system 1 is in fact such a surface. The observation of indications of a few palaeosol features might confirm this (Figs. 5a, 6a). In addition the XRF results indicate that almost all 9 measurements have their lowest chemical element occurrence at the top of system 1 (Table 5).

The north-south profile suggests that the gully erosion of system 5 had at least predecessors in system 2 and possibly also systems 1 and 3 (Fig. 6). This implies that the position of the gully shape west of the Vlaardingen center has been almost continuously water filled during several stages in the last 3000 years.

In system 3 many small-scale gully erosional forms occur, similar to the upper part of system 5, indicating a reactivation at the end of the sedimentary cycle. This could be caused by high water stands tied to storm events. Also in system 3.1 many small

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erosional or partly depositional traces (sand, sandy clay), point to stream activity in the Late Middle Ages (e.g. during storm events), with the surrounding organic clays interpreted as the accompanying floodbasin deposits. In the other cores clearly two sedimentation cycles have been observed within system 3.1 (Kluiving et al., 2013).

In general, system 3 is a naturally deposited sedimentary system. This can be disputed in the case of a thick sequence in cores 55, 56 en 46, 47 and 49, where archaeologists have interpreted a dike body, based on the occurrence of reed packages, that have been generally observed in dikes in the western Netherlands. It is not unlikely that first flooding and deposition of units 3 and 3.1 took place in the northern part of the study area, after which damming and dike building activities became a necessity.

The interpretation of system 3.1 is also debatable between a natural deposit based on the sedimentological characteristics or an anthropogenic cover layer based on the relatively high number of archaeological artefacts preserved within this unit. Based on lithological characteristics a number of gullies have been observed around the position of the old church supporting a natural origin of these deposits. A number of distortions at the top of system 3.1. testify of human influence at this surface.

Regarding the lithological signature of the human induced terp layers the working hypothesis is that the terp layer lithology reflects the content of the immediate natural substrate. There appears to be a hiatus in deposition after deposition of System 1 associated lithological unit sediments. The hiatus is supported by relative dating methods, traces of observed initial soil formation, and trends in XRF analyses.

The upper two systems, 3 and 3.1 have a stratigraphically high position with their top surfaces up till 0 and 0.50 m + NAP for system 3 and between 0 and 1.20 m + NAP for system 3.1. In the Late Middle Ages (AD 1200–1500) the palaeosurface was assumed to be at approximately 1 m + NAP, which was before the considerable surface lowering due to human induced peat drainage. This Late Middle Age surface is already lowered to approximately 2 m – NAP at AD 2000 (Vos and Eijskoot, 2009). This elevation corresponds with the top surface of system 3.1 at the western side of the city heart (Fig. 5)

The fact that we interpret system 3.1 as initial naturally deposited during flooding events is supported by observations on grain size, archaeological dating results. The difficulty in this interpretation is that the surface and upper part of system 3.1 after the flooding event has been subjected to building activities, such as houses and dikes. Potentially the interpreted dike in the subsurface of the north-south profile has been erected after the flooding event associated with the deposition of system 3 (Fig. 6). This implies that the dike did not survive the flooding event associated with system 3.1, when we consider this material as naturally deposited.

The discussion to classify between natural or cultural deposits is a typical interdisciplinary research question. Regionally so far no comparisons have been found of city histories in a lowland environment. Future research will have to consider if the hypothesis that systems 3 and 3.1 are in essence naturally deposited systems can be tested positively given new archaeological, historical and sedimentological research, including soil analyses on fluvisols in this region.

6 Conclusions

An integrated interdisciplinary analysis of the subsoil of Vlaardingen Stadshart has delivered the following key data:

- The Medieval city heart of Vlaardingen is situated on top of an old river inversion landscape that delivered opportunities for settling conditions.
- The oldest system in this study correlates with the Hoogstad creek of the Vlaardingen system and is relatively dated to have ended 2000 years before present (de Ridder and van Loon, 2007). This relatively old river course is confirmed by the initial soil development of fluvisols that has been observed in a few cores.
- The gully shape east of the city heart has been active with water running from North to South from more than 2000 years BP until AD 1400–1500.

– The higher systems 3 and 3.1, although intensively anthropogenically disturbed have been debated in this paper as representing the last natural deposits until AD 1300 corresponding with the increased frequency of floods in the Late Middle Ages. Future research focussing on the genesis of the surficial systems in this urban context will undoubtedly contribute to this interdisciplinary research question.

– The upper system 5 is interpreted to have been piled up by human action starting from AD 1400 until the present. Premature soil formation (decalcification) may have affected the system in the previous 600 years. The nature of the lithology of this anthropogenic system suggests provenances from other places than the Stadshart.

Author contributions. S. Kluiving coordinated the research and wrote the manuscript. T. de Ridder held the archaeological supervision on the project and contributed in writing. M. van Dasselaar carried out the archaeological research in Vlaardingen and contributed in writing. S. Roozen constructed the figures. M. Prins supplied the GSA and TGA data and contributed in writing.

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Table 1. Metrical data of cores in Vlaardingen Stadshart.

Number of mechanical cores, core diameter 5 cm	Depth of core below street level, in m
60	6
1	7
15	9
Total: 76	–

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Table 2. All units described in this research above the Holland Peat layer that belong to the Walcheren layer of the Naaldwijk Formation and the anthropogenous top layers.

Unit	Lithology	Natural/cultural	Interpretation
4	Sand, clayey	Natural or cultural	Gully deposits or Culturally deposited*
5	Cultural layer (peat)	Cultural	Culturally deposited*
6	Cultural layer (other)	Cultural	Culturally deposited*
7-1	Clay, sandy/Sand, silt poor	Natural	Gully deposits
7-2		Natural or cultural	Gully deposits or Culturally deposited
7-3		Natural or cultural	Gully deposits or Culturally deposited
8	Clay, with sand lamination	Natural	Point bar deposits
9-1	Clay, silt poor	Natural	Floodbasin deposits (medium- deep water)
9-2	Clay, silt poor	Natural or cultural	Floodbasin deposits (medium- deep water) or Culturally deposited
10-1	Clay, silt poor, organic	Natural	Floodbasin deposits (shallow water)
10-2	Clay, silt poor, organic	Natural or cultural	Floodbasin deposits (shallow water) or Culturally deposited
11-1	Peat,	Natural	Holland Peat, Nieuwkoop Formation
11-2	Peat,	Natural	Holland Peat, Redeposited
12	Clay, silt poor	Natural	Wormer layer, Naaldwijk Formation

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Table 3. End-member data organised in units and subunits, specified by systems.

Unit	System	EM1 %	EM2 %	EM3 %	EM4 %	*n*	Sum EM1 and −2 %
4	3.1	12.34	19.32	58.95	9.40	2	31.65
	6	6.62	56.48	3.95	32.95	3	63.10
5	3.1	0.95	9.34	25.83	63.88	2	10.30
	6	8.99	36.00	33.20	21.81	4	44.99
7-1	1	0.00	7.75	85.33	6.92	2	7.75
	4	27.01	32.40	30.99	9.59	4	59.42
	5	15.86	16.92	41.84	25.38	6	32.78
7-2	3.1	1.69	17.95\	72.60	7.76	2	19.64
	6	16.08	44.48	17.14	22.30	13	60.56
7-3	3.1	1.60	0.00	63.71	34.69	1	1.60
	6	5.70	85.81	5.65	2.84	2	91.51
8	1	0.22	6.00	70.33	23.45	9	6.22
	2	0.26	10.05	65.98	23.71	5	10.30
	3	0.00	12.92	75.31	11.77	2	12.92
	4	0.00	19.84	77.61	2.55	4	19.84
	5	0.24	9.36	62.11	28.29	7	9.60
9-1	1	5.37	6.74	42.49	45.40	7	12.11
	2	0.38	4.64	70.51	24.47	12	5.02
	3	0.69	1.54	50.50	47.26	1	2.24
	4	0.33	4.79	70.23	24.65	2	5.12
	5	2.11	11.26	34.82	51.82	7	13.37
9-2	3.1	0.53	9.17	43.28	47.02	9	9.69
	6	3.26	16.2 %	44.29	36.23	8	19.48
10-1	1	1.78	3.95	48.49	45.78	14	5.73
	2	1.37	0.00	11.42	87.22	1	1.37
	3	2.71	9.12	50.91	37.25	9	11.83
	4	0.00	10.18	84.47	5.34	1	10.18
	5	1.32	15.19	36.31	47.18	8	16.51
10-2	3.1	5.37	14.18	36.48	43.98	20	5.73
11-2	6	6.19	21.17	36.65	35.99	12	27.36

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Table 4. Endmember, TGA and lithological and archaeological data organised by systems, specified per unit. Chronology by archaeological and C14 AMS dating. For interpretation of depositional units see Table 2.

System	Unit	EM1 %	EM2 %	EM3 %	EM4 %	*N* samples	Lithology	Color	LOI 330 gr. C.	LOI 550 gr. C.	(LOI 550–330) gr. C.	Carbonate content %	Chronology	sumEM1 and 2 %
1	10-1	1.78	3.95	48.49	45.78	14	Silty clay, humus/detritus banding and staining	Grey to dark grey	4.36	7.86	3.50	13.36	Roman/Iron Age	5.73
1	9-1	0.57	5.21	46.62	47.59	7	Silty clay	Grey to light grey	3.61	7.07	3.46	12.78	Roman/Iron Age	5.78
1	7-1	0.00	7.75	85.33	6.92	2	Sandy clay	Grey to grey brown	1.77	3.31	1.54	19.22	Roman/Iron Age	7.75
1	8	0.22	6.00	70.33	23.45	9	Sandy clay, sand layering	Grey to grey brown	2.06	4.03	1.97	18.39	Roman/Iron Age	6.22
2	10-1	1.37	0.00	11.42	87.22	1	Silty clay, detritus/peat banding	Light brown	8.47	13.52	5.05	6.39	AD 1100–1200	1.37
2	9-1	0.38	4.64	70.51	24.47	12	Silty clay,	Grey	1.71	3.62	3.30	8.40	AD 1100–1200	5.02
2	8	0.26	10.05	65.98	23.71	5	Silty clay, sand banding	Grey	2.30	4.21	1.91	14.16	AD 1100–1200	10.30
3	10-1	0.73	2.58	56.94	39.75		Silty clay, humus/detritus banding and staining	(Dark) grey to (light) brown	3.67	6.30	2.63	10.14	AD 1200–1300	3.31
3	9-1	0.69	1.54	50.50	47.26	1	Silty clay,	Grey	5.53	8.83	3.30	8.40	1200-1300 AD	2.24
3	8	0.00	12.92	75.31	11.77	2	Sandy to silty clay, with silt/sand banding	Grey	0.60	1.65	1.04	15.36	AD 1200–1300	12.92
3.1	10-2	5.37	14.18	36.48	43.98	20	Silty clay, humus staining	Dark grey to grey brown	7.27	10.97	3.70	8.52	AD 1200–1300	19.55
3.1	5	0.95	9.34	25.83	63.88	2	Peat, mixed w/clay and cultural remains	Black	8.17	13.87	5.70	8.55	AD 1200–1300	10.30
3.1	9-2	0.53	9.17	43.28	47.02	9	Silty clay	(Dark-)Grey	2.27	4.88	2.61	11.73	AD 1200–1300	9.69
3.1	7-2	1.69	17.95	72.60	7.76	2	Sandy clay	Dark grey to dark brown	3.09	6.02	2.92	10.73	AD 1200–1300	19.64
3.1	4	12.34	19.32	58.95	9.40	2	Clayey sand	Brown grey	8.86	13.38	4.52	10.49	AD 1200–1300	31.65
3.1	7-3	1.60	0.00	63.71	34.69	1	Sandy clay	Grey	3.54	6.38	2.84	12.47	AD 1200–1300	1.60
4	10-1	0.00	10.18	84.47	5.34	1	Silty clay, light humus content	Grey	2.39	4.51	2.11	14.3		10.18
4	9-1	0.33	4.79	70.23	24.65	2	Silty clay	Grey	1.56	3.14	1.58	19.28		5.12
4	7-1	27.01	32.40	30.99	9.59	4	Silty sand	Grey	1.78	3.37	1.59	19.09		59.42
4	8	0.00	19.84	77.61	2.55	4	Silty clay, silt banding	Grey to light brown	1.78	3.37	1.59	19.09		19.84
5	10-1	1.32	15.19	36.31	47.18	8	Silty clay, humus banding/staining	Grey to dark brown	6.06	10.06	4.01	7.30	AD 1100–1200	16.51
5	9-1	2.11	11.26	34.82	51.82	7	Silty clay	Grey to grey brown	9.72	16.44	6.72	7.49	AD 1100–1200	13.37
5	7-1	15.86	16.92	41.84	25.38	6	Sandy clay	Grey	3.92	6.63	2.71	8.69	AD 1100–1200	32.78
5	8	0.24	9.36	62.11	28.29	7	Silty clay, sand and humus banding	Grey	1.90	3.83	1.93	17.66	AD 1100–1200	9.60
6	10-2	6.19	21.17	36.65	35.99	12	Silty clay, peat banding, humus staining	(Dark) grey to grey black	8.23	13.00	4.77	7.13	AD 1400–present	27.36
6	5	8.99	36.00	33.20	21.81	4	Peat, mixed w/clay and cultural remains	Black	26.47	45.28	18.81	5.30	AD 1400–present	44.99
6	9-2	3.26	16.23	44.29	36.23	8	Silty clay	Grey	2.27	4.88	2.61	11.73	AD 1400–present	19.48
6	7-2	16.08	44.48	17.14	22.30	13	Sand, sandy clay, humic	Dark grey	7.33	11.70	4.36	8.66	AD 1400–present	60.56
6	4	6.62	56.48	3.95	32.95	3	Clayey sand	Various	1.87	3.60	1.73	6.71	AD 1400–present	63.10
6	7-3	5.70	85.81	5.65	2.84	2	Silty sand	Various	3.93	6.61	2.68	6.02	AD 1400–present	91.51
					Total samples	186								

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Table 5. Depth of transitions P, Cu and/or Pb as measured by a handheld XRF analyser indicated in m down core and relative to NAP. In three cores trends of slightly increasing elements below the basal transition are indicated (*).

Core	Depth of transitions (/) in m down core (m ± NAP)
1	−2.55(0.69)/ – 3.0(0.23)/ – 4.51(−1.28)/ trend Cu and P*
5	−2.70(0.58)/ – 3.20(0.08)/ – 5.26(−1.98)/ trend Cu, P and Pb*
10	−2.37(−2.03)/ – 3.40(−3.13)/ – 3.75(−3.42)
14	−2.45(−3.20)
20	−2.55(0.59)/ – 3.00(0.13)/ – 3.36(−0.23)/ – 4.12(−1.00)
25	−2.00(1.66)/ – 2.40(1.26) – 3.40(0.26)/ – 4.00(−0.34)/ – 5.00(−1.43)
30	−3.00(0.66)/ – 4.10(−0.44)/ – 4.85(−1.29)/ – 5.21(−1.66)/ trend P*
35	−3.33(−3.22)
40	−2.0(−0.95)/ – 2.2(−1.15)/ – 3.04(−1.99)/ – 5.0(−3.95)

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Table 6. Types of shell rests divided over cores.

Shell rest type	Core numbers	Group
Freshwater (and continental)	1, 5, 6, 8*, 9, 10, 12, 23*, 24*, 26, 31*, 35, 37, 42, 50*, 53, and 56*	A ($n = 17$)
Saltwater (on top of freshwater)	14, 18, 20*, 22*, 25, 29*, 30, 36, 41, 45*, 46*, en 54*	B ($n = 12$)

* indicates shell rests present in systems 3.1, 5, and 6.

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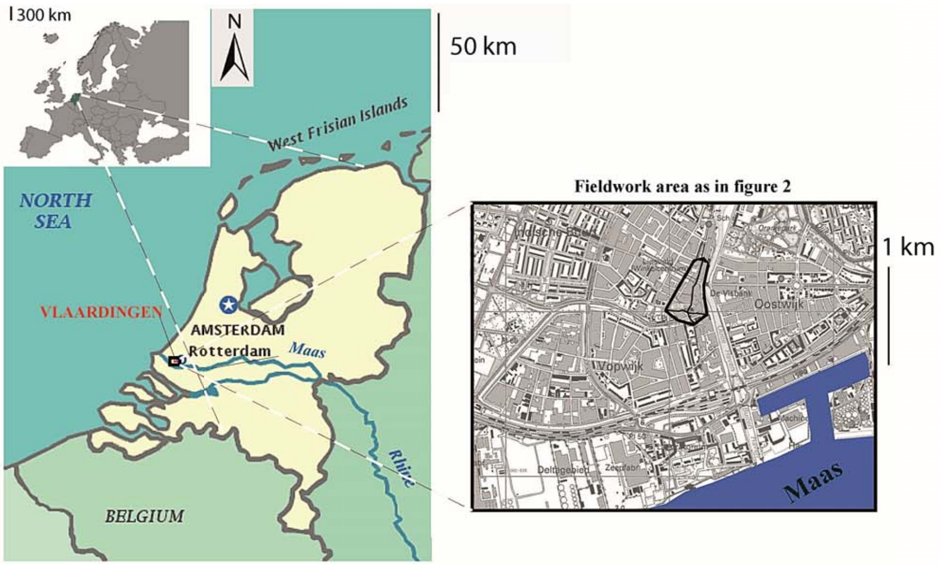

Figure 1. Map of Europe and Netherlands showing locations of main cities and Vlaardingen, location of study area.

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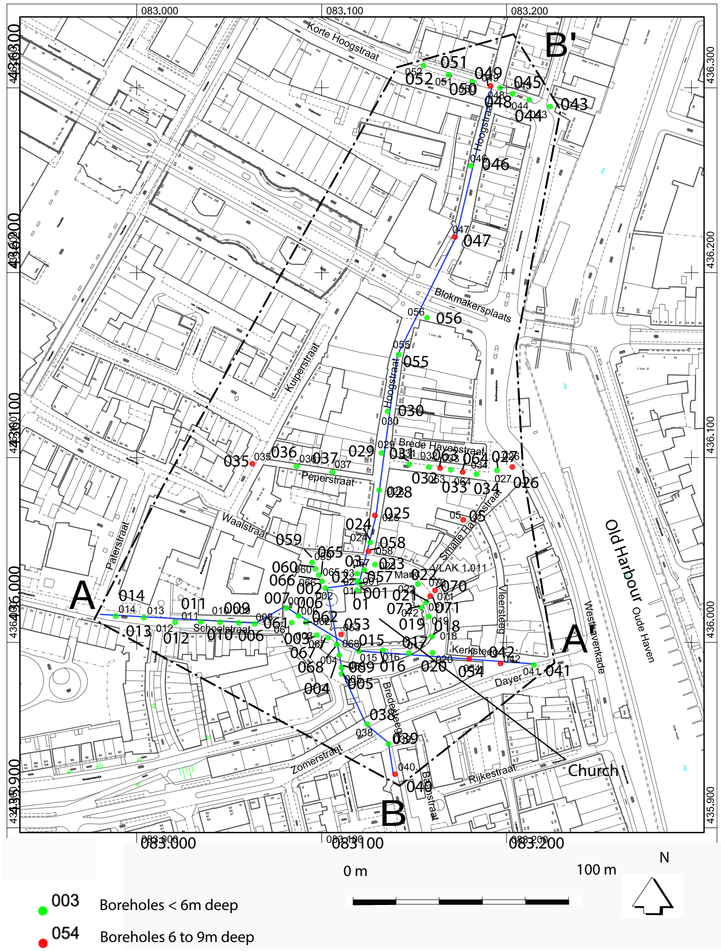

Figure 2. Study area within city center of Vlaardingen with locations of 76 mechanical cores and position of two cross-sections A and B.

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VLAA-Sample nr	Poz-lab. nr.	C-14 years BP	Core nr. (core depth cm)	Material dated
1	45584	1425 ± 30	17 (500-515)	W
2	45585	895 ± 35	18 (433)	W
3	45586	945 ± 30	53 (500-520)	W
4	45587	940 ± 30	53 (463-478)	W
5	45589	1090 ± 30	18 (366)	W
6	45590	915 ± 30	25 (500-505)	W
7	45591	1075 ± 30	31 (532)	W
8	45592	850 ± 30	06 (260-300)	W
9	45593	1140 ± 30	25 (480)	W
10	45594	1110 ± 30	56 (532)	W
11	45595	895 ± 30	33 (454)	W
12	45604	1060 ± 35	37 (433-450)	W
13	45761	935 ± 25	19 (345-372)	W
14	45596	935 ± 30	03 (315-357)	W
15	45597	1025 ± 30	20 (580)	W
16	45599	1240 ± 30	20 (436-438)	W
17	45600	1130 ± 35	29 (438)	W
18	45644	975 ± 30	54 (610)	W
19	45601	990 ± 30	54 (430-440)	W
20	45602	980 ± 30	54 (370)	W
21	45603	1000 ± 30	54 (450-500)	W
22	46026	1045 ± 30	19 (420)	B
23	46028	1085 ± 25	15 (425-430)	B

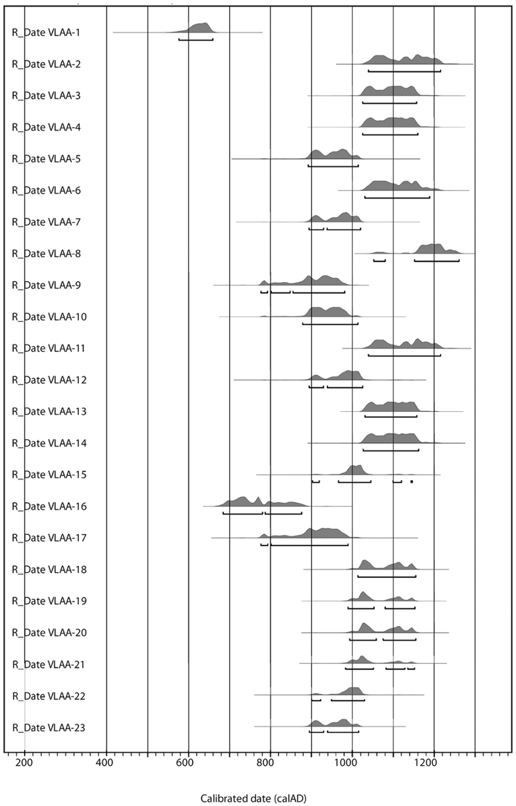

Figure 3. AMS radiocarbon dates.

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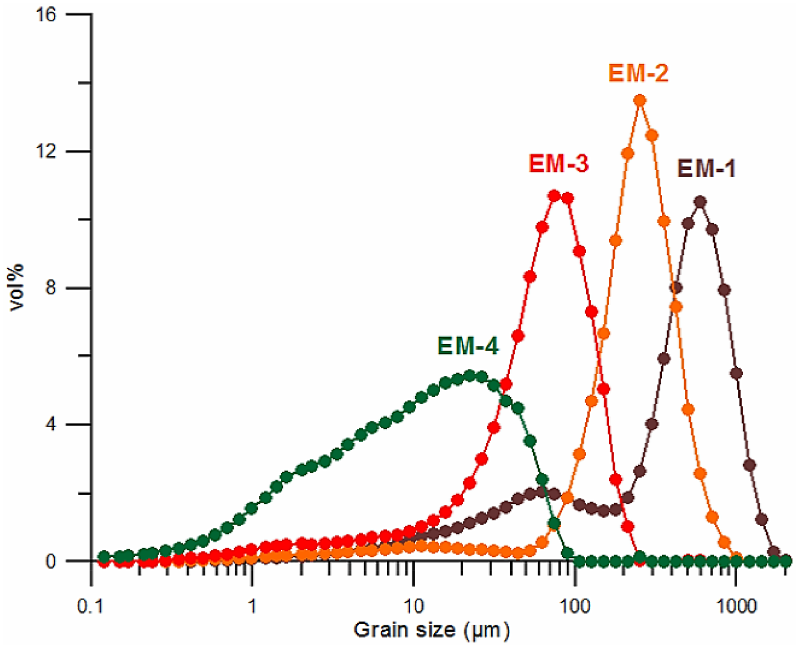

Figure 4. Modelled grain-size and division of end members in Vlaardingen Stadshart.

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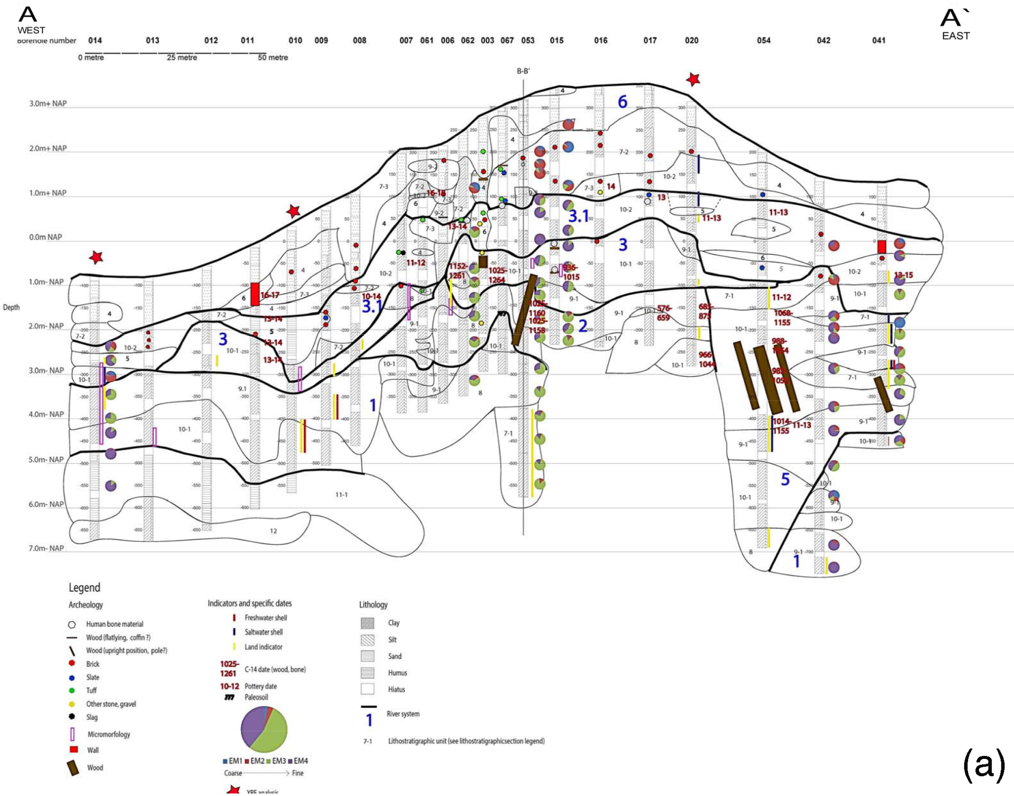

Figure 5.

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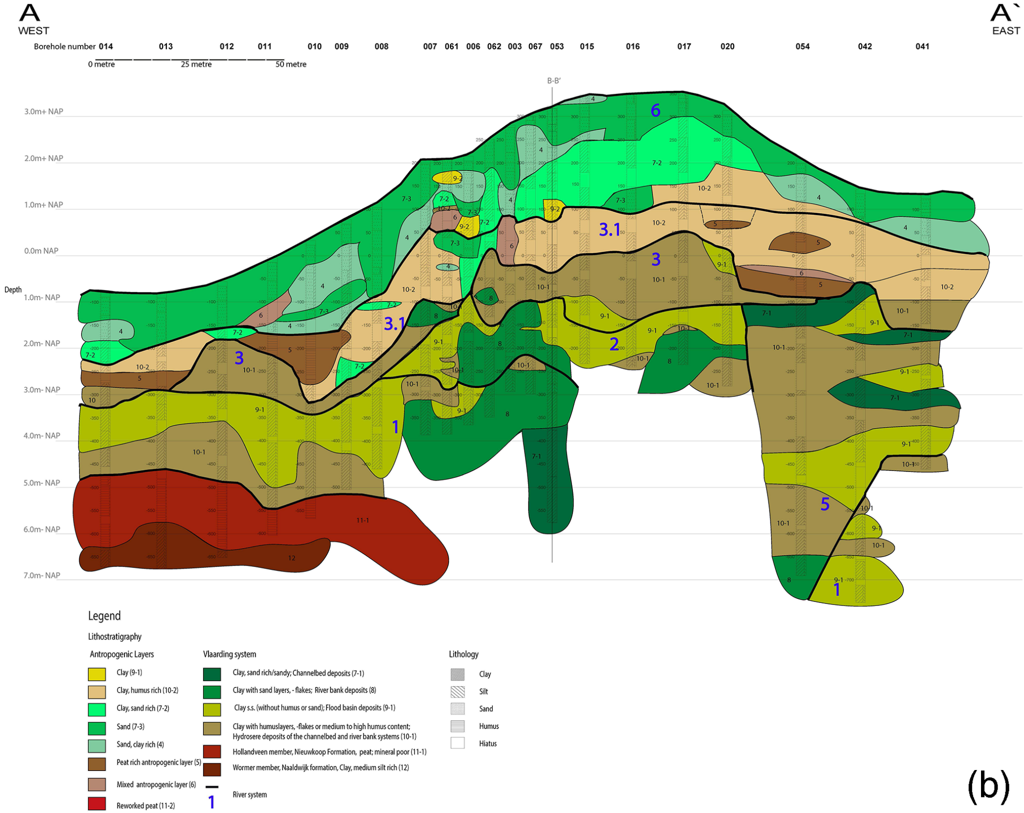

Figure 5. (a) East–West (A–A') east-west cross-section of mound of Vlaardingen Stadshart and its natural subsurface. Data sheet. **(b)** East–West (A–A') east-west cross-section of mound of Vlaardingen Stadshart and its natural subsurface.

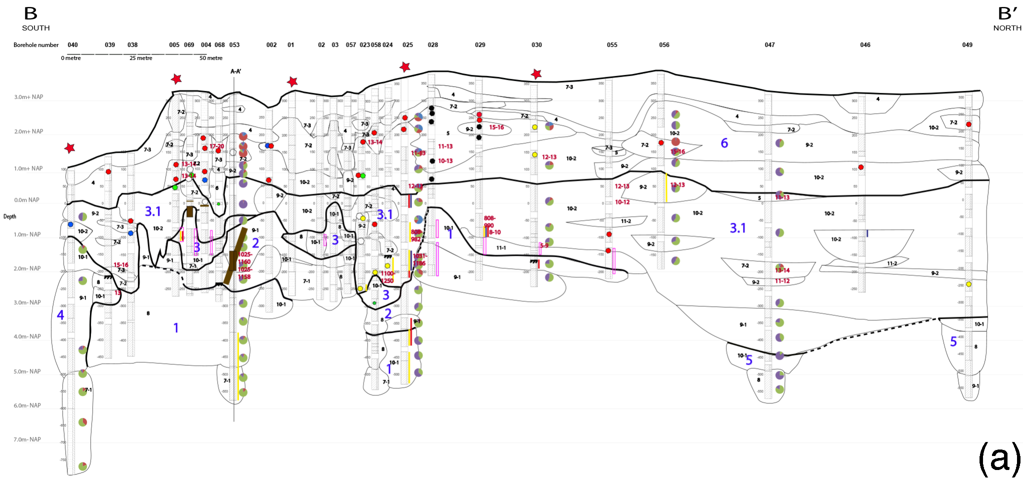

Figure 6.

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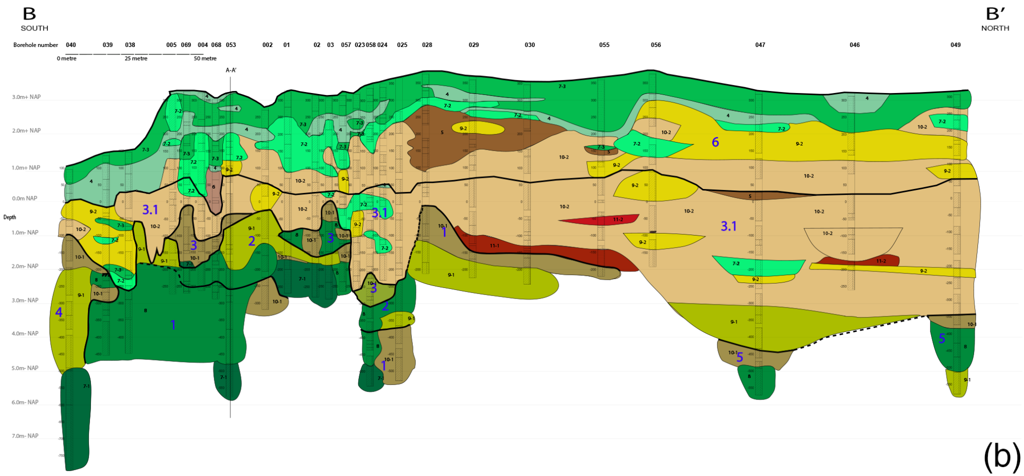

Figure 6. (a) North–South (B–B’) north-south cross-section of mound of Vlaardingen Stadshart and its natural subsurface. Data sheet. **(b)** North–South (B–B’) north–south cross-section of mound of Vlaardingen Stadshart and its natural subsurface.

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