From lake to swamp. A Lateglacial to Late Holocene soil archive from the Moervaart depression at Klein-Sinaai "Boudelo" (prov. of East Flanders, BE)

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1. *Introduction*

During the archaeological excavation in August 2011 of the outer court of the Cistercian abbey of Boudelo (De Smedt *et al.*, 2013), situated along the northern edge of the Lateglacial Moervaart palaeolake, an intact soil sequence of lacustrine sediments was revealed. Although very similar to the *master sequence* of Moerbeke "Suikerfabriek" located more towards the center of the Moervaart lake (Bos *et al.*, 2017, 2018a), the Klein-Sinaai "Boudelo" sequence provides new evidence on the post-glacial evolution of the Moervaart depression thanks to the presence of a ca. 50 cm thick peaty deposit covering the lacustrine sediments. This peat cover was locally preserved as it was protected by a sandy layer, deposited by the Medieval inhabitants of the site.

2. *Study area, site and excavation*

2.1. *Study area*

The Moervaart area, situated in the coversand lowland of the Lower Scheldt basin (Fig. 1a-c), is known for its numerous high-resolution and high-quality palaeoenvironmental archives dating to the Lateglacial and Early Holocene (Crombé *et al.*, 2011). It is characterised by a complex and dynamic palaeolandscape. The most important features of this region are (Fig. 1d): (1) the Great Coversand Ridge of Maldegem-Stekene (80 km long, locally 3 km wide, height 5-15 m a.s.l., average elevation ca. 3-4 m; De Moor & Heyse, 1978; Verbruggen *et al.*, 1996; Crombé *et al.*, 2012), including numerous shallow dune-slacks and ponds; (2) a large but shallow freshwater inland lake, i.e., the Moervaart palaeolake (ca. 25 km^2, length: ~15 km, width: ~2.5 km) immediately south of the Great Coversand Ridge (Heyse, 1979, 1983); and (3) a deep meandering palaeochannel of the Kale (upper course) or Durme (lower course) River, a tributary of the River Scheldt.

The area was intensively exploited during the Lateglacial and Early to Mid-Holocene, as indicated by the large number of prehistoric sites, dating from the Final Palaeolithic, ca. 14 000-13 000 cal BP), Mesolithic (ca. 10,700-6500 cal BP) and Neolithic (ca. 6500-4000 cal BP). Especially the high density of *Federmesser* Culture sites consisting of temporary campsites along the northern bank of the Moervaart palaeolake is striking (Crombé *et al.*, 2011, 2013, 2014). During the Mesolithic on the other hand, hunter-gatherers settled preferably along the dry banks of the meandering Kale/Durme River. However, the Neolithic period is still badly understood, but the numerous lithic finds of polished tools and arrowheads on almost every Mesolithic site tends to suggest continued exploitation during the 6th and 5th millennium cal BP (Van Vlaenderen *et al.*, 2007). Despite intensive research, there is surprisingly hardly any archaeological evidence from the Bronze Age until Medieval times, i. e. from ca. 4 000 cal BP untill the 12th century AD, not just along de Moervaart depression but also in the wider region to the south as far as the border of the Scheldt floodplain (Crombé *et al.*, 2011; In t' Ven & De Clercq, 2005). This lack of evidence is difficult to explain, given the fact that both to the east and the west of the Moervaart depression there are numerous (proto)historic sites, in particular concentrated on the Great Coversand Ridge Maldegem-Stekene (Van Neste, 2014), and on the sand-ridges closely lining the river Scheldt alluvium to the south (e. g. S. N., 2003). A possible explanation could be found in the ill-drained nature of the soils as well as in the lack of substantially extended sandy elevations south of the Moervaart depression, that would create suitable conditions for profitable farming (De Clercq & In 't Ven, 2005). In fact, historic and archaeological data are increasingly pointing to the existence of extensive forests in these areas that existed for ages. In Medieval times, the region in between the rivers Scheldt and Durme is known from written sources to have been an extended forest named the *nemus intra Scaldem and Dormam*, and further to the east of the Moervaart

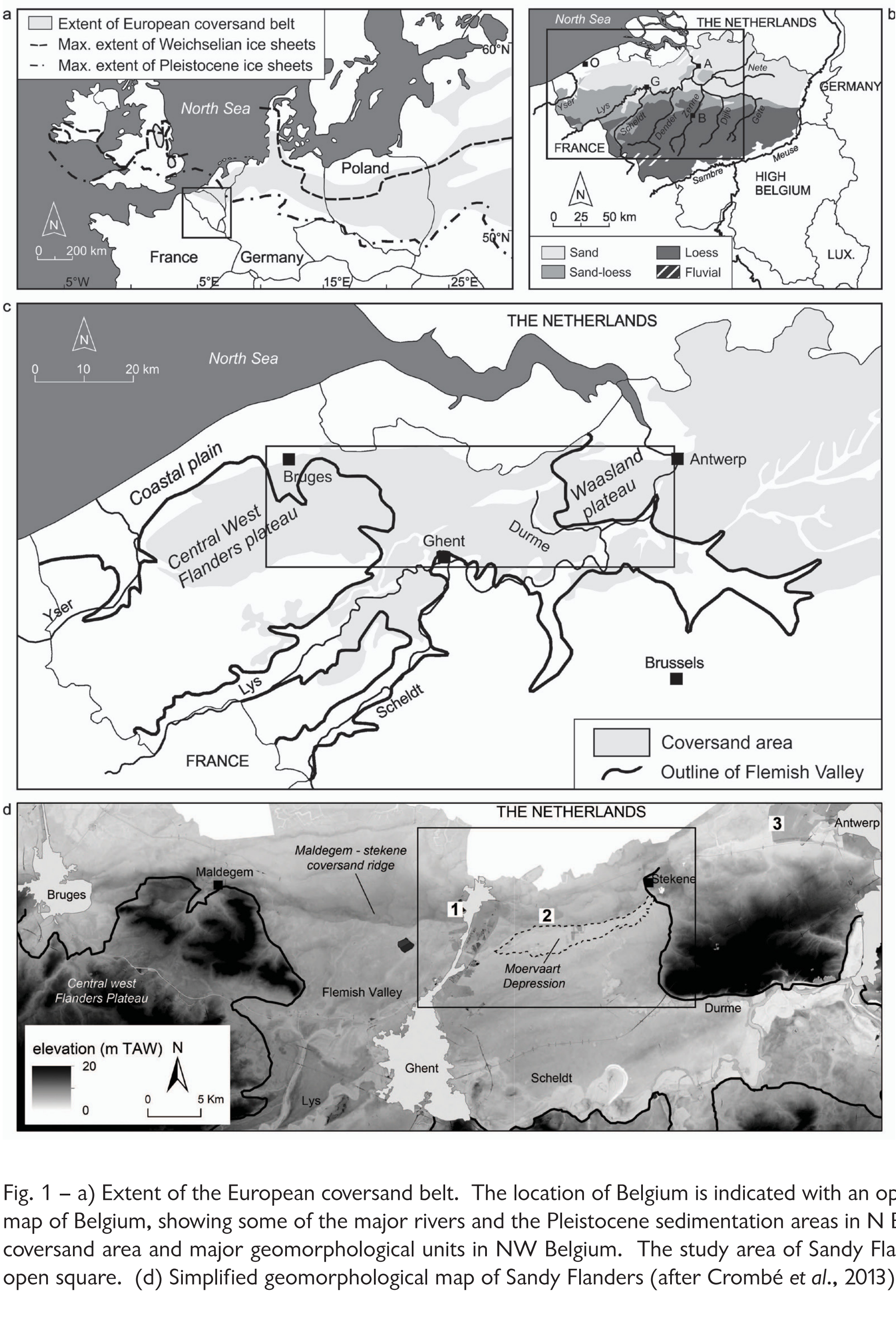


Fig. 1 – a) Extent of the European coversand belt. The location of Belgium is indicated with an open square. (b) Schematic map of Belgium, showing some of the major rivers and the Pleistocene sedimentation areas in N Belgium. (c) Extent of the coversand area and major geomorphological units in NW Belgium. The study area of Sandy Flanders is indicated with an open square. (d) Simplified geomorphological map of Sandy Flanders (after Crombé *et al.*, 2013).

the *Koningsforeest* (King's Forest) is mentionned as yet another important woodland area. To the west of the Moervaart and south of the Coversand Ridge Maldegem-Stekene the fringes of the *Heroaldolugo* forest are located (Tack *et al.*, 1993). Extensive archaeological and palaeo-ecological research at the Ghent harbour Kluizendok-project has indeed confirmed and demonstrated that this region was a densely forested low-lying area, that was only –moderately– logged and reclaimed in Roman times (in the 2nd century AD). In the early Medieval period the forest fully recovered, only to be exploited again by 1000 AD (Laloo *et al.*, 2009). The Moervaart depression itself obviously was not suited for permanent human occupation. It was reclaimed by the Boudelo-abbey for large-scale peat-extraction in Medieval times (Van Bocxstaele, 1978).

2.2. *Site and excavation*

During 2011 and 2012 and following extensive geophysical EMI-survey, two trenches were laid out at the outer court of the former Cistercian abbey of Boudelo at Klein-Sinaai (De Belie, 1997; De Smedt *et al.*, 2013; Dalle, 2014). The principal aim of this research was to gather *in situ* information on the nature, chronology and state of preservation of the anomalies observed in geophysical survey, features supposedly belonging to the outer court of the Medieval abbey. The excavation confirmed the Medieval (13th-14th century AD) date of the structures, consisting of moated enclosed platforms with brick architecture on top, and the southernmost part of the abbey's main enclosing moat. While the abbey's principal court is located on a coversand ridge, the adjacent outer court was located in the northernmost part of the Moervaart depression, which is lined in the north by the 1-1.5 m higher steep edge of the coversand ridge.

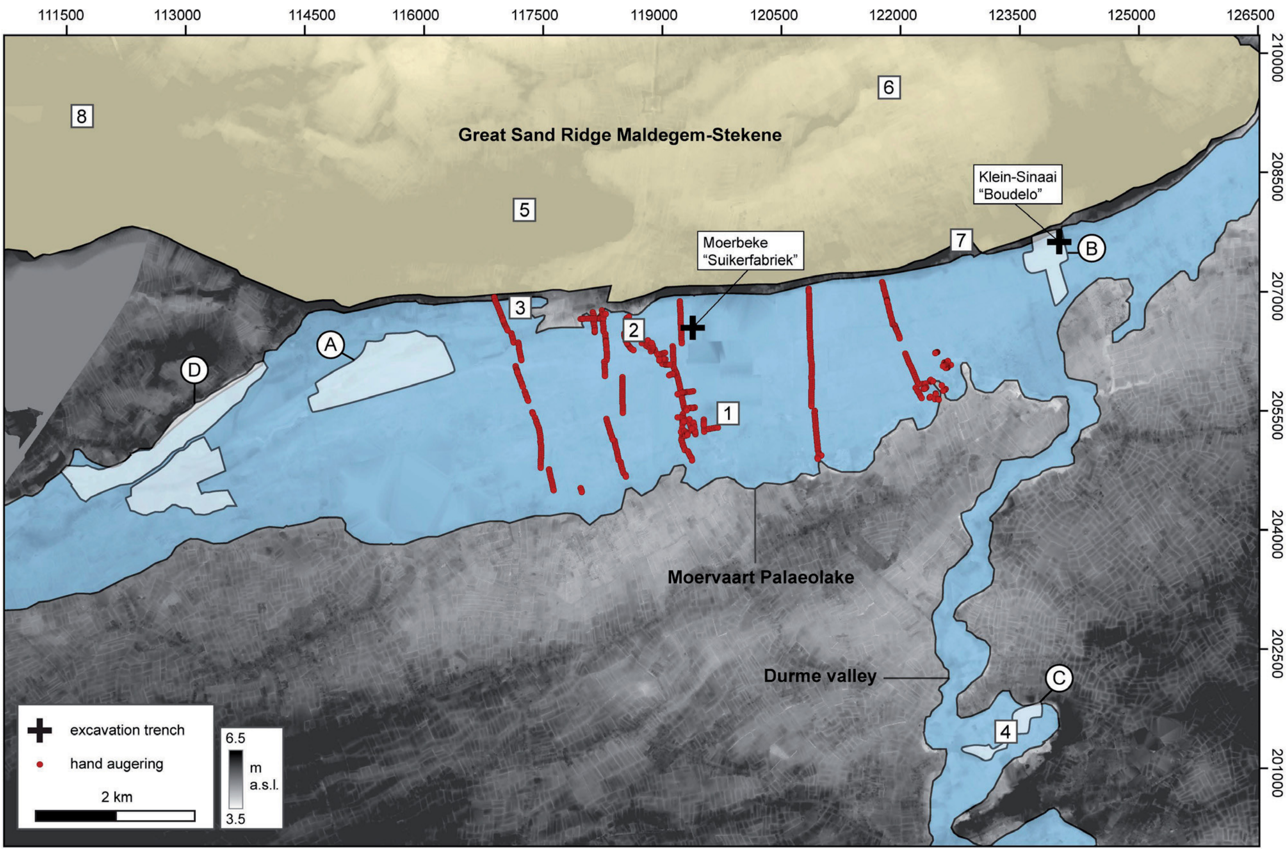


Fig. 2 – The location of the trenches of the Klein-Sinaai "Boudelo" and Moerbeke "Suikerfabriek" sites within the Late Glacial Moervaart depression. In the central part of the palaeolake (indicated in red), manual auger transects are given (Figure adapted after Crombé *et al.*, 2013).

The excavation of the outer court area in the Moervaart depression yielded lacustrine sediments, comparable to the ones sampled and studied at the nearby site of Moerbeke "Suikerfabriek" (Bos *et al.*, 2017, 2018a; Fig. 2), however covered by a relatively thick peaty layer. The latter is exceptional within the Moervaart depression, given the fact that most peat has been either eroded (through oxidation) or extracted during Medieval times (Jongepier *et al.*, 2011). A multi-proxy palaeoecological analysis of this peat may reveal important environmental information on the evolution of the Moervaart depression after the Lateglacial lake had disappeared.

3. *Material and methods*

3.1. *Fieldwork and sedimentological analyses*

At Klein-Sinaai "Boudelo" a sediment sequence was collected by means of three metal boxes (KSB14, MS3 and MS4; Fig. 3). The sedimentological layers recognised in this sequence can be correlated to those in the *master sequence* of Moerbeke "Suikerfabriek" (e. g. Bos *et al.*, 2017, 2018a) mainly based on their pollen content and in the lower parts also on their lithology.

Furthermore, samples were collected for loss-on-ignition (LOI) and granulometry measurements. The lowermost samples (58-72 cm) were taken from the MS4 box, the upper samples (10-58 cm) from the KSB14 box. Organic carbon and $CaCO_3$ contents were determined on samples with 2 cm resolution by automated loss-on-ignition (LOI) using a PrepASH 229 Precisa following Heiri *et al.* (2001). Grainsize analysis was carried out following Mulitza *et al.* (2008). The grain sizes concerned range from 0.1 to 3500 µm. The terminology follows the Folk classification (1954) and the statistical parameters of Folk and Ward (1957).

3.2. *Botanical analyses*

Microfossil samples were collected at 2-9 cm intervals from the KSB14 box (Fig. 3). The sample resolution in the upper part of the sequence is lower as the focus in this sequence was on the Lateglacial and Early Holocene deposits. Samples (2-3 cc) were prepared following Fægri and Iversen (1989) and Moore *et al.* (1991) with additional treatment with

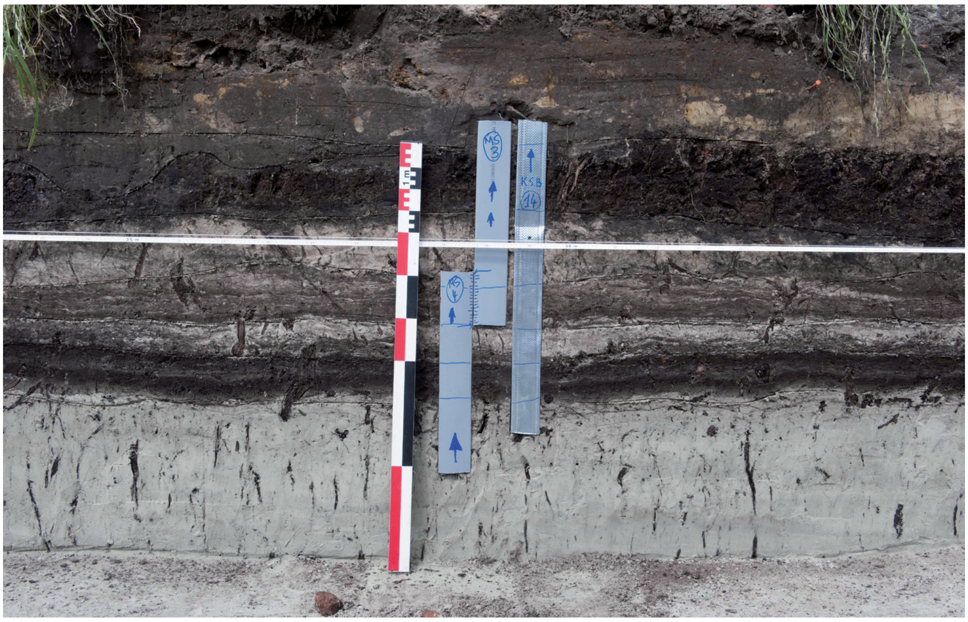


Fig. 3 – The Klein-Sinaai "Boudelo" sedimentological sequence and location of the metal boxes, with the KSB14 box to the right and MS3 (top) and MS4 (bottom) boxes to the left.

warm (80° C) 40 % HF and sieving over 150 µm. Residues were mounted in glycerine jelly and sealed. A light microscope (magnification 400 x and 1000 x) was used for analysis. Pollen and spore types were identified by comparison to modern reference material and identification keys of Moore *et al.* (1991) and Beug (2004). Identification of non-pollen palynomorphs (NPP-types) was based on the type classification of van Geel and colleagues (Miola, 2012). Microfossil taxa were divided into regional and (extra-)local components following Janssen (1973). Combined AP and NAP totals were employed for percentage calculations. The pollen sum (ca. 300-1000) includes trees, shrubs, Ericales, upland herbs and Poaceae and is directly comparable with the pollen sum of the Dutch and northern Belgium Lateglacial regional pollen zonation scheme (Hoek, 1997). Pollen and spores of the local aquatic or marsh vegetation (including Cyperaceae) and thermophilous trees were excluded. However, it should be noted that, in part of the record, wetland grasses may have contributed to the Poaceae group.

Plant macroremains, analysed for ^{14}C dating, were recovered by washing the subsamples over a 125 µm mesh sieve, handpicked from the residue and stored at 4ºC in Eppendorf vials. A dissecting microscope (magnification of 8-40 x) was used for isolation and identification. Plant macrofossils were identified by comparison with modern reference material and identification keys of Berggren (1969, 1981), Anderberg (1994) and Cappers *et al.* (2006).

3.3. Radiocarbon dating

To obtain an accurate chronostratigraphical framework for the sediments at Klein-Sinaai, a series of radiocarbon samples, preferably reflecting atmospheric ^{14}C concentrations was selected for AMS ^{14}C dating from the MS3 and MS4 boxes (Tab. 1). Due to the absence of sufficient datable 'terrestrial' material, especially in the upper part of the sequence, only four samples were selected (Tab. 1). All ^{14}C samples were pre-treated and dated at the Royal Institute for Cultural Heritage, Brussels (Belgium). Radiocarbon dates were converted to calendar years using CALIB 7.1 and the INTCAL13 calibration curve (Stuiver *et al.*, 2018; Reimer *et al.*, 2013).

Depth (cm)	*Lab. Nr.*	*Box*	*Recovered material*	*^{14}C dated material*	*Age (^{14}C years BP)*	*Age (calendar years BP)*
22-25*		KSB14	Wood (roots) +			
38.5-42*		KSB14	Wood (roots) +++, *Schoenoplectus lacustris* nutlet 1x			
45-49	RICH-12637	MS4	Wood (roots) ++, *Potamogeton* sp. fruits 45x and stem remains +, *Schoenoplectus lacustris* nutlets 14x	*Schoenoplectus lacustris* 13x nutlets	11,621 ± 47	13,540-13,520 (5.6%) 13,500-13,390 (62.6%) 13,570-13,340(95.4%)
59.5-62.5	RICH-12635	KSB14	Wood (roots) +, Acari +, Characeae ++, *Carex rostrata* nutlets 2x, *Schoenoplectus lacustris* nutlets 55x	*Schoenoplectus lacustris* 40x nutlets	12,194 ± 48	14,160-14,010 (68.2%) 14,250-13,930 (95.4%)
62-63	RICH-12634	MS4	Wood (roots) +, Characeae ++, *Potamogeton* cf. *mucronatus* 2x, *Carex rostrata* nutlets 2x, *Carex* sp. trigonous nutlet 1x, *Carex* cf. *oederi* nutlets 3x, *Schoenoplectus lacustris* nutlets 120x	*Schoenoplectus lacustris* nutlets 50x	12,140 ± 52	14,120-13,940 (68.2%) 14,170-13,810 (95.4%)
63-67	RICH-12636	MS4	Wood (roots) +, *Thalictrum minus* fruit 1x, *Schoenoplectus lacustris* nutlets 3,5x, *Carex* sp. biconvex nutlets 4x, *Carex* sp. trigonous nutlet 1x	*Schoenoplectus lacustris* nutlets 3,5x, *Thalictrum minus* fruit 1x, *Carex* sp. biconvex nutlets 4x, *Carex* sp. trigonous nutlet 1x	12,125 ± 44	14,100-13,920 (68.2%) 14,150-13,810 (95.4%)

Tab. 1 – List of macroremains and AMS ^{14}C dates of the Klein-Sinaai sequence.
*Absent or not sufficient material for AMS ^{14}C dating.

4. Results and interpretation

4.1. Stratigraphy, incl. granulometry and Loss-On-Ignition (LOI)

4.1.1. Description

The following lithostratigraphical units have been defined (Fig. 4):
- Unit 1 (68 cm depth and deeper): sand with a low mean organic matter (= OM) and calcium carbonate (= $CaCO_3$) content, respectively 2.51 % and 0.33 %. The latter increases towards the deeper (not sampled) levels of this unit. According to its grain-size it can be classified as moderately sorted fine sand composed of 89.7 % on average of sand and 0.3 % of silt. This deposit most likely dates back to the late Pleniglacial;
- Unit 2 (68-58 cm depth): dark brown silty sand. In this unit the OM increases drastically to an average of 19.31 %. The $CaCO_3$ on the other hand increases only very weakly (0.51 %). Grain-size analysis indicates an almost even representation of sand (mean 58.8 %) and silt (mean 40.6 %). The clay content remains below 1 % (0.6 %). Based on this the sediment can be determined as a poorly sorted, very coarse silty to very fine sand. Between 64-66 cm the OM content is slightly lower (mean 12.13 %). Just below this level the clay content is weakly higher (1.4 %) and the sand-silt ratio slightly different (41.1 % against 57.6 %). Finally the presence of coarser sands and to a lesser degree also medium and fine-grained sands needs to be mentioned;
- Unit 3 (58-50 cm depth): brownish to greyish sand. In this unit the mean OM content decreases markedly (2.26 %), whereas $CaCO_3$ remains stable (1.65 %). With a mean of 96 % of sand, this sediment can be classified as moderately well sorted fine sand;
- Unit 4 (50-36 cm depth): brown silty sand. The mean OM content increases again to 7.095 %, while $CaCO_3$ decreases again (0.27 %). With a mean content for sand of 86.6 %, for silt 13.4 % and clay <1 %, this sediment corresponds to a moderately very coarse silty to very fine sand. Furthermore it is characterised by the presence of a small amount of very fine gravel at its base and a relatively important amount of coarse sand;
- Unit 5 (36-25 cm depth): brownish sand. Based on the OM/$CaCO_3$ ratio this unit can be subdivided into two subunits. Subunit 5a has a lower OM content (mean 1.46 %) with respect to 5b (mean 5.83 %). Similarly the $CaCO_3$ doubles from subunit 5a (mean 0.17 %) to 5b (mean 0.30 %). Also within the grain-size distribution a certain evolution can be observed. Subunit 5a is classified as a moderately well sorted fine sand, while 5b tends more towards a poorly sorted coarse silty fine sand with a mean of 0.2 % of clay. However, the overall sand content amounts to 92.6 % on average;
- Unit 6 (25-5 cm depth): sandy to silty (degraded) peat with a mean OM content of 59.4 % ; the $CaCO_3$ amounts to just 1.08 %. According to the grain-size analysis it concerns a poorly sorted fine sandy to coarse silt composed on average of 52.4 % of sand and 47 % of silt. Furthermore this layer contains the highest amount of clay of all units (mean 0.6 %). Interesting is also the presence of small amounts of coarser sands in some levels of the peat;
- Unit 7 (5-0 cm depth): artificial layer consisting of dark brownish sand intensively homogenised by bioturbation, in particular at its top. Its base is more heterogeneous due to an admixture of yellow sands and brownish sands from the underlying layers.

4.1.2. Interpretation

The Klein-Sinaai "Boudelo" sequence consists of an alternation of layers of almost pure sand (units 1, 3 and 5), organic silty sand (units 2 and 4) and peat (unit 6; Fig. 4). The former are characterised by a good size sorting and an almost complete absence of clay, indicating an aeolian origin. The organic silty layers and sandy/silty peat, on the other hand, in particular units 2 and 6, are less well sorted, including coarser sand and clay. This may result from some kind of alluvial influence within a lacustrine environment; for unit 2. Dated to the start of the Lateglacial (see below) this is probably connected to the existence of an anastomosing river system in the western section of the Moervaart depression (Crombé *et al.*, 2013). Interestingly, the short but abrupt increase of sand between 64 and 66 cm depth within unit 2 may point to a short phase of aeolian activity, possibly during the Bølling period (see below). Unit 4, situated in the middle of the studied sequence, sedimentologically relates to an intermediary environment, which can be defined as a lacustrine environment dominated by aeolian activity, but also under influence of a nearby water-way, possibly the Kale/Durme meandering river (Crombé *et al.*, 2013; Bos *et al.*, 2017, 2018b).

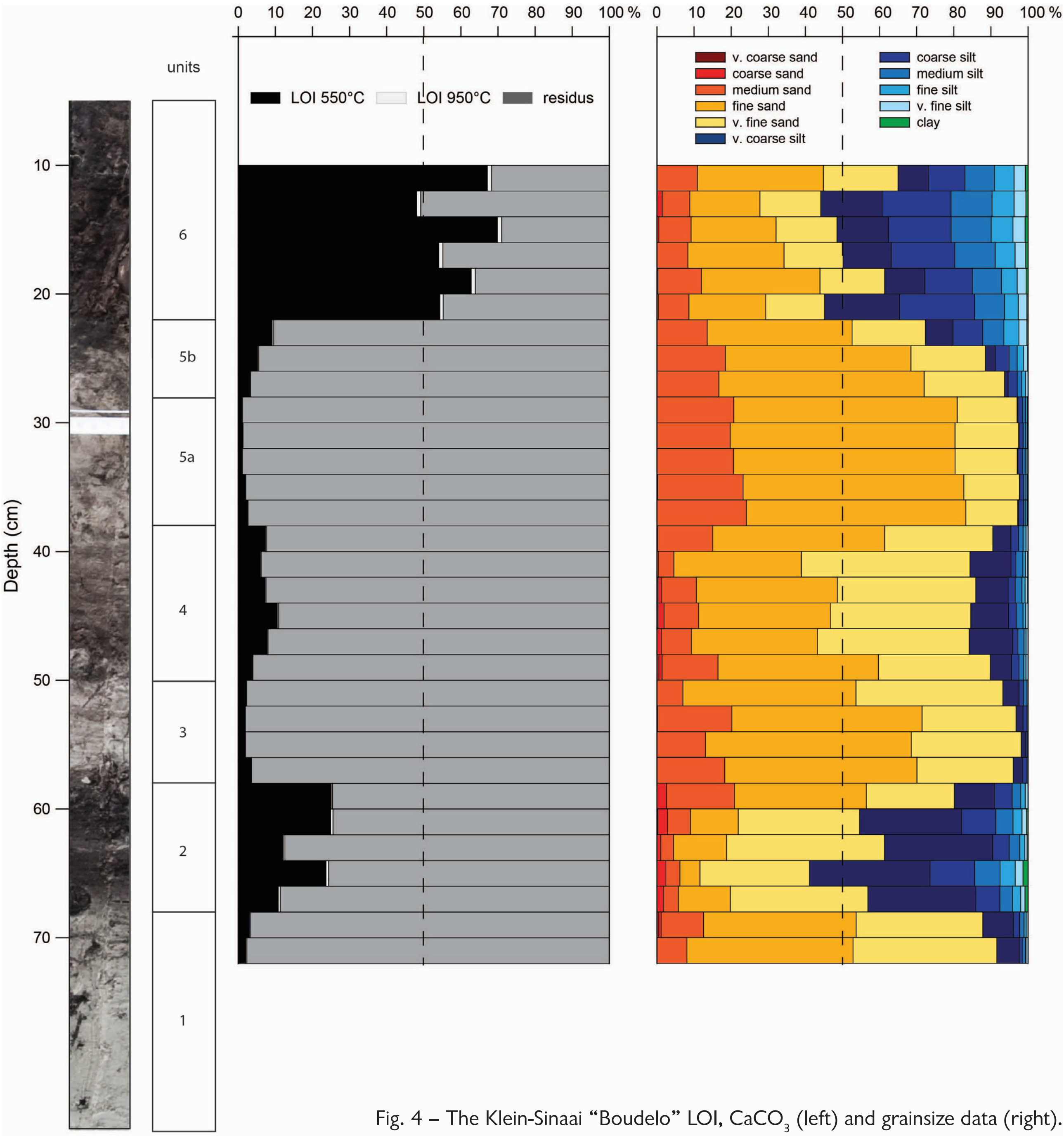
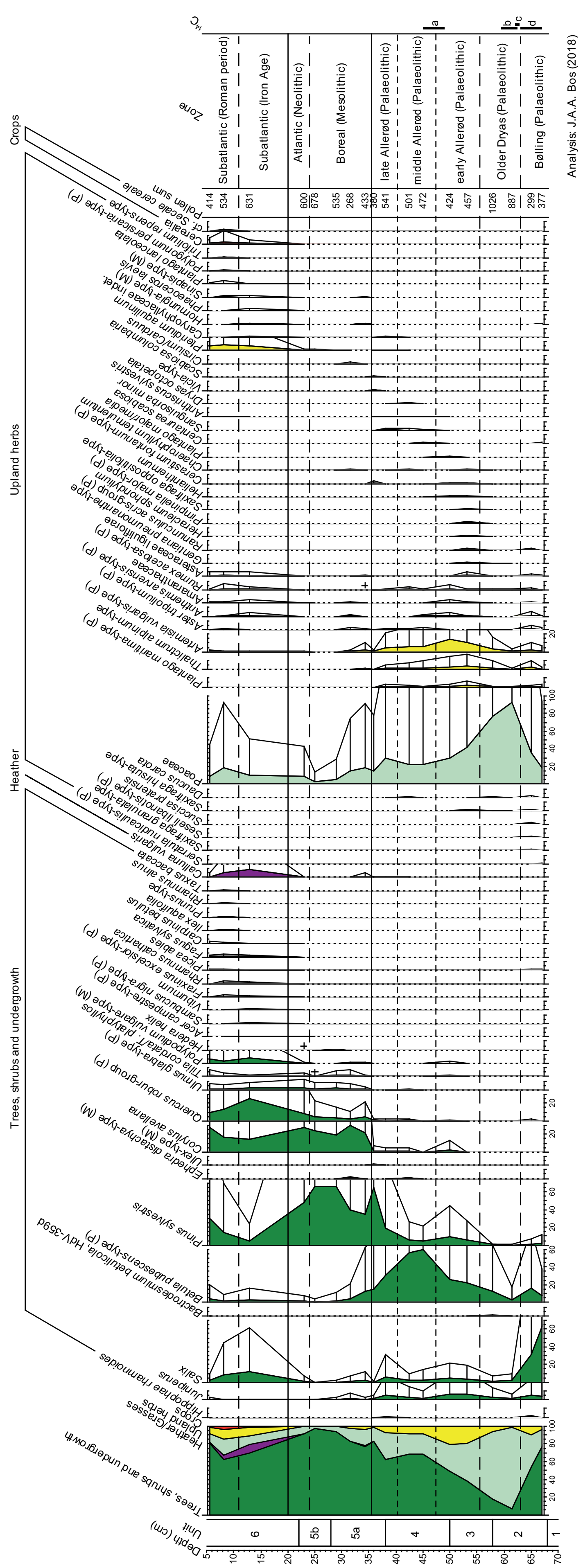


Fig. 4 – The Klein-Sinaai "Boudelo" LOI, $CaCO_3$ (left) and grainsize data (right).



4.2. Radiocarbon record

The Lateglacial chronology of the record was provided by four radiocarbon dates (Tab. 1) and comparison with the regional pollen zones in the pollen diagrams of the near-by Moerbeke "Suikerfabriek" and Rieme records (Bos *et al.*, 2013, 2017, 2018a). The three lowest ^{14}C dates (12,125 ± 44 ^{14}C BP, 12,140 ± 52 ^{14}C BP and 12,194 ± 48 ^{14}C BP) for the upper part of the Bølling and transition to the Older Dryas periods agree well with those in the Moervaart lake *master sequence* and with the expected age of ca. 12,100 ^{14}C BP based on a correlation with Hoek (1997). Also the radiocarbon date of 11,621 ± 47 ^{14}C BP agrees well with the expected age (ca. 11,500 ^{14}C BP, Hoek, 1997) for the transition between the early and middle Allerød. This shows that the regional pollen zones in the pollen diagram can be correlated to the Lateglacial regional pollen zonation scheme of the Netherlands and northern Belgium (Hoek, 1997) and to the major Lateglacial climatic events, as identified in the Greenland oxygen isotope records (Rasmussen *et al.*, 2014). In the section below we will refer for the Lateglacial part to this event stratigraphy used by the INTIMATE group and Hoek (1997). For the Holocene part we refer to Berendsen and Zagwijn (1984).

4.3. Palynological record

The Klein-Sinaai "Boudelo" sediment sequence covers almost the whole Lateglacial Interstadial, with accumulation starting during the late Pleniglacial. The first pollen samples analysed date to the start of the Lateglacial.

Pollen samples at 65 and 67 cm (lower part of unit 2): the AP values, including mainly willow (*Salix*), juniper (*Juniperus*) and birch (*Betula*), are relatively high (70 %), while herbs such as composites (*Artemsia*, *Aster* type, *Anthemis* type), saxifrages (*Saxifraga* spp.), plantain (*Plantago*) and grasses (Poaceae) were present (Fig. 5). These pollen samples reflect the climate amelioration that occurred at the beginning of the Bølling period (corresponding to GI-1e). Taxa such as sedges (*Schoenoplectus lacustris*, *Carex* spp., Tab. 1) and semi-aquatics (*Sparganium/Typha*, *Equisetum*, *Glyceria* type; Fig. 5) and algae indicate the formation of a local marsh, probably as result of an increase in effective precipitation, an increase in lateral groundwater input from the surrounding coversand ridges and melting of permafrost (e.g., Bohncke, 1993; Hoek *et al*. 1999; Hoek & Bohncke, 2002; Bos *et al*., 2006).

Pollen samples at 58 and 61.5 cm (upper part of unit 2): the AP values strongly decrease, while the Poaceae values strongly increase. This pollen assemblage is typical for the colder and drier Older Dryas period (corresponding to GI-1d). Records of the NPP-type *Bactrodesmium betulicola* (HdV-359d) may indicate the presence of decaying wood of branches of *Betula* (Van Geel *et al*., 1981), which may have occurred due to the colder and drier climate. Locally the water table in the marsh lowered and a wet meadow (i. e. grasses, Fig. 5) developed at the site.

Pollen samples at 50 and 53.25 cm depth (unit 3): the Poaceae values decrease and the AP (especially birch) values increase again. This indicates the immigration of tree birch in the Moervaart area. Also the diversity in herbaceous species strongly increases. In the local flora, taxa of open water communities appear (e.g., *Potamogeton*, *Myriophyllum* spp., *Ranunculus aquatilis* group, *Nymphaea alba*, Fig. 5) indicating the presence of a lake with submerged veg-

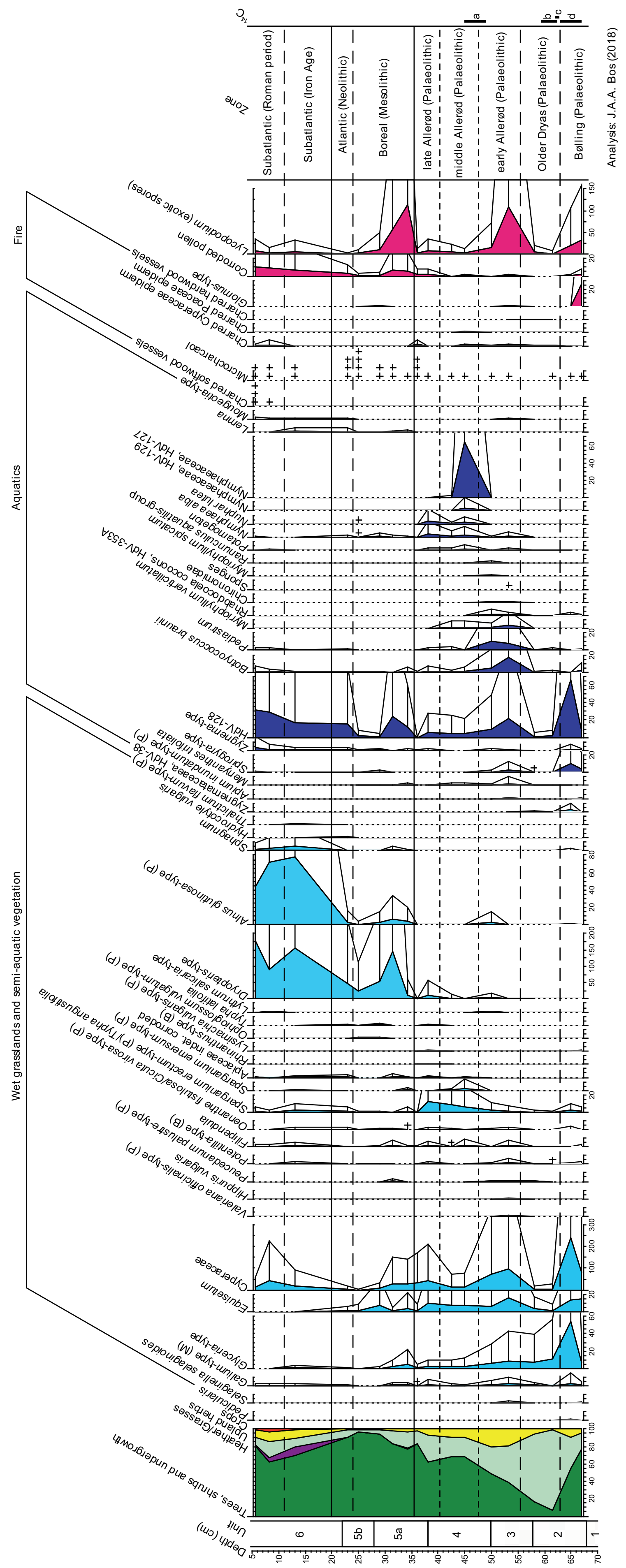


Fig. 5 – Pollen diagram of the Klein-Sinaai "Boudelo" site. In the pollen diagram (KSB14 sequence), the botanical taxa are arranged stratigraphically and grouped by habitat. Microfossils are shown as curves (%). Microcharcoal was indicated as: + = present, ++ = often present, +++ = abundant and ++++ = very abundant. The diagram was constructed using TILIA and TG.VIEW (Grimm, 1992-2004). Fig. 5a. (opposite page) Summary and regional pollen diagram; Fig. 5b. Summary and local pollen diagram. ^{14}C dates: *a*) 11 621 ± 47 BP (13 570-13 340 BP); *b*) 12 194 ± 48 BP (14 250-13 930 BP); *c*) 12 140 ± 52 BP (14 120-13,940 BP); *d*) 12 125 ± 44 BP (14 100-13 920 BP).

etation in the deeper parts and floating vegetation in the more shallow parts. This pollen zone can be correlated with the early Allerød (corresponding to GI-1c).

Pollen samples at 42.5 and 45 cm depth (middle part of unit 4): the birch pollen values further increase, which suggests a further expansion of birch woodlands in the Moervaart area. Nymphaeaceae (*Nymphaea alba* and *Nuphar lutea*) become more abundant suggesting a decrease in the water table. This lowering of the water table occurred during the middle Allerød (corresponding to GI-1c) when an outlet for the Moervaart palaeolake was formed in the east possibly as a result of the incision of the Kale/Durme river (Bos *et al*., 2017, 2018a).

Pollen samples at 36 and 38 cm depth (lower part of unit 5a): the pollen samples in this zone are characterised by an increase in pine pollen and reflect the immigration and establishment of pine woodlands in the Moervaart area during the late Allerød (corresponding to GI-1c/b). The higher values of microcharcoal at 36 cm depth are clearly linked to the gradual appearance of pine, as the species is very sensitive to natural burning caused by lightning. In the local flora, taxa of open water slowly decrease and semi-aquatic taxa and ferns (*Dryopteris* type) increase, which indicates that the lake changed into a swamp with pools of open water.

Pollen samples at 34.25, 31.5, 29 and 25 cm depth (unit 5): trees ans shrubs of thermophilous taxa such as hazel (*Corylus avellana*), oak (*Quercus robur* group), elm (*Ulmus glabra* type) and lime (*Tilia cordata/platyphyllos*) appear, indicating the immigration of these taxa and formation of mixed oak forests on the lower, more fertile soils. On the higher, more sandy soils, such as the coversand ridge, pine forests expanded. The pollen in this assemblage corresponds with the Boreal (Early Holocene). This indicates that a palynological hiatus is present between 36 and 34.25 cm depth.

Pollen sample at 23 cm depth (lower part of unit 6): this sample from the peat base is characterised by a decrease in the pine pollen values, while those of alder (*Alnus glutinosa* type) start to increase. The pollen assemblage is typical for the early Atlantic. This is in agreement with ^{14}C results (8671 ± 43 ^{14}C BP) from a bone tool that was found in an organic layer just below the peat deposit in a nearby trench at the site of Klein-Sinaai (Crombé *et al*., 2012). A ^{14}C date from the peat deposit at the same location gave an age of 5760 ± 34 ^{14}C BP (= Middle Atlantic), which also suggests that peat growth started sometime during the early Atlantic. During this period, locally a peatbog was present with ferns and some pools of open water.

Pollen sample at 13 cm depth (middle part of unit 6): pollen of beech (*Fagus sylvatica*) and hornbeam (*Carpinus betulus*) appear together, which suggests a Subatlantic age. This sample probably reflects the Iron Age and it records the first human impact at this location, as pollen of cereals (Cerealia) appear together with antropogenic herbaceaous taxa, such as narrowleaf plantain (*Plantago lanceolata*), composites (Asteraceae, *Anthemis, Artemsia*), sorrel (*Rumex acetosa/acetosella*), amaranth family (Amaranthaceae) and bracken (*Pteridium aquilinum*). During this period, deforestation of the area started when small openings were made in the forests for the development of agricultural fields on which cererals were cultivated and agricultural herbs were growing. The high values of alder indicate that locally an alder carr developed with some pools of open water and on the higher and drier parts ferns. It is possible that a hiatus is present in the peat deposit and that a large part of the Atlantic and Subboreal is missing. However, there was no visible hiatus within the peat. It is also likely that due to the fact that this part was sampled at a low resolution, these periods are not covered by the pollen samples.

Pollen samples at 8.25 and 5.5 cm depth (top of unit 6): These samples probably refer to the Roman period, with the largest human impact recorded at 8.25 cm depth. In the latter sample, there is a decrease of arboreal taxa and an increase of cereals, grasses, and other anthropogenic indicators (i. e. narrowleaf plantain, composites, sorrel, amaranths, crucifers and bracken). Also two badly preserved pollen grains of possibly rye (cf. *Secale cereale*) were recorded. This suggests a further deforestation of the area and the presence of agricultural fields. Furthermore, the pollen values of alder and peat-moss (*Sphagnum*) are high, while those of ferns decrease. This indicates the presence of a local alder carr and a slightly wetter local environment (i. e. with larger pools of open water). In the uppermost sample (5.5 cm) there is an increase in the AP values (especially pine and hazel), which may suggest a reforestation of the area during the early Medieval period (Dark Ages). However, in the pollen diagrams of the coversand areas generally mainly oak and beech show an increase in the pollen values during the early Medieval period and not pine and hazel (Gouw-Bouman, pers comm.). The higher pine values therefore also can be caused by a more open landscape favouring the distribution of pine pollen. In the local environment the values of ferns and algae (*Zygnema*, *Botryococcus braunii* and HdV-128) increase and plants of open water (*Nymphaea alba* and *Potamogeton*) re-appear, while those of alder decrease. This suggests that the alder forest is replaced by open marsh vegetation with (on the drier grounds) ferns and pools of open water. The peat deposit was covered by an artificial sand layer deposited during the Late Medieval period (Fig. 3).

5. Discussion

5.1. Comparison with the Moervaart palaeolake record

The regional vegetation development reflected in the Klein-Sinaai "Boudelo" pollen diagram can be well compared with the vegetation reconstruction based on the Moerbeke "Suikerfabriek" palaeolake record (Bos *et al*., 2017, 2018a). However, on a local scale there are some differences. These are well reflected in the local pollen curves and lithology of both records. The Klein-Sinaai "Boudelo" sequence must have been collected close to the original shores of the Moervaart palaeolake.

During the Bølling, a marsh was present at the Klein-Sinaai "Boudelo" site, while the pollen diagram of Moerbeke "Suikerfabriek" already reflects a shallow lake. During the drier Older Dryas, the lake water level lowered in the area and at the Klein-Sinaai site a wet grassland developed. At the Moerbeke "Suikerfabriek" site the shallow lake changed into a marsh. Here humic calcareous gyttja was deposited from the early Allerød onwards. At the Klein-Sinaai site, due to the nearby Great Coversand Ridge of Maldegem-Stekene, sand was blown into shallow water, which resulted in the accumulation of sand. Slightly later than at the Moerbeke "Suikerfabriek" site, floating-leaved vegetation with white and yellow water lily developed at the Klein-Sinaai site. This occurred at the end of the early/start of the middle Allerød and from that period onwards a sandy lacustrine sediment (unit 4) was deposited. Also during the late Allerød, the terrestrialisation process was already more progressed at the Klein-Sinaai site and a swamp was formed. Due to the closeby coversand ridge, the Lateglacial lacustrine deposits at the Klein-Sinaai site were covered by aeolian sands (unit 5). These sands are absent at Moerbeke "Suikerfabriek", where a small remnant of an early Holocene peat deposit directly lies on top of the Lateglacial gyttja. The exact timing of the aeolian deposition, however, remains difficult to determine. According to the pollen spectra it probably started during the late Allerød. However, the main part of unit 5 palynologically belongs to the Boreal. Although in recent years aeolian activity during the Early Holocene has been clearly demonstrated, e. g. in northern Germany (Tolksdorf & Kaiser, 2012) and The Netherlands (Kasse *et al*., 2018), the Boreal age of unit 5 at Klein-Sinaai can be questioned as there is no obvious lithostratigraphical hiatus within unit 5 (cf. LOI and granulometric evidence). Therefore it seems more likely that aeolian deposition continued during the Younger Dryas and even the Preboreal, whereafter Boreal pollen percolated into these sands. This hypothesis is partly corroborated by the presence of *Ephedra distachya* type pollen (Fig. 5), which is often recorded in Younger Dryas deposits (Hoek, 1997). The presence of numerous microcharcoal fragments in unit 5 indicates that wind deflation was not only triggered by increased coldness but probably also by forest fires, both leading to an increased openness of the environment.

5.2. Human occupation

A few hundred meters north of the studied location, along the relatively steep southern edge of the Great Coversand Ridge of Maldegem-Stekene, at least six *Federmesser* Culture sites are reported, situated at close distance of each other (Van Vlaenderen *et al*., 2007; Crombé *et al*., 2011). From the palaeoecological study it is clear that the presence of the extensive Moervaart lake in particular during the (early) Allerød explains this "dense", and probably recurrent occupation by Lateglacial hunter-gatherers. Once the lake had vanished human occupation shifted towards the dry banks of the river Kale/Durme (Crombé *et al*., 2011). Except for some microlithic armatures, discovered on the above-mentioned *Federmesser* Culture sites, there is no hard evidence of Mesolithic occupation immediately north of the sampled site of Klein-Sinaai "Boudelo". The Early Mesolithic bone tool found isolated during the excavations at the latter site probably represents an object that was lost or dumped in the marshy depression of the former Moervaart lake. It thus seems that the northeastern section of the Moervaart depression, situated at some distance from the Kale/Durme river, was only marginally exploited during the Mesolithic.

Despite the total lack of archaeological evidence, from the Iron Age onwards, humans clearly settled again nearby the Klein-Sinaai "Boudelo" site. In the pollen diagram there is palynological evidence for human disturbance (e. g., deforestation, trampling), forest herding (i. e., high values of *Pteridium aquilinum*, see Behre, 1986) and cereal cultivation in the area. Plant taxa such as composites (*Artemisia, Aster-* and *Anthemis*-type), *Rumex acetosella,* Cruciferae (*Hornungia*-type and *Sinapis*-type) and Amaranthaceae were growing on and along the agricultural fields, while the liverwort *Phaeoceros laevis* (Koelbloed & Kroeze, 1965) suggests that the agricultural fields layed fallow for part of the year. Due to deforestation, grass- and heathlands (with *Calluna vulgaris*) became more abundant in the area, while records of narrowleaf plantain (*Plantago lanceolata*) point to increased trampling. Finds of probably rye (cf. *Secale cereale*) may point to the wild agricultural herb, however, from the 1th-4th centrury AD onwards it is known that rye was grown on the poorer soils in NW Europe (Van Zeist 1976; Behre, 1992), which also may have been the case here. During the Roman period deforestation and human impact increased and cereals were grown in the area. Due to the bad preservation of the pollen grains, however, it is not known (besides cf. rye) what kind of cereals were grown in the Iron Age and Roman period.

Based on the relative stratigraphical position and by comparing with the human impact on the landscape as observed during the large-scale palaeoecological research in the Kluizendok-project (Laloo *et al*, 2009), it is very likely that the maximum of deforestation observed at 8.25 cm depth in the Klein-Sinaai "Boudelo" pollen diagram, along with the appearance of cereals, corresponds with the landscape of the Roman period. Bronze Age barrows and a Roman farm have indeed been discovered at Stekene-Dorpsstraat at only 5 km to the northeast of the Boudelo-excavation (Van Neste, 2014). This site confirms the intense human exploitation of the sandridge, very close to the Moervaart depression. Its location hints at the likeliness of presence of similar proto- and early-historical complexes, closer to the Boudelo site and at the origin of the image of deforestation visible in the Klein-Sinaai "Boudelo" pollen diagram.

From the late 12th and in the 13th century, the area was reclaimed by the monks of the Boudelo-abbey who partially extracted the peat, drained the area and built the Cistercian abbey on the sandridge. The Moervaart depression became part of the outer court of the abbey and was occupied by moated sites with artificially raised platforms, indicating that permanent occupation had become possible, but that the area still was a wetland to a certain extent. It seems, however, that the occupation in the depression was shortlived:

starting in the late 13th century it ended already in the 14th century, probably because of increased flooding (Dalle, 2014).

6. Conclusions

In this study, pollen, macrofossils, ^{14}C dating, organic matter, calcium carbonate and grain size were analysed on a sediment sequence that was collected near Klein-Sinaai "Boudelo" in the northeast of the Moervaart palaeolake area. The Moervaart palaeolake was formed in a depression south of a large Pleniglacial/Lateglacial coversand ridge when at the onset of the Lateglacial rising temperatures caused melting of permafrost in the neighbouring region and groundwater tables rose. Infilling of the palaeolake occurred during almost the whole Lateglacial and this is recorded in both the pollen diagrams of the Klein-Sinaai "Boudelo" and Moervaart "Suikerfabriek" palaeolake records. The two pollen diagram show that during the Lateglacial local differences in the lake vegetation existed. However, the Klein-Sinaai site was located more nearby the original shore, in the shallower part of the Moervaart palaeolake and thus closer to the Pleni- and Lateglacial coversand ridge. The influence of sand transport during the Lateglacial is well recorded at this location and influx of sand during the whole Lateglacial is clearly visible in the sedimentological record, especially during the early and late Allerød and most likely also during the Younger Dryas.

From the start of the Allerød onwards, the area provided a very suitable landscape for *Federmesser* Culture hunter-gatherers with the Moervaart palaeolake providing drinking water and extensive and fertile woodlands for hunting and gathering. The drying up of the lake, which started in the late Allerød, and the return to colder climate conditions during the subsequent Younger Dryas hindered prehistoric man to remain settled in the area. This led to a marked decrease or even a hiatus in the human occupation, which lasted more than 2000 years. Hunter-gatherers returned to the Moervaart area during the Boreal where (in contrast to the pine forests on the sandy coversand ridge) mixed oak forests had developed on the lower, fertile soils as a result of the warmer temperatures and higher precipitation. However, they did not occupy the northeastern side of the former Moervaart lake, but settled along the dry banks of the river Kale/Durme. It is not until Proto-historic times and in the Iron Age more precisely that the northeastern side of the Moervaart depression was exploited again by man. This means that this particular area of the Moervaart depression was "uninhabited" during a period of 10 millennia, probably as a result of environmental constraints, mainly the absence of open water.

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Abstract

Excavations at the Cistercian abbey of Klein-Sinaai "Boudelo" in 2011 and 2012 revealed the pre-sence of a well-preserved sedimentological archive, providing additional information on the Lateglacial and Holocene evolution of the Moervaart depression. Situated at the northeastern bank of a former Lateglacial freshwater lake, the sequence was studied in a multi-proxy way, combining loss-on-ignition (organic matter, CaCO3), granulometry, botany (pollen, NPP, plant macroremains) and ^{14}C dating. The results demonstrate that the Moervaart lake reached its maximal extend and depth at the end of the early/start of the middle Allerød, creating an extensive (ca. 25 km^2) water reservoir. The latter probably had a strong attraction on contemporaneous wild game and hunter-gatherers, as numerous, though undated *Federmesser* Culture sites, are known along the relatively steep and dry northern lake bank. During the late Allerød, however, the lake gradually turned into a swamp, in which windblown sands accumulated. This process of wind deflation, which likely continued into the Younger Dryas, was probably triggered by the increasing cold and repeated forest fires. The latter are indicated by the presence of numerous microcharcoal fragments in these aeolian sediments. From the early Atlantic onwards peat started to grow, turning the Moervaart depression into a peatbog, preventing humans to settle in the area. Instead Mesolithic hunter-gatherers focused on the dry banks of the nearby Kale/Durme River. Renewed human activity at the Klein-Sinaai site dates to the Iron Age as indicated by the occurrence of pollen of cereals (Cerealia) together with anthropogenic herbaceaous taxa in the upper peat levels.

Keywords: Lateglacial, Holocene, pollen analysis, palaeolake, prehistory, Klein-Sinaai "Boudelo", province of East Flanders (BE).

Samenvatting

Tijdens de opgraving van een cisterciënzerabdij te Klein-Sinaai "Boudelo" in 2011 en 2012 kwam een goed bewaarde bodemsequentie aan het licht, die extra informatie opleverde over de ontwikkeling van de noordoostelijke randzone van de Moervaartdepressie. De sequentie werd bestudeerd op basis van verschillende landschappelijke proxies, waaronder het gehalte aan organisch en kalkrijk materiaal (LOI), de bodemtextuur (granulometrie), stuifmeel en macroresten gecombineerd met ^{14}C dateringen. Hieruit kon worden afgeleid dat de Moervaartdepressie tijdens het Allerød een uitgestrekt zoetwatermeer vormde, die zijn grootste uitbreiding en diepte bereikte op de overgang van het vroeg naar het midden Allerød. Zowel het toenmalige wild als de jagers-verzamelaars werden hiertoe aangetrokken, getuige hiervan het voorkomen van verschillende sites van de *Federmesser* cultuur onmiddellijk ten noorden van de bestudeerde locatie. Tijdens het laat Allerød nam het meer geleidelijk in omvang af om uiteindelijk in een moeras te veranderen. Ongeveer gelijktijdig hiermee kwam er vanaf de aangrenzende dekzandrug zand ingewaaid onder invloed van de toenemende koude en bosbranden. Dit proces ging vermoedelijk door tijdens de Jonge Dryas. Pas aan het begin van het Atlanticum begon de Moervaartdepressie zich met veen op te vullen, waardoor het gebied voor de mens minder aantrekkelijk werd. De eerste botanische indicaties van hernieuwde menselijke activiteit dateren uit de IJzertijd, wanneer de mens het bos begin te kappen in functie van de landbouw.

Trefwoorden: Laat Glaciaal, Holoceen, palynologisch onderzoek, paleomeer, prehistorie, Klein-Sinaai "Boudelo", prov. Oost-Vlaanderen (BE).

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