

Comments of topical editor and replies:

Pedologically, it is

relevant to refer to the next step in soil development. The authors mention 'initial soil formation'. Initial soil formation, or better, the next step in soil evolution of fluvisols, can

mean (1) transformation of sedimentary lamination in a more homogenous horizon, due to bioturbation, (2) decalcification, (3) increase of soil organic carbon and (4) the translocation of clay particles from the actual Be to a (future) Bt horizon. Such processes

can identify initial soil development during a period of landscape stability. The first scope of the study is the development of the Vlaardingen site, that means archaeology.

The results of the multi proxy analysis of the soil archives of the (palaeo)fluvisols is an important tool to realize this study. The EGU subdivision SRP (Soils as a Record

of the Past) promotes such investigations in which soil archives analysis play an important

role. That is the reason that my advice is to accept this paper for publication in the special volume of SOIL, after minor revision.

- Text has been adapted according to comments

Especially the definition of the properties

and further initial processes of the Fluvisols (with prefix qualifiers as tidalic, umbric and

suffix qualifiers as calcaric, clayic, silty, arenic) needs some attention

- Text has been adapted according to comments

- Text has been adapted according to suggestions annotated document of topical editor, see also marked document (at the end of this document) with changes in yellow

- Internal discussion between co-authors have led to modify the system 3.1 interpretation into an a. and b. subsystem, diversifying into a natural flood (a.) and a cultural dike construction (b.).

- We changed the interpreted age of system 2 into 600-1170 AD in Table 4 and in the text.

- We adapted the figures 5 and 6 based on the comments and internal discussion.

- For further textual changes we refer to the marked document.

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 the early 8th century AD was already located here. In a short period of time Vlaardingen developed in the 11th century AD into an international trading place, and into one of the most important places in the former county of Holland. Starting from the 11th century AD the river Meuse threatened to flood the settlement. The flood dynamics have been registered in the archives of the Fluvisols and were recognised in a multidisciplinary sedimentary analysis of these archives.

To secure the future of these vulnerable soil archives an extensive interdisciplinary research (76 mechanical drill holes, grain size analysis (GSA), thermo-gravimetric 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 description, 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 interdisciplinary 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 phosphorus 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, in geological terms it is assumed that the medieval landscape was drowned while it was inhabited in the 12th century AD. After a final drowning phase in the late 12th century AD, as a reaction to it, inhabitants started to raise the surface. Within archaeological terms the boundary between natural and anthropogenic layers is stratigraphically lower, so that in their interpretation the living ground was dry during the 12th and the 13th centuries AD. In the discussion the geological interpretation will be compared with alternative archaeological visions.

Keywords: Fluvisols, soil archives, sedimentology, archaeology, anthropogenic layers

57 1. Introduction

58 Since the fifties of the last century archaeological excavations in the city centre of Vlaardingen started
59 to turn the view on Vlaardingen's history at first adopted by 17th and 18th century history writers that
60 the old medieval city was flooded by the river Meuse (Fig. 1; De Ridder, 2002). Archaeological finds
61 in the research area are dated to the Middle Ages (500-1500 AD), while archaeological excavations in
62 the city centre south of the old church revealed the border of a medieval cemetery that has been in use
63 between 1000 and 1050 AD. This discovery comprised a more complete story of the medieval
64 structure of Vlaardingen and made clear that today's position of the church was also the position at
65 1000 AD. Assuming that there have been no other reasons to move the church it must have been the
66 same position in 726/727 AD (Koch 1970, number 2).

67
68 Despite a long period of archaeological research combined with soil observations a number of research
69 questions regarding the landscape and soil development still exist. Based on previous research a
70 number of fluvial channels are assumed to date from the Iron Age, Roman Age and Middle Ages
71 spanning a period of almost 2000 years of dynamic landscape and soil development (De Ridder & van
72 Loon, 2007; Kluiving & Vorenhout, 2010, 2011). It is still unknown what the exact location, age of
73 initiation and cessation of river gullies is. Also the extent, nature and stratification of the thick
74 anthropogenic cover layer that underlies the old town has not been systematically researched in the
75 past. In general the complex interrelation between natural processes like river flow, sea level rise and
76 flooding with the cultural history of Vlaardingen and initial soil development will be addressed in this
77 paper.

78
79 Archaeological research in general is dedicated to small-scale excavations or limited coring campaigns
80 that do not always address such complex interactions of dynamic landscape development and cultural
81 habitation. This is further enhanced by the covered and protected status of the old city of Vlaardingen,
82 because the narrow streets and old infrastructure do not allow large scale excavations or intensive
83 coring campaigns to take place. In addition currently rarely developments take place that make
84 archaeological research necessary following Dutch legislation.

85 This site evolution is based on a multi proxy approach of the soil archives in a combination and
86 collaboration of multiple research methodologies and correlations of heterogeneous results that is
87 paramount in geoarchaeological research. Standard descriptions of mechanical drill holes, grain size
88 analysis (GSA), thermo-gravimetric analysis (TGA), dating of archaeological remains, soil analysis,
89 C14 dating methods, micromorphology, and microfauna are combined in this paper. The approach is
90 carried out in this paper in order to reconstruct the fluvial history and deposition of the past 3000 years
91 of this region in combination with the formation of Fluvisols combined with the archaeological and
92 settlement history. Fluvisols are characterised that the parent material originates from fluvial and
93 estuarine sedimentation, while they can be sandy, silty or clayey. The next step in soil evolution of
94 Fluvisols, can mean (1) transformation of sedimentary lamination in a more homogenous horizon, due
95 to bioturbation, (2) decalcification, (3) increase of soil organic carbon and (4) the translocation of clay
96 particles from the actual Be to a (future) Bt horizon. Such processes can identify initial soil
97 development during a period of landscape stability. In a next phase in pedological terms clay
98 translocation causes the formation of Luvisols. The good natural fertility of most Fluvisols and
99 attractive dwelling sites on river levees and on higher parts in marine landscapes were
100 recognized in prehistoric times (WRB, 2014).

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103 An important asset of this study is the collaboration between geologists and archaeologists to approach
104 the intertwined relation between natural processes and cultural activities in an urban context. To
105 combine different aspects of scale as well as methods of measure against historical data (cf. van de
106 Biggelaar et al, 2014) has not been a straightforward task so far. The results in this study, and
107 especially the sequence of events around the historical flooding of 21 December 1163 AD (Buisman
108 en Van Engelen, 2000, p. 348-349; and Hoek 1973) will be further elaborated in the discussion. From
109 an archaeological context the boundary between natural and anthropogenic layers is interpreted at a
110 lower elevation, than based on geological arguments. This has major implications on how the

medieval history of Vlaardingen has to be understood. From an archaeological point of view the terp was a safe and dry living environment, while a geological interpretation indicates that the church hill has been regularly flooded in the 12th and 13th century during which relatively thick sediment layers were deposited. This elementary conflict in interpretation may have an impact on other research that focusses on distinguishing the contact between natural and anthropogenic layers. This could have major implications into the research of other dikes and terps in the Holocene plains of NW Europe. In this paper a geological analysis and interpretation will be executed, the outcome of which will be compared in the discussion with alternate archaeological interpretations.

2. Background

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 yr 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 & Eijsskoot, 2009). Generally the Wormer layer can 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 -2m NAP (Vos & Eijsskoot, 2009), although that surface may be higher above old gully complexes that have become inversion ridges.

Around 1300 years BP (700 AD) 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 & de Ridder, 2006). Vlaardingen is one of the oldest settlement nuclei of the Western Netherlands, and grows in the 11th and 12th centuries AD 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 AD for the first time coins have been produced on which counts titles appear. In the year 1163 AD 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 1273 AD. On the other hand the importance of the city decreased relative to other cities in Holland in the 13th and 14th centuries AD. 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 AD (Torremans & 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 meter, built up in a 4-5 meter 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 1000-1050 AD, 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). Vlaardingen was a principal settlement in the past. In this paper we attempt to link the rise and fall of a city like Vlaardingen with the fluvial and tidal dynamics in this region and to show how important the analysis of soil archives of Fluvisols can be to reconstruct landscape development.

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 meters 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 archived 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).

Micromorphology was described on 21 thin sections of 15x3 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 & Heintzberger, 1975), which have been analysed with polarising microscope with enlargements 200x (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 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 artefacts.

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 %.

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 Fluvisol 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 in system 1 showing the lowest energy and in system 4 exhibiting 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 936-1015 AD (nr. 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). 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 occurrence of chemical elements have been established (Table 5).

First results show that there appears a correlation between phosphor (P) and the archaeological 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.

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 (Figures 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 900-1000 AD and one in the 1050-1200 AD 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 figures 5 and 6.

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 Fluvisol profile in unit 10 below the peat in core 29 (Fig. 6a) suggest a stable surface for a considerable amount of time (500-1000 years).

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 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 0.00 and 0.50 m – NAP, dated 1000-1170 AD bracketed by radiocarbon dating and archaeological remains in that system (Kluiving et al, 2014; Dasselaar, 2011). The basal parts of system 2 suggest a Medieval age (600-1000 AD) of the fluvial sediments, given by the radiocarbon and archaeological dates in cores 29 and 30 (Fig. 6) and core 17 (Fig. 5).

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 discontinuous presence in the east-west profile (Fig. 5), while also 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 meters 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 + NAP in the east-west profile A-A. System 3 is dated 1170-1300 AD 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 1170-1300 AD by relative dating (Figs 5a, 6a). Within system 3.1 at some locations we are able to distinguish two sub-systems, system 3.1a and system 3.1b (Fig. 6). While 3.1a can be interpreted as an erosive phase forming gullies, 3.1b is on the contrary interpreted as i) a dike body and ii) as sediments raised by man to elevate the surface. While the gullies are dated around 1170AD, the dike body and raised sediments are dated after that date (1170-1300 AD).

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 1170 AD (stratigraphically below system 3.1). System 4 correlates with Maas river deposits, Echteld Formation (Fig. 6).

System 5 gully deposits (unit 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 (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 1100-1170 AD, 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 meter's 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 meter (Fig. 5). The relative age of this system is determined at 1300AD at the base until the present at the surface, interpreted as an entirely cultural system, caused by human interference, as opposed to the other naturally deposited systems 1, 2, and 4 that , while systems 3, 3.1 and 5 are interpreted as minor to major influenced by human's actions.

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 yrs 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 top of system 1 reaches at a few places elevations of almost 0 m NAP, indicative of erosive processes later on.

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 & 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.e. 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, and that elements P, Cu, and Pb increase above this level (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 filled with water during several stages in the last 3000 years.

System 2 is interpreted as a former river deposit only occurring in the centre of the study area, and being deposited between 600 and 1170 AD, just before the late medieval storms started to threaten the city. It is inferred that shortly after deposition of this system most system 2 sediments around the medieval terp have been eroded and swept away during later storms and floods, explaining the now isolated occurrence of these sediments. Between cores 038 and 005 in figure 6 the age of interpretation of the upper part of system 2 can be disputed based on the fact of an archaeological excavation that the cemetery at this location has been anthropogenically raised since 1000 AD. However in this case it is tempting to test the hypothesis that the cemetery was raised by inhabitants as a reaction to the flooding and sedimentation of system 2 starting in 1000 AD. It can be discussed that the lower age of 600 AD of system 2 may feed the hypothesis that in the 6th or 7th century AD renewed activity of creeks and rivers started to make the area more attractive for habitation. Potentially a church was then built at the location of Vlaardingen that was existing already in the early 8th century (Koch, 1970). Following this the traces of soil formation observed at the top of system 1 suggest a relatively long stable period in the order of 500 years, when no deposition or other sedimentary processes were present and soil forming processes could dominate.

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 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, 2014).

In geological terms system 3 can be considered as a naturally deposited sedimentary system. This is in contrast with the case of a thick sequence in cores 55, 56, 46, 47 and 49, where archaeologists have interpreted a dike body (system 3.1b), 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 **observed in system 3.1b** (Fig. 6).

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.

The subdivision within system 3.1 in sub-systems 3.1a (semi-natural) and 3.1b (cultural) clearly observed in the north-south profile (fig. 6) might be a guide to perform more detailed analysis in the near future on these multiple natural and cultural systems that date roughly between 1070 and 1300 AD. In our current interpretation the semi-natural system 3.1a has eroded the substrate until -2.5 m NAP and -4.5 m NAP in resp. the middle and northern parts of the B-B' cross-section (Fig. 6).

Regarding the lithological signature of the human induced layers the working hypothesis is that the top 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.

A specific feature in this study is the comparisons between scales, while archaeology usually is concerned on small scale excavations on the contrary geology adheres to the 500-1000 meter long profile reconstructions. It is important to bear in mind that in the dynamic landscape history in the Late Medieval Vlaardingen elevation differences of systems occur leaving relatively old surfaces as non-eroded cliffs intact at relatively high elevations, while younger systems may be incised at a lower level on a meter scale.

The upper two systems below system 6, 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 (1200-1500 AD) the palaeosurface for the peat area in the 'Vergulde Hand' 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 for the peat area is already lowered to approximately 2 meters – NAP at 2000 AD (Vos & 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 partly 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. **In our current interpretation the dike in the subsurface of the north-south profile (system 3.1b) has been erected after the flooding event associated with the deposition of system 3.1a (Fig 6). More detailed analysis will be necessary to compare lithology, trends and archaeological dating on a specific time frame, e.g. 1000-1300 AD, to sort out differences in natural and cultural layers.**

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 with similar research approaches. Future research will have to consider if the hypothesis that systems 2, 3 and 3.1 are in part 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 (1) 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 & 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. This is supported by the XRF analysis that indicate that the elements P, Cu, and Pb increase above this system.
- The start of system 2 around 600 AD correlates with archaeological evidence of the church that was present at least in 726/727 AD (Koch 1970, number 2), hypothesizing the start of the Vlaardingen village after a relatively long period of stability.
- 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 1400-1500 AD.
- The higher systems 2, 3 and 3.1, although in part intensively anthropogenically disturbed have been debated in this paper as representing in part natural and anthropogenetic deposits until 1300 AD 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 intriguing interdisciplinary research question to further unravel the history of Vlaardingen.
- The upper system 6 is interpreted to have been piled up by human action starting from 1300 AD 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 originating from other places than the Stadshart.

Author contribution

Sjoerd Kluiving coordinated the research and wrote the manuscript. Tim de Ridder held the archaeological supervision on the project and contributed in writing. Marcel van Dasselaar carried out the archaeological research in Vlaardingen and contributed in writing. Stan Roozen constructed the figures. Maarten Prins supplied the GSA and TGA data and contributed in writing.

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Figures

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

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

Fig. 3 AMS radiocarbon dates

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

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

Fig. 5b East-West (A-A') east-west cross-section of mound of Vlaardingen Stadshart and its natural subsurface.

Fig. 6a North-South (B-B') north-south cross-section of mound of Vlaardingen Stadshart and its natural subsurface. Data sheet.

Fig. 6b North-South (B-B') north-south cross-section of mound of Vlaardingen Stadshart and its natural subsurface.

Tables

Table 1: Metrical data of cores in Vlaardingen Stadshart

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.

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

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.

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 (*).

Table 6 Types of shell rests divided over cores. * indicates shell rests present in systems 3.1, 5, and 6.

696 Table 1

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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699 Table 2

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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702 Table 3
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Unit	System	EM1 %	EM2 %	EM3 %	EM4 %	n	Sum ⁷⁰⁴ 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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707 Table 4

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	sum EM1 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	1100-1200 AD	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	1100-1200 AD	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	1100-1200 AD	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	1200-1300 AD	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	1200-1300 AD	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	1200-1300 AD	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	1200-1300 AD	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	1200-1300 AD	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	1200-1300 AD	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	1200-1300 AD	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	1200-1300 AD	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	1100-1200 AD	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	1100-1200 AD	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	1100-1200 AD	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	1100-1200 AD	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	1400 AD-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	1400 AD-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	1400 AD-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	1400 AD-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	1400 AD-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	1400 AD-present	91.51
					Total samples	186								

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710 Table 5

Core	Depth of transitions (l) 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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713 Table 6
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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)

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