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The evolution of the sedimentary environment in the lower River Scheldt valley (Belgium) during the last 13,000 a BP

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ABSTRACT. The sedimentary evolution of the alluvial plain of the lower River Scheldt between Wetteren and Dendermonde, was studied based on more than 1000 hand borings, radiocarbon, dendrochronological and OSL dating, palynological analysis and archaeological surveys. The results show a laterally migrating river during the Late Glacial, creating large meander loops. During the Late Dryas fluvial processes interacted with aeolian processes, resulting in dune formation. During the early Holocene, fluvial activity diminished resulting in an underfit river in which vertical accretion became the dominant fluvial process. The presence of multiple small channels in some parts of the study area demonstrates that the fluvial system evolved locally to an anabranching river. Meanwhile vertical accretion continued. Short before the Roman period, the River Scheldt returned to a distinct single-channelled meandering pattern. As lateral migration was limited vertical accumulation processes continued to dominate the fluvial environment. This process was halted by the construction of an extensive network of dikes from the medieval period onwards.

KEYWORDS: Late Glacial, Holocene, fluvial environment, lateral and vertical accretion

1. Introduction

1.1. Background and objectives

As a consequence of the flood risk management programme 'Sigmaplan', historical, archaeological and geological/ geomorphological heritage values will be disturbed or even destroyed in a number of areas in the alluvial plains of the lower Scheldt basin. The intensity of these threats varies according to the difference in envisaged developments, ranging from a rise of the water table to full tidal restoration . To evaluate these threats and to formulate mitigation strategies, an interdisciplinary survey is being conducted since 2008, including geological, palaeo-botanical, archaeological and cultural-historical research (Bogemans et al., 2008, 2009a, 2009b). This paper focuses on that part of the alluvial plain of the Lower Scheldt known as the 'Kalkense Meersen cluster', which includes the Kalkense Meersen, Wijmeers 1 and 2, Bergenmeersen, Paardeweide en Paardebroek areas (Fig. 1).

This study describes the Late Glacial and Holocene geology and sedimentary characteristics of the study area through the introduction of a set of sedimentary units. A chronological framework for the landscape evolution is provided through radiocarbon, dendrochronological and OSL dating, pollen analyses and archaeological finds.

1.2. Geographical and Quaternary geological setting

Except for a small area belonging to the Meuse basin, the River Scheldt dominates the drainage system in northern Belgium. Its lower course, between the North Sea and the city of Ghent, shows a tidal regime, with an average amplitude of 2.5 m in the study area (Coen, 2008).

In the study area the River Scheldt borders the southern edge of the Flemish Valley (Vermeire et al., 1999), a vast palaeo-depression of Middle Pleistocene age. As a consequence of the opening of the Pas de Calais (Sommé et al., 1999; De Mulder et al., 2003), the general course of the rivers in the Scheldt Basin shifted from the north towards the northwest, creating a large valley. The expansion of the Flemish Valley was an associated process of erosion and sedimentation during several glacial and interglacial periods. Throughout the Weichselian the Flemish Valley was filled up with fluvial deposits from braided rivers (De Moor, 1963, 1974; Paepe & Vanhoorne, 1967; Paepe, 1971;

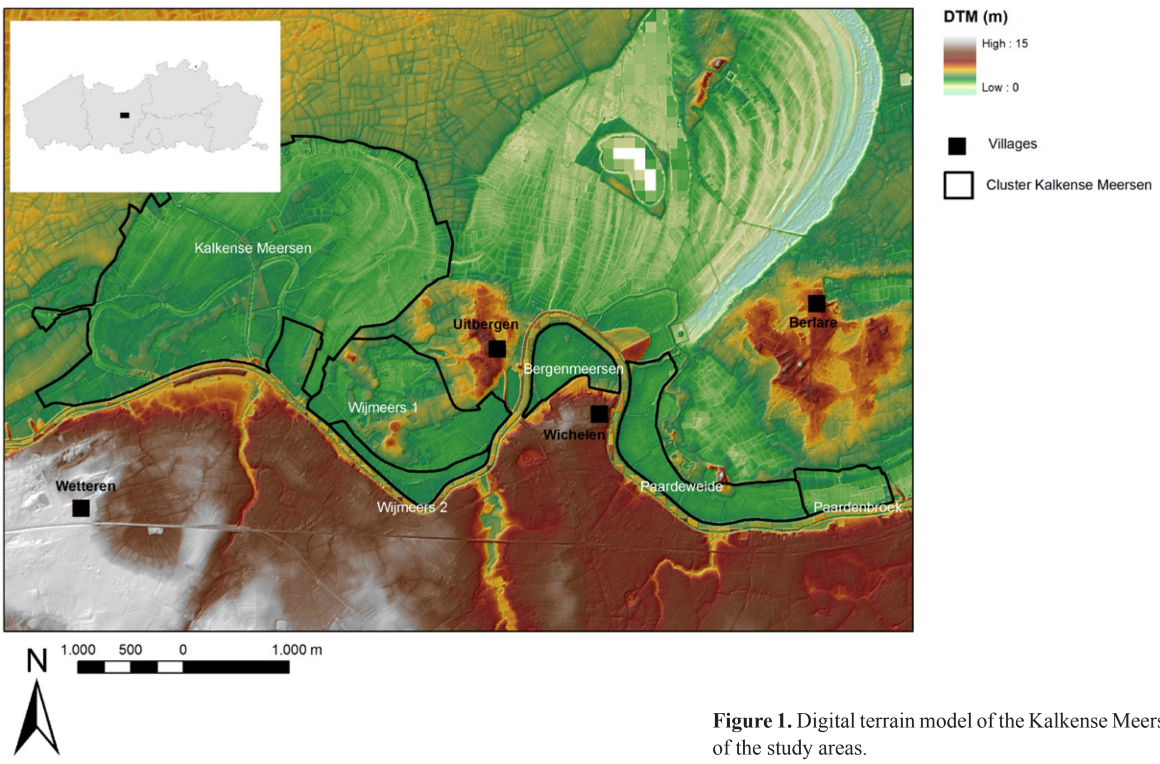

Figure 1. Digital terrain model of the Kalkense Meersen cluster with indication of the study areas.

De Moor & Heyse, 1978; Bogemans, 1993) and covered with aeolian sediments (Paepe & Vanhoorne, 1967, 1976; Tavernier & De Moor, 1974; De Moor & Pissart, 1992; Bogemans, 1993). The result is a flat landscape, only dissected in limited zones by the current rivers.

The cluster of the Kalkense Meersen is characterized by the presence of large palaeo-meanders, bordered by a broad alluvial plain. The topography of the area is flat, with elevations between +3.5 to +4.0 m TAW (TAW: Belgian ordnance level), and only a few local undulations formed by river dunes reaching heights of maximum +16 m TAW.

2. Methods

Several, but spatially restricted geological studies exist on the development and evolution of the River Scheldt during the last 13,000 years in and around the study area (e.g. De Coster, 1977, 1982; Kiden, 1989a & b, 1991; Kiden & Verbruggen, 2001; Mijs, 1986; Mijs et al., 1983; Verbruggen, 1971; Verbruggen & Kiden, 1989; Verbruggen et al., 1991). For our survey area however no such studies exist, except for Mijs (1986).

The study presented here is based on more than 1000 geological hand borings using an Edelman and a gauge hand auger. As the reconstruction of the sedimentary palaeoenvironments is mainly based on sedimentary structures (Cant, 1978; Cant and Walker, 1976; Miall, 1977, 1978, 1996; Rust, 1978) the gauge auger was used as soon as conditions were favourable. Each borehole was located using a GPS with a horizontal precision of 1m, while z values were derived from a high resolution Lidar based DTM.

Sedimentary characteristics such as colour, texture, sedimentary structures, bedding planes, palaeontological remains, Fe/Mn concretions and other mineral inclusions, and pedological characteristics, were described in the field and constitute the components of the lithofacies. Additional data were provided by soundings and drillings executed by the Geotechnics Division (Department of Mobility and Public Works, Flemish Government) and through exposures in archaeological excavation pits.

To optimize data processing, each boring was initially defined according to a series of lithofacies. However, since not all data contained information about sedimentary structures and bedding planes, some of the defined lithofacies are in fact a set of lithofacies in the sense Miall (1996) described them. In the frame of reconstructing the sedimentary environments, the genetically associated lithofacies were grouped as units, each of them standing for a depositional element.

The chronological framework is based on radiocarbon and OSL dating, dendrochronology, and the results of the archaeological surveys and excavations. Radiocarbon dating was carried out on bulk samples, seeds from terrestrial plants, wood fragments as well as charcoal from geological and archaeological borings and archaeological excavation pits. Since little was known about the age of the dunes along the River Scheldt in Belgium, five samples for OSL dating were taken in a pit of ca. 280 cm deep, dug in the neighbourhood of Aard (Schellebelle) (Fig. 5). This location was chosen because of the preserved dune morphology there, when comparing historical topographic maps with the current topography.

Samples for palaeo-ecological analyses were taken from channel and alluvial deposits using hand augering and bulk sampling in the archaeological excavations.

3.Results

A total of six sedimentary units have been distinguished, five of which are of fluvial origin.

3.1. Unit I (Channel deposits)

3.1.1. Description

The common characteristics of this unit are the sand fraction, the presence of shell fragments and botanical remains. Through variations in bedding structures and composition two distinct subunits are defined. The top of this unit shows an irregular topography with differences in height of up to 7 m (Fig. 2).

-The first subunit consists of slightly glauconitic, fine, less commonly medium sand; which are horizontally to subhorizontally stratified, and contain clayey or silty laminae or thin beds with both gradual and distinct bounding surfaces. The fine clastic deposits are occasionally rich in organic matter.

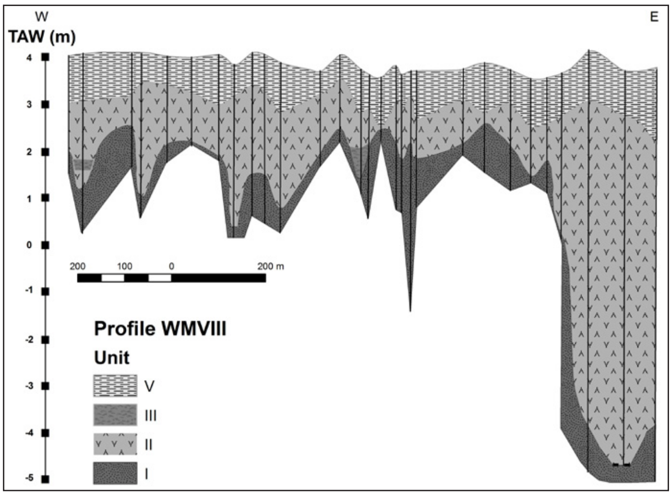

Figure 2. Schematic cross section of the Wijmeers 2 area. Note the well-developed ridge and swale topography of unit I. The base of unit I does not correspond with the lower bounding plane. Unit II is deposited in the channel as well as on the floodplain.

-The second subunit is typified by simple bedsets consisting of slightly glauconitic sand with similar grain sizes as described above. Because of the water saturated nature of the sediments no sedimentary structures could be observed in the field. Within this subunit finer grained zones are frequently present.

Detailed topographical mapping, as a result of archaeological borehole surveying and geophysical research, show an undulating topography, often composed of ridges and small depressions.

In the top of both subunits a primary stage of soil development as well as vertically oriented vegetation remains are often present. Shell fragments are dominated by Bithynia tentaculata and Valvata piscinalis.

3.1.2. Interpretation

This unit is composed of channel deposits. However, as sedimentary structures and bounding characteristics were not always visible, a subdivision into different channel elements (cf. Miall, 1996) was not possible for a number of borings. Unit I encloses primarily lateral accretion elements (point bar deposits), as well as channel elements consisting of sandy channel fills and benches. Some point bars possess a well pronounced ridge and swale topography, which are partly still visible on Lidar derived elevation models (Fig. 1). A variety of facies associations within the point bar deposits is observed and is in accordance with the findings of Bernard & Major (1956), Harms et al. (1963), Mc Gowen & Garner (1970), Bluck (1971), Singh (1972), Jackson (1976), Nanson (1980) and Bhattacharya (1997). The prevalence of lateral accretion deposits linked with one dominant channel is indicative of a migrating meandering river system.

Archaeological prospection showed the presence of numerous finds ranging from the Early Mesolithic to the Early Bronze Age, which were all situated on top of this unit (Bats, 2005; Bats et al., 2006; Bats & De Rue, 2006 and Perdaen et al., 2008, 2009).

3.2. Unit II (Fine clastic/organic channel fill and floodplain deposits)

3.2.1. Description

This unit differs from unit I by both its fine grained texture, clay or silt, and the presence of organic matter, most frequently accumulated in situ. The fine grained clastic sediments usually have a simple structure, although in some localities composite bedsets with sandy or organic laminae or layers are present. Within the clayey deposits, vivianite rich levels as well as zones with a friable structure are observed. Shell fragments and plant remains, the latter sometimes in a vertical position, occur in the clastic sequence. The composition of the organic matter diverges from peat to organic mud. The degree of decomposition of the organic matter varies from weakly putrefied with a large concentration of wood and other plant remains to amorphous clastic deposits with the organic material totally perished. However, an organic-mineral mixture dominates the unit. Calcium carbonate nodules and tufas are found in both the organic and the clastic deposits but are, with a few exceptions, never dominant.

The compound structure of this unit creates complex sequences, although a broad-stratigraphic arrangement is observed. Clastic sediments are dominant in both the basal and upper parts, while organic rich deposits prevail in between.

3.2.2. Interpretation

Unit II predominantly is a channel fill deposit, accumulating in the main channel as well as in local channels, and finally extending beyond the confines of these channels forming floodplain deposits. Unit II is a depositional unit generated during a tranquil hydraulic regime characterized by slack or slow moving water, as indicated by the presence of pollen from Myriophyllum spicatum, M. verticillatum, Nuphar, Nymphaea and Potamogeton (Perdaen et al., in press). In some restricted sections of the study area the accumulation of organic deposits started during the Late Glacial (Table 1), in the form of organic muds (gyttja). Radiocarbon dating indicates that peat growth started, on a regional scale, from the second part of the Preboreal onwards (Table 1). The presence of clastic sediments within the organic facies demonstrates a continuation, although limited, of regional water input. In a general sense the river activity did not have a negative impact on the maintenance of organic sedentation; only local gully relocations interrupted temporary the peat formation. As the channel infilling was for its greatest part complete, the deposition of fine clastic sediments extended beyond the confines of these channels. The gradual rise of the groundwater in combination with channel gradient reduction stimulated organic accumulation on the floodplain. The oldest radiocarbon ages of peaty sediments within this extended floodplain in the study area are 4020 ± 30 a BP and 4310 ± 40 a BP (Table 1). Pollen analysis of the base of the fill of a point bar swale shows a reduction of arboreal pollen in the area during this period (Perdaen et al., in press). Radiocarbon dates from the top of this Unit II demonstrate that the accretion of organic rich deposits stopped in the Subboreal (Table 1).

3.3. Unit III (Local channel deposits)

3.3.1. Description

In contrast with previous units, the extension of this unit is both lateral and vertical restricted. The dominant grain size is sand, varying from very fine to medium fine, with admixtures of silt or clay in different quantities along the sequence, sometimes resulting in a multistoried succession. The sediments are slightly glauconitic. The depositional features belonging to this unit most often have an erosional base except those with a sheet-like constitution. The stratification is either indistinct, usually in combination with a scarce amount of organic material, or very pronounced. The latter type was present and studied in detail in one of the archaeological test pits. There, the majority of the sandy facies enclose organic rich and/or clastic laminae or layers. According to the classification of Campbell (1967) the laminae have a slightly wavy continuous and discontinuous shape. Their lower boundaries are regularly marked by root traces. If the rhythmic arrangements are made up of layers, these layers have a concave up geometry in the basal part, often with a diminishing curvature towards the top. The sand layers are internally stratified by predominantly discontinuous wavy laminae, rich in organic debris. Organic remains, of different dimensions, are also scattered all over the sand layers. Deformation as well as bioturbation structures are common.

The stratigraphic relations between these local channel bodies in the Wijmeers 2 area indicate that these local channels are to be contributed to different chronological stages and fluvial systems. A number of shallow crevasse gullies and crevasse splay deposits erode or cover a system of older gullies, the latter in general narrower and deeper.

3.3.2. Interpretation

Unit III consists of infilling deposits within local channels, small chute channels or crevasses, the latter sometimes extending into crevasse splays. Generally, unit III is the result of fluvial activity restricted in time as well as in space. In the Wijmeers 2 area relicts of numerous small channels are observed in the subsurface. On the one hand their characteristics and the uniform sedimentological properties of the infilling sediments are indicative of the presence of a small multiple-channel system (an anabranching river system, according

Lab. No	**Site**	**Depth m TAW**	**^{14}C a BP**	**Cal. 2σ**
Oldest deposits				
Beta 245742	Kalkense Meersen KM08A	- 1.78 m	10,410 ± 60	12650 – 12050 BP
Beta 245743	Kalkense Meersen KM08A	- 2.23 m	10,910 ± 60	12950 – 12820 BP
Beta 245744	Kalkense Meersen KM08A	- 2.68 m	11,120 ± 60	13180 – 12900 BP
General start of peat accumulation within the channel				
Beta 260286	Bergenmeersen 1635	- 2.35 m	9450 ± 50	11050 – 11040 BP 10780 – 10570 BP
Beta 245740	Kalkense Meersen 7.4	-1.17 m	8350 ± 50	9480 – 9260 BP
Beta 245738	Kalkense Meersen 6.2	-0.35 m	8420 ± 50	9530-9400 BP 9360 – 9320 BP
Beta 245734	Kalkense Meersen 2.2	+ 0.63 m	7910 ± 50	8990 – 8590 BP
General start of the peat accumulation on the floodplain				
KIK 39412	Wijmeersen WME-23	+ 1.9 m	4020 ± 30	2620 - 2470 BC
Beta 260286	Bergenmeersen 1605	+ 0.48	4310 ± 40	4960 - 4830 BP
End of the peat accumulation on the floodplain				
Beta 245737	Kalkense Meersen 6.1	+ 1.38 m	3750 ± 40	4240 - 3980 BP
KIK 39416	Kalkense Meersen KM08A	+ 1.5 m	4010 ± 40	2840 – 2810 BC 2640 - 2460 BC
Beta 245739	Kalkense Meersen 7.1	+ 2.28 m	2170 ± 40	2320 – 2050 BP

Table 1.
AMS radiocarbon dates, according their stratigraphic position.

to the definition by Nanson & Knighton, 1996). On the other hand a number of crevasse gullies or crevasse splay deposits are more probably related to fluvial activity originating from a meandering River Scheldt. Organic matter present in the lower part of the channel fill, observed in an archaeological test pit, is dated 1850 ± 30 a BP (KIA 39410) while an oak (Quercus sp.) trunk from the base of the channel was dated by dendrochronology between 85 AD and 104 AD (calendar years). The presence of numerous Roman artefacts indicates that the aggradation of this channel was already complete by the end of the 2nd century AD. Pollen records show an almost treeless landscape in this part of the alluvial plain during this period (Meylemans et al. 2009; in prep.).

The same archaeological test pit also provides chronological insights in the development of the locally extensive crevasse splay ‘lobes’, present in both the Wijmeers 2 and the Bergenmeersen areas. On top of these deposits a number of Roman features and artefacts from the 2nd century AD are present, showing that the crevasse activity is to be situated before this period.

3.4. Unit IV (Lateral accretion deposits)

3.4.1. Description

The sedimentological properties of unit IV are very similar to those of unit I. Again two subunits are recognized. The first one consists of fine to medium fine slightly glauconitic sand, intercalated with laminae and layers up to 20 cm of mud, plant remains, or a combination of both. The degree of decomposition of the plant remains varies. The fine clastic sediments contain both complete and fragmented shells. The second subunit has a homogeneous sandy structure. Nevertheless differentiations in the grain size distributions are common as a result of variations in both the sand fractions and the presence or absence of a mud admixture. This unit always has an erosive lower boundary, accentuated in some places by a concentration of medium sand, broken shells and other residue.

3.4.2. Interpretation

The sedimentological characteristics of this unit point to lateral accretion (point bar) deposits. These deposits are related both to local channels within the alluvial plain (Fig. 3) and the main channel; the River Scheldt. Point bar deposits directly related to the River Scheldt are however only observed in the Bergenmeersen area. In the rest of the study area the channel of the current river Scheldt has remained relatively stable after its incision. Radiocarbon dating of plant macrofossil remains from the lower part of these point bar deposit associated with the channel present in one of the archaeological test pits (supra) gives an age of 2460 ± 25 a BP (KIA 33609).

3.5. Unit V (Floodplain deposits)

3.5.1. Description

Unit V is for most of the area the outcropping unit and is described in the field as an unstratified clay showing a disrupted homogeneity in the basal part because of the presence of discontinuous laminae or spots of sand and/or shell grit. Very specific for this unit are iron oxide precipitants, mainly concentrated at the base, and mottling features. Plant remains are almost absent, except at the top where they are linked to the present vegetation. Charcoal fragments are frequently observed, as well as complete and fragmented shells. Large variations in thickness typify this unit.

3.5.2. Interpretation

This unit is a floodplain deposit of which the variability of its thickness is determined by the location along the river, the floodplain morphology and the position on the floodplain. The restriction of sandy intercalations to the basal part may be ascribed to a reduction of the flood strength through time whereas the iron oxide and mottling features are indications of a temporary well-drained floodplain. In relation to unit II, this unit has a much greater lateral extend (Fig.4).
Archaeological features and objects from different periods are found within this unit. In the north of the Wijmeers 2 area Roman ceramics were found in the basal part of this unit, while a shallow pit feature containing a charcoal concentration, also in the Wijmeers 2 area, is dated 1560 + 40 a BP (Bèta276412) (Meylemans et al., in prep.). In the northern part of the Bergenmeersen the clay deposit must be younger since charcoal fragments associated with iron slag, situated on the point bar deposits present underneath this unit, are dated 1240+40 a BP (Bèta263625). The aggradation of this unit is expected to have ended in the 12th century AD with the construction of an extensive dike system, as described by historical sources.

3.6. Unit VI (aeolian deposits)

3.6.1. Description

Contrary to most other units, this unit is still visible in the present-day topography. Elevations up to +16 m TAW are observed, although most are below +10 m TAW. The original morphology of this unit is highly

Figure 3. Cross section of point bar deposits associated with a local gully in the Wijmeers 2 area.

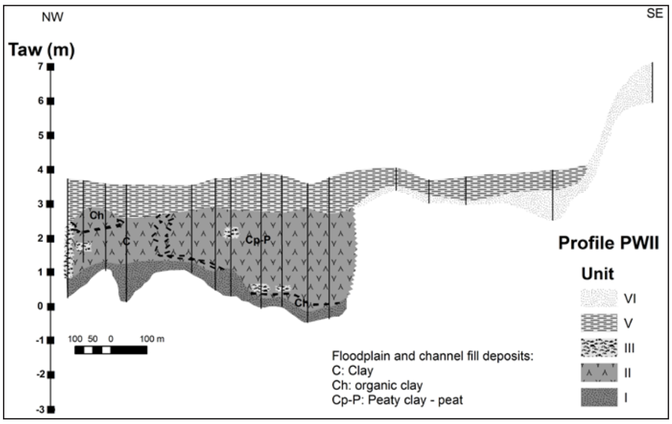

Figure 4. Schematic cross section in the Paardeweide area, with dune deposits bordering the floodplain of the Scheldt River. Note the enlarged lateral extension of the present day floodplain.

disturbed by sand exploitation for road constructions, and levelling due to tillage practices.

The exposed sequence showed slightly glauconitic, loosely packed sand with faint horizontal to very low-angled stratification. Illuviation bands are present all over the profile. In borings, executed in the surrounding area, the above described deposits contain in their lower section a small amount of silt, which in the still deeper part of the sequence changes into loamy intercalations.

3.6.2. Interpretation

The sedimentary characteristics of this unit are typical for aeolian deposits. Its morphology, or what is currently preserved, is associated with dunes. As in the study area all dunes are in general severely eroded, the initial dune type remains uncertain, although Heyse (1984) mentioned the presence of parabolic dunes bordering the Paardeweide area (Fig. 4). Peeters (1943), Gullentops (1957) and Verbruggen (1971) described all dunes along the Belgian rivers as being of the parabolic type. For a discussion concerning the age of the river dunes in Belgian we refer to Bogemans & Vandenberghe (2011). OSL dates from these deposits are clustered around a mean value of 12.0 ± 0.9 ka (Bogemans & Vandenberghe, 2011). Thus at least 1.5 m of sediment accumulated during a single event (i.e. within the given limit on the time-resolution) in the Late Dryas. On top of one of the ‘arms’ of the dune complex archaeological fieldwalking delivered a small number of artefacts which can probably be attributed to the final stages of the Late Glacial period.

4. Discussion

4.1. Evolution

Analogue to the observations in former studies of e.g. Huybrechts (1985,1989), Kiden (1989a, 1991) a single-channelled river dominated the fluvial environment (Fig. 5). It created well-developed but irregular meander bends. The formation of chute channels, chute cut offs as well as avulsions were part of this river system. Through migration of the main channel point bar sediments were deposited (unit I), most often resulting in a distinct scroll bar morphology. These within channel deposits form, in exception of the Wijmeers 1, the basal post pleni - Weichselian deposits in the study area.

The exact date for the incision of this river system is not clear, either during the Late Glacial, or in the transitional stage from the pleni - Weicheselian to Late Glacial period. Nevertheless, it was prior to the Alleröd since the earliest infilling deposits in the area are dated from this period. Indeed, during the Alleröd the landscape evolved from a non-forested to a forested one. The water balance changed through which the water discharge in the river diminished. On a local scale channel infilling started, initially with gyttja.

The outcropping dune complexes (unit VI) present at the edge of the alluvial plain, date from the Late Dryas. The age of these aeolian deposits is in agreement with results obtained in the Netherlands and neighbouring countries (e.g. Kasse, 1995, 2002; Isarin et al., 1997). Also in Flanders a growing dataset of OSL dates demonstrates that the Late Dryas period is characterized by intensive aeolian activity and the formation of dune complexes (Bats et al. 2010; Derese et al., 2010), but also intensive pre- Alleröd dune formation has been documented (Derese et al., 2009). Since the samples for OSL dating were taken neither at the top nor at the base of the dune deposits, it is possible that the sediment accumulation on the one hand started earlier, on the other continued until the beginning of the Holocene.

As after the Late Dryas a dense forest was installed on the one hand the transpiration augmented and on the other hand the surface runoff declined. The discharge of the river decreased in such a way that vertical aggradation processes predominated the fluvial environment. Beside, fluvial activity further decreased resulting in the accumulation of fine clastic deposits (unit II) in both the local and regional channels. From the second part of the Preboreal

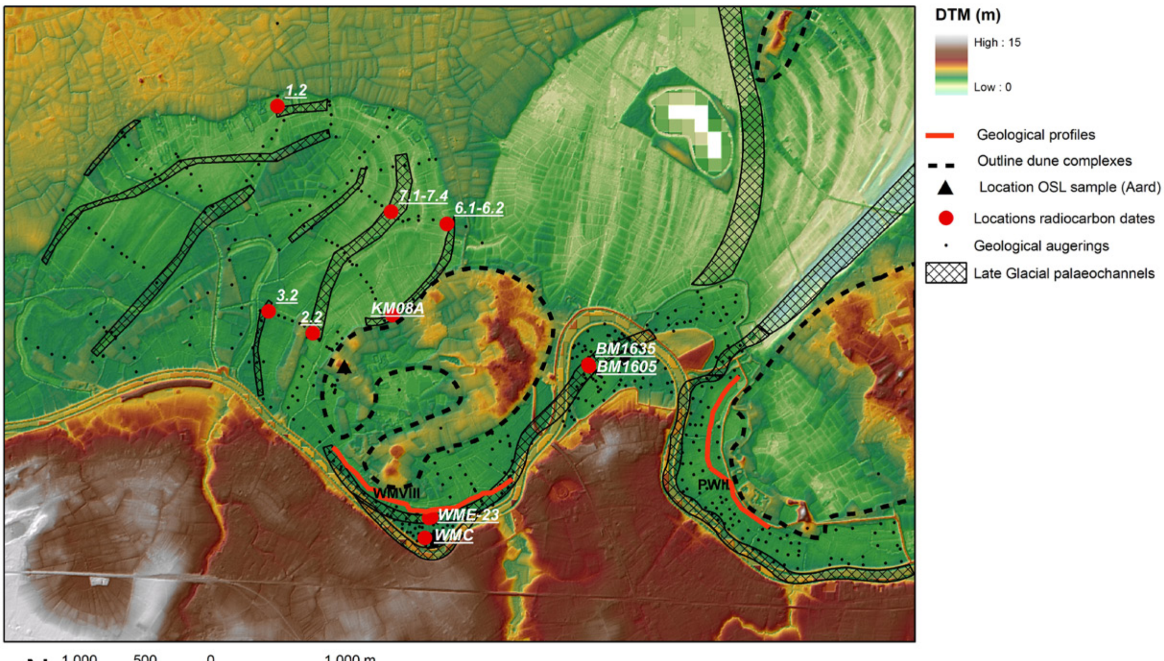

Figure 5. DTM of the study area with indication of mapped stretches of palaeochannels: the main channel but also the remains of chute channels and channels belonging to a counter point bar, the latter ones especially in the Kalkense Meersen area. The position of the channel in the north-eastern part is based on De Coster (1977).

onwards organic accumulation (also unit II) started to replace clastic deposition, a fact that is also observed in former studies. The River Scheldt transformed into an underfit river confined within its Late Glacial meandering channel. In this channel only a rivulet remained. Peat formation became the dominant process in the remainder of the channel, occasionally interrupted by the deposition of clastic matter. While the aggradation progressed, sea level rise had an indirect impact on this part of the River Scheldt from the late Atlantic onwards (Verbruggen et al., 1991; Kiden & Verbruggen, 2001). The vertical aggradation accelerated within the confines of the Late Glacial channel and extended beyond its borders at least at the beginning of the Subboreal period, as indicated by radiocarbon dating. This resulted in an extended swampy alder carr forest. Within this environment no major contemporary watercourse has been observed. However, although generally assumed by Mijs et al., (1983), Mijs (1986), Kiden (1989a & b, 1991), Kiden & Verbruggen (2001), the presence of an anabranching system replacing such a single channel fluvial system is only proven in the Wijmeers 2 area, where these channels are characterized by sandy infillings(incorporated in unit III). In the other studied areas the existence of an anabranching river system within this palaeoenvironment remains a hypothesis.Radiocarbon dating indicates a strong decline and most often a cessation of the accumulation of organic matter during the Subboreal – not considering the slightly organic mud deposits as organic deposits.

Our insights in the events taking place in the early stages of the Subatlantic period are for the most part based on the observations in the archaeological test- pit in the Wijmeers 2 area. These indicate the incision of a dynamic local gully system, possible crevasses, developing some point bars (unit IV). The incision of this gully system, as the incision of the new River Scheldt which is to be considered its source, is to be dated somewhere around the transition from the Subboreal to the Subatlantic period (infra).The sedimentary properties show a rather stable meandering River Scheldt with minor lateral migration, for example in the Bergenmeersen area. Vertical accretion of clastic sediments on the floodplain remained the foremost sedimentological process interrupted by local break-troughs, thus resulting in crevasse gullies and –splays (unit III) . Several of these sandy lobes are present in both the Wijmeers 2 and Bergenmeersen areas. Pollen records indicate that in the Early Subatlantic period (Iron Age) the alluvial plain was already partly deforested.

In the Roman period, at least from the 2nd century AD onwards, the alluvial plain seems to be at least a periodically well drained environment, allowing intensive Roman exploitation of the alluvial plain, as indicated by archaeological finds and pollen records. The priory deposited crevasse lobes became ‘high and dry’ areas within the alluvial plain, allowing settlement. The migration of crevasse gullies also ends, and the aggradation of these channels starts. From the 3rd century onwards this aggradation was also completed, and the lateral expansion of the alluvial plain through aggradation of fine clastic deposits (Unit V) becomes the dominant process (Meylemans et al., in prep.).

The chronology of the built up of this clay cover seems to indicate strong local differences. While in the Wijmeers 2 area it started in the Roman period, continuing at least to the 6th century AD, in the Bergenmeersen it seems that, at least in part, this expansion is to be situated from the 9th century AD onwards.

Although the lower course of the River Scheldt and its main tributaries became tidally influenced from about 1100 AD (Snacken, 1964; Mijs, 1981; Kiden, 1989, 2006), no sedimentological evidences of this phenomenon are observed, as an extensive network of dikes installed from the 12 – 13th century onwards prevented further fluvial/estuarine influence in the alluvial area of the cluster of the Kalkense Meersen.

4.2. The Late Glacial Dune formation

Contrary to the Dutch rivers (e.g. Berendsen et al., 1995; Huisink, 1997, 2000; Kasse et al., 2005), the channel pattern of the River Scheldt remained unchanged in the Late Dryas period. In the Netherlands large parts of the braided rivers provided the sand necessary for the dune construction during low water periods. The maintenance of the meandering river system does not necessarily exclude dune formation. Observations in periglacial areas by Dijkmans & Koster (1987) show that meandering rivers, although fast migrating and with great discharge fluctuations, may indeed function as important source areas for aeolian sediments. Exposed point bars during low water stages constitute the source for this process. According to the same authors, different types of parabolic dunes are formed as the result of limited sand supply and scarce vegetation. Besides, point bars are, with their undulating topography, outstanding places for the accumulation of aeolian deposits (e.g. Bernard & Major, 1956; Harms et al., 1963), more particular in the swales where the moist to wet state of the surface prevents redistribution of the sand particles. Since point bar deposits most probably acted as sources in the study area, the presence of a silt/loam fraction within unit VI is not surprising. On the one hand experiments reveal that the fine grained admixture in sand deposits results from a simultaneous dumping of all fractions present in a basal flow which glides over the dune surfaces during deflation periods (De Ploey, 1977). On the other hand, although loamy intercalations are described, as typical for pleniglacial aeolian sediments, Schwan (1988) and Kasse (2002) observed similar deposits of Late Dryas age and associated their presence with moist conditions present at the base of dunes.

4.3. A change in hydrological conditions during the Subboreal/Subatlantic transition, and the incision of the ‘new River Scheldt’

Verbruggen et al. (1991) indicated a significant anthropogenic deforestation from 4000 a BP which intensified through time. As deforestation continued, the water balance and soil hydrology became further disrupted (Mullenders et al., 1966; Huybrechts, 1985, 1989, 1999; Verbruggen et al., 1991). Consequently a flood regime was installed, the organic accumulation was pushed back and clastic sediments became the predominant building material of the alluvial plain (upper part of unit II).

The date of the change in fluvial style from an anabranching pattern of small and shallow gullies to the incision of the ‘new River Scheldt’ is traditionally believed to occur somewhere ‘before the Roman period’ (Kiden, 1991). The 14C date obtained from plant remains within the point bar sediments of a crevasse gully associated with this new River Scheldt provides a t.a.q. of the ‘Halstatt plateau’ date of 760-410 cal BC for this incision. It is tempting to assume that this major change in fluvial regime took place during the transition of the Subboreal to the Subatlantic period. This timeframe is associated with a general shift to a colder and wetter climate throughout NW Europe at ca. 800 cal BC, as derived from numerous climatic proxi data (e.g. Van Geel et al., 1996; Van Geel & Renssen, 1998). In the upper Rhine area this transition period is also believed to have caused river incision and meander formation (Dambeck & Thiemeyer, 2002).

Although more data concerning this topic in the Scheldt valley is certainly needed, the results obtained from point bar sediments of the crevasse gully excavated in the Wijmeers 2 area do suggest that the incision of the new River Scheldt, and in general an intensification of fluvial activity, dates within this transitional period.

4.4 Changing hydrological conditions in the Roman period

In the central river area of the Netherlands a pattern of major changes in the river courses occurs in the 3th century AD. This includes abandonment and aggradation of older river channels by the end of the Roman period, and floodplain sedimentation near the new channels mainly from 250 AD onwards. Human occupation is only found associated with the older channel system. During the Roman period a simultaneous pattern of ‘wet’ and ‘dry’ conditions is observed, depending on local geomorphological conditions. In general however, there seems to be evidence through pollen analysis of peat bogs in pingo remnants for a ‘dry’ Roman period, followed by a wetter period between approximately 200 and 450 AD. This possible climatic change at ca. 200 AD might account for the change in river pattern, with wetter conditions provoking higher discharges and new river incisions (Berendsen, 1990). These data seem to accord with the evolution visible in the Wijmeers 2 area. This is invoked by the intensive 2nd century AD exploitation of the alluvial plain, when the previously deposited crevasse lobes formed dry outcrops. Further evidence demonstrate wetter conditions, with the aggradation of relic channels and the expansion of the alluvial plain, commenced from the 3rd century AD onwards. In general an intensification of overbank deposition from the Roman period onwards is witnessed in a large number of areas throughout Europe (for example Wojcicki, 2010).

5. Conclusion

This study shows that in the cluster of the Kalkense Meersen the alluvial plain of the River Scheldt contains a diverse archive of sedimentological, ecological and archaeological features. The reconstruction of the sedimentary palaeo-environments shows that the Late Glacial River Scheldt was a migrating river creating large meanders. No sedimentological indications are present to sustain a change in channel pattern during the cold phases of the Late Glacial as described in the neighbouring countries. Yet, there is an agreement with regard to dune formation during the Late Dryas. From the beginning of the Holocene onwards regional fluvial activity diminished and vertical accretion, both with clastic and organic matter, became predominant. The River Scheldt turned into an underfit stream which evolved, at least locally, to an anabranching river. However, before the Roman period, hydraulic conditions changed in such a way that the River Scheldt transformed into a single-channel river with low to intermediate sinuosity. Vertical accretion nevertheless remained the major sedimentation process, extending the floodplain laterally. This meandering river became subjected to a tidal regime from about 1100 AD onwards, but the impact on the natural environment was strongly reduced due to dike constructions.

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7. References

Bats, M., 2005. Prospectief booronderzoek in de Kalkense Meersen (prov. Oost-Vlaanderen, België). Notae Praehistoricae, 25, 203-207.

Bats, M., Bastiaans, J. & Crombé, P., 2006. Prospectie en waardering van alluviale gebieden langs de Boven-Schelde. CAI-project 2003-2004. In Cousserier, K., Meylemans, E. & 'T Ven, I. (ed.), CAI-II. Thematisch inventarisatie- en evaluatieonderzoek. VIOE Rapporten 2, Brussel, 75-100.

Bats, M.& De Reu, J.,2006. Evaluerend onderzoek van boringen in de Kalkense Meersen (Oost-Vlaanderen, België). Notae Praehistoricae 26, 171-176.

Bats, M. et al., 2010. Continued geoarchaeological research at the Moervaart palaeolake area (East Flanders, Belgium): prelimenary results. Notae Praehistoricae, 30, 15-21.

Berendsen, H.J.A., 1990. River courses in the Central Netherlands during the Roman Period. Berichten van de Rijksdienst voor het Oudheidkundige Bodemonderzoek. 40:243-249.

Berendsen, H.J.A., Hoek, W.Z. & Schorn, E.A., 1995. Late Weichselian and Holocene River Channel Changes of the Rivers Rhine and Meuse in the Central Netherlands (Land van Maas en Waal) European river activity and climate change during the Lateglacial and early Holocene. Paleoclimate Research, 14, 151-171.

Bernard, H.A. & Major, C.F., 1956. Sedimentary features diagnostics of alluvial point bar sands. EPR (Exploitation and Production Research) Memorandum report, 23.

Bhattacharya, A., 1997. On the origin of non-tidal flaser bedding in point bar deposits of the river Ajay, Bihar and West Bengal, NE India. Sedimentology, 44, 973-975.

Bluck, B.J., 1971. Sedimentation in the meandering River Endrick. Scottish Journal of Geology, 7, 93-138.

Bogemans, F., 1993. Quaternary geological mapping on basis of sedimentary properties in the eastern branch of the Flemish Valley. Memoirs of the Geological Survey of Belgium, 35.

Bogemans, F., Meylemans, E., Perdaen, Y., Storme, A. & Verdurmen, I., 2008. Paleolandschappelijk, archeologisch en cultuurhistorisch onderzoek in het kader van het geactualiseerde Sigmaplan, sigma-cluster Kalkense Meersen, zone Wijmeersen 2. Deel 2:bundeling rapportages deelonderzoeken. Intern rapport, Vlaams Instituut voor Onroerend Erfgoed (Brussel).

Bogemans, F., Jacops, J., Meylemans, E., Perdaen, Y., Storme, A. & Verdurmen, I., 2009a. Paleolandschappelijk, archeologisch en cultuurhistorisch onderzoek in het kader van het geactualiseerde Sigmaplan, sigma-cluster Kalkense Meersen, zone Wijmeersen 1. Intern rapport, Vlaams Instituut voor Onroerend Erfgoed (Brussel).

Bogemans, F., Jacops, J., Meylemans, E., Perdaen, Y., Storme, A. & Verdurmen, I., 2009b. Paleolandschappelijk, archeologisch en cultuurhistorisch onderzoek in het kader van het geactualiseerde Sigmaplan, sigma-cluster Kalkense Meersen, zone Bergenmeersen en Paardenweide. Intern rapport, Vlaams Instituut voor Onroerend Erfgoed (Brussel).

Bogemans, F. & Vandenberghe, D., 2011. OSL dating of an inland dune along the lower River Scheldt near Aard (East Flanders, Belgium). Netherlands Journal of Geosciences, 90-1, 23-29.

Campbell, C.V., 1967. Lamina, laminaset, bed and bedset. Sedimentology, 8, 7-26.

Cant, D.J., 1978. Development of a facies model for Sandy braided River sedimentation: comparison of the South Saskatchewan River and the Battery point Formation, In Miall, A.D. (ed.), Fluvial Sedimentology, Canadian Society of Petroleum Geologists, 627-639.

Cant, D.J. & Walker, R.G., 1976. Development of a braided fluvial facies model for the Devonian Battery Point Sandstone, Quebec. Canadian Journal of Earth Sciences, 13, 102-119.

Coen, I., 2008. De eeuwige Schelde? Ontstaan en ontwikkeling van de Schelde. Waterbouwkundig laboratorium, Borgerhout.

Dambeck, R. & Thiemeyer, H., 2002. Fluvial history of the Northern upper Rhine River (southern Germany) during the Lateglacial and Holocene times. Quaternary International.93-94,53-63.

De Coster, R., 1977. Bijdrage tot de kennis van de geomorfologische evolutie van de oude Scheldemeander te Berlare, Onuitgegeven Licentiaatverhandeling, UGent.

De Coster, R., 1982. Evolutie van de oude Scheldemeander te Berlare. De Aardrijkskunde, 4, 317-332.

De Moor, G., 1963. Bijdrage tot de kennis van de fysische landschapsvorming in Binnen-Vlaanderen. Bulletin de la Société belge d'Etudes Géographie, 32, 329-433.

De Moor, G., 1974. De afzetting van Dendermonde en haar betekenis voor de jong kwartaire evolutie van de Vlaamse Vallei. Natuurwetenschappelijk Tijdschrift, 56, 45-75.

De Moor, G. & Heyse, I., 1978. De morfologische evolutie van de Vlaamse Vallei, De Aardrijkskunde, 4, 343-375.

De Moor,, G. & Pissart, A., 1992. Het Reliëf. In Denis J. (ed.) Geografie van België, Brussel.129-215.

De Mulder, F.J., Geluk, M.C., Ritsema, I., Westerhoff, W.E. & Wong, Th.E. (eds) 2003. De ondergrond van Nederland, Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek TNO.

De Ploey, J., 1977. Some experimental data on slopewash and wind action with reference to quaternary morphogenesis in Belgium. Earth Surface Processes, 2, 101-115.

Derese, C., Vandenberghe, D., Paulissen, E. & van den Haute, P., 2009. Revisiting a type locality for Late Glacial aeolian sand deposition in NW Europe: Optical dating of the dune complex at Opgrimbie (NE Belgium). Geomorphology, 109, 27-35.

Derese, C., Vandenberghe, D. .A.G., Zwertvaegher, A., Verniers, J., Crombé, P. & van den Haute, P., 2010. The timing of aeolian events near archaeological settlements around Heidebos (Moervaart area, N Belgium), Netherlands Journal of Geosciences, 89:173-186.

Dijkmans, J.W.A. & Koster, E.A., 1987. Eolische verschijnselen in (actuele) periglaciale milieu's. K.N.A.G. Geografisch Tijdschrift, XXI, 152-167.

Gullentops, F., 1957. L'évolution du relief depuis la dernière glaciation. Bulletin de la Société Belge d'études Géographiques, XXVI, 1,71-87.

Harms, J.C., Mackenzie, D.B. & Mccubbin, D.G., 1963. Stratification in modern sands of the Red River, Louisiana. Journal of Geology, 71, 566-580.

Heyse, I., 1984. Geomorphologische typekartering van de Vlaamse Vallei. Nationaal Centrum voor Geomorphologisch Onderzoek, Werkstukken, XXIV, 123-132.

Huisink, M., 1997. Late-glacial sedimentological and morphological changes in a lowland river in response to climate change: the Maas, southern Netherlands. Journal of Quaternary Science, 12, 209-223.

Huisink, M., 2000. Changing river styles in response to Weichselian climate changes in the Vecht valley, eastern Netherlands. Sedimentary Geology, 133, 115-134.

Huybrechts, W., 1985. Morfologische evolutie van de riviervlakte van de Mark (Geraardsbergen) tijdens de laatste 20.000 jaar. Onuitgegeven doctoraatsverhandeling, VUB Brussel.

Huybrechts, W., 1989. Palaeohydrologic conditions in the Mark River Basin during the last 15 000 years. Geologie & Mijnbouw, 68, 175-187.

Huybrechts, W., 1999. Post-Pleniglacial floodplain sediments in Central Belgium. Geologica Belgica, 2, 29-37.

Isarin, R.F.B., Renssen, H. & Koster, E.A., 1997. Surface wind climate during the Younger Dryas in Europe as inferred from aeolian records and model simulations. Palaeogeography, Palaeoclimatology, Palaeoecology, 143, 127-148.

Jackson II, R.G., 1976. Depositional model of point bars in the lower Wasbash river. Journal of Sedimentary Petrology, 46, 579-594.

Kasse, C., 1995. Younger Dryas cooling and fluvial response (Maas River, the Netherlands). Geologie & Mijnbouw, 74, 251-256.

Kasse, C., 2002. Sandy aeolian deposits and environments and their relation to climate during the Last Glacial Maximum and Lateglacial in northwest and central Europe. Progress in Physical Geography, 26, 507-532.

Kasse, C. et al., 2005. Late Glacial fluvial response of the Nierse-Rhine (western Germany) to climate and vegetation change. Journal of Quaternary Science, 20, 377-394.

Kiden, P., 1989a. Temse en de Schelde: de geomorfologische achtergrond In Thoen, H. (ed.) Temse en de Schelde: Van IJstijd tot Romeinen, Brussel, Gemeentekrediet, 13-27.

Kiden, P., 1989b. The Late Holocene evolution of the Perimarine part of the River Scheldt. In Henriet, J.P. & De Moor, G. (eds), The Quaternary and Tertiary geology of the Southern Bight, North Sea. Ministerie van Economische Zaken, Belgische Geologische Dienst, Brussel, 173-184.

Kiden, P., 1991.The Late-glacial and Holocene evolution of the Middle and Lower River Scheldt, Belgium. In Starkel, L., Gregory, K.L. & Thornes, J.B. (eds). Temperate Palaeohydrology, London, 283-299.

Kiden, P., 2006. De Laatglaciale Schelde in Nederland. Belgeo, 3, 279-294.

Kiden P. & Verbruggen, C., 2001: Het verhaal van een rivier: de evolutie van de Schelde na de laatste ijstijd. In Bourgeois, J., Crombé, Ph, De Mulder, G. & Rogge, M. (eds), Een duik in het verleden Schelde, Maas en Rijn in de pre- en protohistorie. Publicaties van het PAMZOV-site Velzeke, Gewone reeks nr. 4, Zottegem, 11-35.

MC Gowen, J.H. & Garner, L.E., 1970. Physiographic features and stratification types of coarse-grained point bars: Modern and ancient examples. Sedimentology, 14, 77-111.

Meylemans, E., Perdaen, Y., Bogemans, F., Storme, A. & Verdurmen, I., 2009. Prospectief en evaluerend onderzoek in het kader van het Sigmaplan: een intensieve exploitatie van de alluviale zone van de “Wijmeersen” (Schellebelle, Oost-Vlaanderen) in de midden Romeinse periode. Romeinendag – Journée d’archéologie Romaine, Brussels,53-59.

Meylemans, E. et al., in prep. Een intensieve exploitatie van de ‘wetlands’langs de Schelde in de Romeinse periode in de Wijmeersen (gemeente Schellebelle, Oost-Vlaanderen), Relicta.

Miall, A.D., 1977. A review of the braided river depositional environment. Earth Science Review, 13, 1-63.

Miall, A.D., 1978. Lithofacies types and vertical profile models in braided river deposits: a summary, In Miall, A.D. (ed.) Fluvial Sedimentology, Canadian Society of Petroleum Geologists, 597-604.

Miall, A.D., 1996. The Geology of Fluvial Deposits. Springer-Verlag, Berlin.

Mijs, M., 1981. Geomorfologische landschapsdifferentiatie in de Scheldepolders ten noorden van Antwerpen. De Aardrijkskunde, ½, 303-314.

Mijs, M., 1986. Rivierevolutie in de omgeving van Berlare. De Aardrijkskunde, 4 257-266.

Mijs, M., Gullentops, F., Janssens, P., Wuytack, M.J. & Stinissen, H., 1983. De holocene evolutie van de alluviale vlakte van de Beneden-Schelde. Tijdschrift Belgische Vereniging voor Aardrijkskundige Studies, 1, 7-33.

Mullenders, W., Gullentops, F., Lorent, J., Coremans, M. & Gilot, P.M., 1966. Le remblaiement de la vallée de la Néthen. Acta Geographica Lovaniensia, 4, 169-181.

Nanson, G.C., 1980. Point bar and floodplain formation of the meandering Beatton River. Sedimentology, 27: 3-29.

Nanson, G.C. & Knighton, A.D., 1996. Anabranching rivers: their cause, character and classification. Earth Surface Processes and Landforms, 21, 217-239.

Paepe, R., 1971. De nieuwe sluis van Zemst. Geologie van het site der Sluis van Zemst. Excavator, 7-15.

Paepe, R. & Vanhoorne, R., 1967. The stratigraphy and palaeobotany of the Late Pleistocene in Belgium. Memoirs of the Geological Survey of Belgium, 8.

Paepe, R. & Vanhoorne, R., 1976. The Quaternary of Belgium in its relationship to the stratigraphical legend of the geological map. Memoirs of the Geological Survey of Belgium, 18.

Peeters, L., 1943. Les dunes continentales de la Belgique. Bulletin de la Société belge de Géologie, Paléontologie, Hydrologie, 52, 51-61.

Perdaen, Y., Meylemans, E., Bogemans, F., Storme, A. & Verdurmen, I., 2008. Prospectie- en evaluatieonderzoek in het kader van het Sigmaplan in de Wijmeersen (gem. Schellebelle, prov. Oost-Vlaanderen). Notae Praehistoricae, 28, 125-134.

Perdaen, Y., Meylemans, E., Jacops, J., Bogemans, F., Storme, A. & Verdurmen, I., 2009. Prospectie- en evaluatieonderzoek in het kader van het Sigmaplan, deel 2 . Notae Praehistoricae, 29, 121-129.

Perdaen, Y. et al.. in press: Op zoek naar prehistorische resten in de ‘wetlands’ van de Sigmacluster Kalkense Meersen Prospectief en evaluerend archeologisch onderzoek in het gebied Wijmeers 2, zone D/E (Wichelen, prov. Oost-Vlaanderen). Relicta.

Rust, B.R., 1978. Depositional models for braided alluvium. In Miall A.D. (ed.) Fluvial Sedimentology. Canadian Society of Petroleum Geologists, 187-198.

Schwan, J., 1988. The structure and genesis of Weichselian to Early Holocene aeolian sand sheets in Western Europe. Sedimentary Geology, 55,197-232.

Singh, I.B., 1972. On the bedding in the natural levee and the point bar deposits of the Gomti River, Uttar Pradesh, India. Sedimentary Geology, 7, 309-317.

Snacken, F., 1964. Verklarende tekst bij het kaartblad Sint-Niklaas 42W. Centrum voor bodemkartering, Gent.

Somme, J., Antoine, P., Cunat-Boge, N., Lefèvre, D. & Munaut, A.-V., 1999. Le Pléistocène moyen marin de la Mer du Nord en France: Falaise de Sangatte et Formation d’Herzeele. Quaternaire, 10, 151-160.

Tavernier, R. & De Moor, G., 1974. L’évolution du bassin de l’Escaut. In Macar, P., (ed.), L’évolution quaternaire des bassins fluviaux de la Mer du Nord Méridionale. Centenaire de la Société Géologique de Belgique, Liège, 159-231.

Van Geel, B., Buurman, J & Waterbolk, H. T., 1996. Archaeological and palaeoecological indications of an abrupt climate change in the Netherlands, and evidence for climatological teleconnections around 2650 BP. Journal of Quaternary Sciences, 11, 451-460.

Van Geel, B. & Renssen, H., 1998. Abrupt climate change around 2,650 BP in North-West Europe: evidence for climatic teleconnections and the tentative explanation. In Issar, A.S. & Brown, N. (eds)Water, Environment and Society in Times of Climatic Change.Kluwer, Dortrecht, 21-41.

Verbruggen, C., 1971. Postglaciale landschapsgeschiedenis van Zandig Vlaanderen. Onuitgegeven doctoraatsverhandeling, UGent.

Verbruggen, C. & Kiden, P., 1989. L’évolution postglaciaire du Bas et Moyen Escaut. Les Cahiers de Préhistoire du Nord, 6, 5-14.

Verbruggen, C., Denys, L. & Kiden, P., 1991. Paleo-ecologische en geomorfologische evolutie van Laag- en Midden-België tijdens het Laat-Kwartair. De Aardrijkskunde, 3, 357-376.

Vermeire, S., De Moor., G. & Adams,R., 1999. Quartairgeologische Kaart van België, Vlaams Gewest, Verklarende tekst bij het Kaartblad (22) Gent (1/50.000), Ministerie van de Vlaamse Gemeenschap, Brussel.

Wojcicki, K.J. 2010. The valley fill deposits of the Kłodnicka river (southern Poland): environmental drivers of facies changes from the Late Vistulian through the Holocene, Geochronometria, 35, 49-65.

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