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Application of Phytolith (Microbiomorphic) and Non-Pollen Palynomorph Analyses to the Geoarchaeological Study of the Graft Farmyard, the Netherlands

Olga Druzhinina[1,2*+], Dario Hruševar[3+], Kasper Jurgen van den Berghe[1], Nancy de Jong-Lambregts[4], Alexandra Golyeva[5], Koraljka Bakrač[6], Božena Mitić[3]

[1]*FindX Research Company, Palestrinalaan Laan 1157, 8031VK Zwolle, the Netherlands*
[2]*Institute of Oriental Stidies Russian Academy of Sciences, Rozhdestvenka Street 12, 107031 Moscow, Russia*
[3]*University of Zagreb, Faculty of Science, Horvatovac 102a, 10000 Zagreb, Croatia*
[4]*Gemeente Alkmaar, Archaeological Centre, Bergerweg 1, 1815 AC Alkmaar, the Netherlands*
[5]*Institute of Geography Russian Academy of Sciences, Staromonetniy Lane 29, 119017 Moscow, Russia*
[6]*Croatian Geological Survey, Milana Sachsa 2, 10000 Zagreb, Croatia*

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A B S T R A C T

The aim of the present paper is to discuss the application of phytolith (microbiomorphic) and non-pollen palynomorph (NPP) analyses to the geoarchaeological study of a Medieval – Early Modern Time period farmyard in Graft, a settlement located in the polder region of North Holland, the Netherlands. The authors have assessed the potential of the methods chosen for studying this type of archaeological site during rescue excavations, when archaeologists often have a limited number of samples or methods for geoarchaeological analysis. The studies conducted have proved the informative value and effectiveness of microbiomorphic and NPP analyses in rescue excavations, especially when applied in combination, thus providing controlling and complementary information for each analysis. The data obtained have provided an important insight into the archaeological interpretation of the cultural layer within the farmyard. In addition, more information was gained on the local palaeoenvironmental dynamics and the phases of economic activity at the farmyard during the 13th–17th centuries CE.

1. Introduction

During rescue excavations, archaeologists often have to operate under the high pressure of time and finances, and when the desired scientific assistance cannot be obtained. As a result, a narrow range of geoarchaeological methods are applied or a limited number of samples is analysed. In rescue excavations carried out in the Netherlands, palynological analysis and radiocarbon dating are the most common methods used. Meanwhile, the palette of geoarchaeological methods for archaeological research is rich and broad, numbering at least two dozen and considering such types of anthropogenic indicators as phytoliths, seeds, microcharcoal, geochemical elements, *etc.* (Golyeva, 2001; 2008; Holliday and Gartner, 2007; Wilson *et al.*, 2008; Cugny *et al.*, 2010; Milek and Roberts, 2013; Dietre *et al.*, 2014; Cuenca-García, 2015; Shumilovskikh *et al.,* 2016; Rashid *et al.*, 2019). In this paper, two of the methods – phytolith (microbiomorphic) and non-pollen palynomorphs analyses, generally accepted as advanced, efficient and affordable methods, are discussed.

Phytolith analysis is one of the rapidly-developing, up-to-date scientific methods in archaeology and palaeoecology (Rashid *et al.*, 2019). The considerable number of plants which grew or were used in a certain area, leave evidence of their prior existence in the form of phytoliths. Phytoliths are resistant to destruction, and can persist in the soil or on the surface of various objects for thousands of years (Piperno,

*Corresponding author. E-mail: olga.alex.druzhinina@gmail.com
+Joint first authorship.

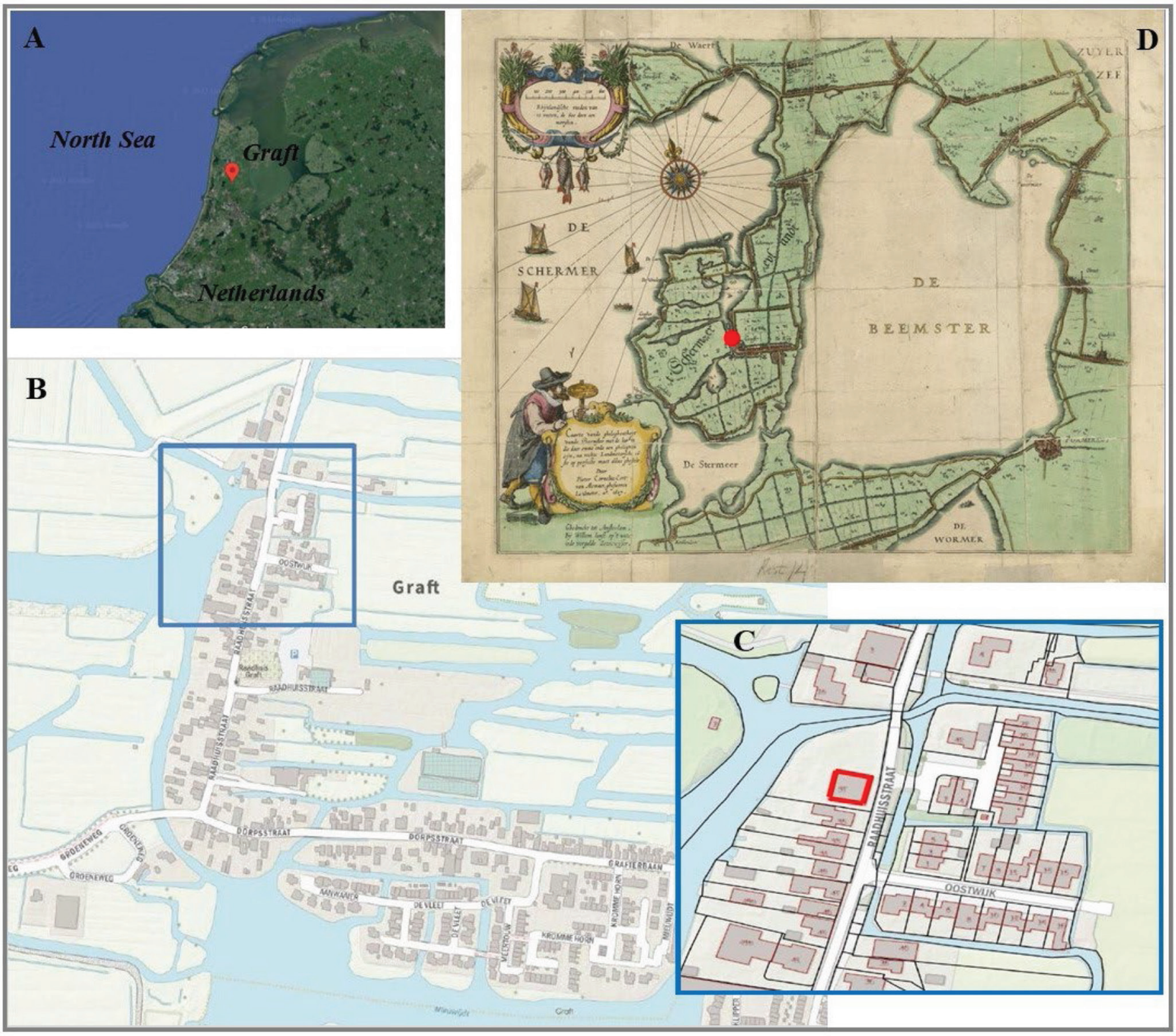

Figure 1. The study area. A: Map showing location of Graft in the Netherlands. B: Graft, excavation area. C: Location of the excavation pit (red square). D: Research location pointed out on a map of 1607.

2006). As Madella and Lancelotti (2012) point out, in general, phytoliths are not transported over long distances because they are relatively "heavy" particles, and they therefore characterise a specific local, rather than regional (as pollen), environmental situation. The property of phytoliths to remain *in situ* is a valuable source of information which can be directly related to human activity or the palaeoenvironment. The development of classical phytolith analysis has led to an extended version of this method; microbiomorphic analysis (Golyeva, 2008). It includes a microscopic study of all the microbiomorphs (organic and silica) retrieved during the chemical processing in a phytolith sample and their comprehensive interpretation. Thus, in addition to the identification of phytoliths, microbiomorpic analysis comprises the quantitative estimation of plant detritus (wood and grass), the shells of diatoms, the spicules of sponges, soil fungi, *etc.* Each of the microbiomorphs is an indicator of certain environmental conditions, thus providing data to supplement and check the information. As a result, a wider spectrum of valid multi-faceted information on the palaeoenvironment can be obtained (Golyeva, 2008; 2016).

Archaeological sediments contain, in addition to pollen grains, an abundance of "extra" microfossils grouped under the name of non-pollen palynomorphs (NPPs). They are highly diverse in nature, comprising the remains of fungi and algae, the eggs of parasites, the shells of amoebae, *etc.* (Shumilovskikh *et al.,* 2016; Shumilovskikh and van Geel, 2020). Each type of NPP occurs under specific conditions, such as the presence of decaying wood; the on-site deposition of manure; wood or manure with parasitic contamination; after fire and erosional events; and drought or waterlogging conditions. They occur together with the increased supply of nutrients or water pollution (Cugny *et al.,* 2010; Chambers *et al.,* 2011; Feurdean *et al.,* 2013; Shumilovskikh and van Geel, 2020). Moreover, due to their restricted dispersal potential, NPPs often provide a local signal. This makes the group of NPPs a valuable indicator of various palaeoecological conditions, while the identification of NPPs at archaeological sites provides more vital information about human activities and the ecological background of the site.

Initially, sampling of any layer or structure for the rescue excavation of the farmyard in Graft (the Netherlands; N 52°33`; E 4°49`), preliminary dated to the Late Medieval – Early Modern time, was not considered in the budget of the project. However, at the later stages of the research, a small-scale pilot project was set up, aiming at assessing the potential of microbiomorphic and NPP methods for studying this type of archaeological site and obtaining more information about the area and its users. Geochronological investigation of the site was carried out as well.

This paper presents the results of microbiomorphic, NPP and geochronological analyses, which not only provide data for archaeological investigation but also provoke new research questions, which can influence the further outcomes of an archaeological study.

2. Regional setting and historical background

The research site is located in Graft, of the municipality of Alkmaar, in the peat polder and reclaimed land in central North Holland (Figure 1). The low moor that originally stretched across almost the entire western and northern Netherlands, the Holland peat, had a thickness of peat down to more than 20 metres at Graft. From a landscape perspective, the study area, representing low moorland, is bordered to the east by the former bay of the North Sea, Zuiderzee, and on the west by the Heiloo-Alkmaar and Akersloot sandy beach ridges (Vos *et al.,* 2011).

Graft was first referred to in a list of possessions of the Egmond Abbey, a document dated between 1091 and 1121 CE (Reh *et al.*, 2005). The founding of the abbey and the reference to Graft in the list of possessions coincides with the beginning of the period in which peatland reclamation began. Due to the Medieval warm period (~ 900–1100 CE), the conditions for this were very favourable. Drought and warm temperatures triggered the drying-out of the upper peat layer, and an enhanced natural drainage of the peatland (Berendsen *et al.*, 2019). The same factors played a negative role in coastal areas; there, sand drifts covered formerly fertile ground (Mantel, 2005; Bazelmans *et al.,* 2009).

From about the mid-10th century CE, the first attempts to reclaim a peat bog from the beach ridge region were made. As early as the 12th century, the peat began to sink and mineralise as a result of reclamation, triggering the subsidence of land up to two metres in some locations (Reh *et al.*, 2005; Berendsen *et al.,* 2019). Meanwhile, the changing climate patterns during the starting of the Little Ice Age brought extra far-reaching consequences for the region. Stronger winds provoked many disastrous floods in the 12th century. Large patches of peat, together with early reclaimed villages, were swept away. In response, the construction of dikes, "Binnenmaden", began in the 13th century. The remaining areas shielded themselves from the surrounding disaster-stricken area that had transformed into large expanses of water. The above events triggered the formation of Schermer Island, sandwiched between the lakes of Schermeer, Beemster and Starnmeer (Kaptein, 1988; Mantel, 2005).

With the construction of the dikes, people also moved here, building dike settlements. Today's Graft is also formed along one of these dikes. The newly-constructed dikes brought new opportunities to the area and its settlers prospered. In the early 14th century, Graft, became a thriving, fully-fledged, agriculturally-oriented settlement with its own church.

After the aforementioned reclamation, the area became suitable for arable farming, horticulture and cattle breeding, though the peat continued to mineralise, increasing soil wetness. A finely-meshed network of ditches was created, leading to larger watercourses, while the land made a transition to less-intensive land-use and the grazing of plots. A dual existence became necessary, where the women kept small farms and the men sailed for a living. Initially, fishing was done in inland waters; later, in the 17th century, herring fishing and whaling were introduced (Reh *et al.*, 2005).

The village of De Rijp was built as an extension of Graft. Its residents focused only on fishing and having their own harbour. The development of De Rijp caused a change in Graft's economy; ropes used for shipping became an important source of income for Graft. Those who did not earn their living at sea did so on the farm or in one of the hemp mills, where rope for ships was made. This then made Graft an important flax- and probably hemp-processing centre for ship's rope and fishing nets (Kaptein, 1988).

The great prosperity that this brought made Graft-De Rijp one of the largest rural communities in North Holland in the 17th century (Kaptein, 1988). In addition to fishing, the new reclamations in the 17th–19th centuries also gave an economic impulse for the area's further development (Berendsen *et al.,* 2019).

3. Material and methods

3.1 Archaeological context and stratigraphic relationships

A small-scale (140 m^2) rescue excavation of the farmyard in Graft took place in 2020 (Figure 2). In the centre of the excavation area, four brick basement blocks were revealed. The blocks, so-called "vierkant" (square), formed the base of the wooden frame of a farmhouse, a so-called "stolp boerderij", a common regional, square-shaped, pyramidically-roofed type of farm, which came into use in the mid-16th century. The pottery found near the blocks dates from the late 16th – early 17th century.

Between the brick basement area, clusters of poles and stakes were present. They are assumed to illustrate an older phase in the use of the farmyard, as indicated by their

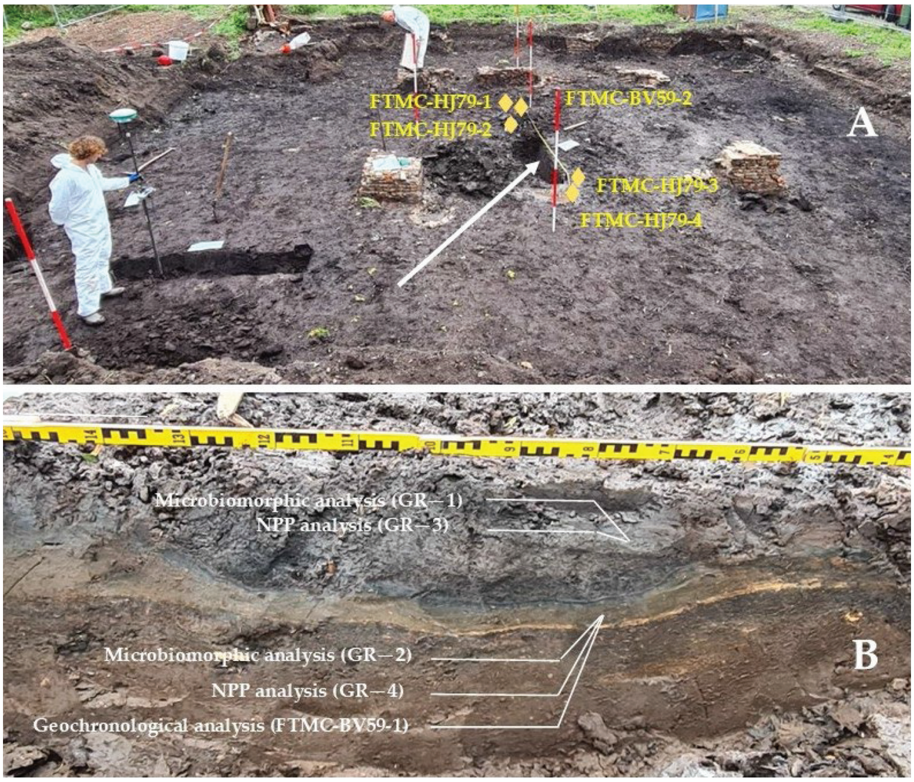

Figure 2. Rescue excavation in Graft. A: Excavation pit and location of the geochronological samples. B: Profile with sampling location.

stratigraphic position and the presence of 13–14th century ceramics in the correlating layers.

The remains of the brick walls built in the 18–19th century, marked the outside of the former farm and the boundary of the study area.

The soil structure within the brick basement area consisted of a layered anthropogenic package. A layer of brownish, highly-humic clay formed its base. It seems to be an elevated earthen body, in which the soil mass was obtained from the vicinity, most likely while digging the watercourse adjacent to the plan area. The watercourse is still there today. On top of it, a layer, interpreted during fieldwork as dung underlaid by a thin straw or reed interlayer, was present. It was overlain by a light-coloured sand body covered by a dark brown-black coloured layer of homogenous humic soil. The top of the layer formed the present-day surface.

Wooden stakes and the "dung" layer were subjected to geochronological research, while the sandy layer and the "dung" layer were sampled for microbiomorphic and NPP analyses (6 and 4 samples, respectively) to obtain more information about the farmyard and the activities of its residents. The research methods and the number of samples chosen, were based on the funds available for the project.

3.2 Microbiomorphic analysis

About 5 g of a substance was taken from two bulk samples for analysis. The samples were prepared according to the standard protocols for phytolith analysis described by Piperno (1988; 2006) and Golyeva (2008). The samples were treated with hot 30% H_2O_2 solution, separated from the sand and clay by sieve and gravity sedimentation techniques based on Stokes's Law and subjected to flotation in a heavy liquid (cadmium iodide and potassium iodide with a specific gravity of about 2.3 g/cm^3). After a 10-minute centrifugation, floating siliceous and other biomorphs were placed into a tube, washed with distilled water several times, immersed in oils (silica oil or glycerine), and studied under the optical and scanning electron microscope at magnifications varying from 200 to 900 times (Nikon Eclipse E200, JEOL 6610LV). The quantitative content of organic and silica microbiomorphs was estimated by counting all the morphotypes found per slide. Phytolith identifications are based on standard determination described in (Golyeva, 2001; Madella *et al.,* 2005). The morphological types of phytoliths were assigned to the existing code according to ICPN 2.0. (2019). The phytoliths were also divided into several biocoenotic groups, such as forest grass, wet meadows, dry meadows, domesticated grass (cereals), *etc.*, according to Golyeva's ecological interpretation (2007; 2008).

3.3 Non-pollen palynomorphs analysis

In order to extract pollen and plant spores, together with non-pollen palynomorphs and charcoal from sediments, about 1 g of two soil samples were sieved (250 µm and 7 µm) and treated with 10% KOH and 20% HCl. Upon the addition of safranin, the palynological samples were stored in silica oil. To improve the conservation of non-pollen palynomorphs (NPPs) during the palynological extraction procedure, acetolysis was avoided. To enable calculation of pollen, NPPs and charcoal concentrations, an exotic marker, *i.e.*, a *Lycopodium* tablet with a known concentration of spores (Stockmarr, 1971) was added to the samples before treatment. Identification of pollen and plant spores followed standard keys (Moore *et al.,* 1991; Beug, 2015). NPP identifications were carried out as in van Geel, 1978; van Geel and van der Hammen, 1978; van Geel *et al.*, 1983; 1989; 2003; Jankovská and Komárek 2000; Komárek and Jankovská 2001; Carrión and Navarro, 2002; Fugassa *et al.*, 2006; Montoya *et al.*, 2012; Barthelmes *et al.*, 2012; Prager *et al.,* 2012; Kołaczek *et al.*, 2013; Dietre *et al.,* 2014; López-Vila *et al.*, 2014; Shumilovskikh *et al.,* 2016; Schlütz and Shumilovskikh, 2017; and Roche *et al.*, 2020. NPP types were assigned to an existing code according to Miola (2012). A few newly-described non-pollen palynomorphs were abbreviated ZAG (*e.g.* ZAG-1, ZAG-2, ZAG-3) as University of Zagreb, Faculty of Science and Croatian Geological Survey in Zagreb, being the institutions where isolation and description of the palynomorphs were made. Palynomorphs and charcoal particles of the two analysed samples (GR-1 and GR-2) were counted until the sum of 100 *Lycopodium* spores was reached so as to equalise the concentration between the samples. This means that more than 200 grains of terrestrial arboreal (AP) and non-arboreal (NAP) pollen per sample were counted (in total, 1125 pollen and plant spores for GR-3 sample, and 314 for GR-4 sample), with simultaneous identification and counting of NPPs. Local pollen and NPP values were expressed as a percentage in relation to total pollen sum (TS = AP + NAP), excluding local mire and wetland plants such as sedge (Cyperaceae) or *Typha latifolia* type, *Sparganium* type, *Potamogeton-Triglochin*, ferns (Polypodiales) and mosses (*Sphagnum*). The percentages of the excluded taxa, NPPs and charcoal particles were calculated individually for each taxon in the ratio to TS + taxon. This is a generally accepted formula for the POLPAL software used to plot diagrams (Nalepka and Walanus, 2003).

3.4 Geochronological analysis

Six samples, including a sample from the dung layer and five samples of wooden stakes, were analysed by means of an AMS ^{14}C survey. The analysis was performed at the Centre for Physical Sciences and Technology, Mass Spectrometry Laboratory (Vilnius, Lithuania). Calibrated data (cal CE) were obtained with OxCal v. 4.4.2. (Bronk Ramsey, 2020).

4. Results

4.1 Microbiomorphs

Well-preserved phytoliths were found in both samples, though the amount of phytoliths in sample GR-2 is nearly 7 times higher. The samples also contained cuticular casts of plant cells, diatoms and fragments of sponge needles, plant detritus and other microbiomorphs indicative of different ecological conditions (Figure 3, Tables 1 and 2).

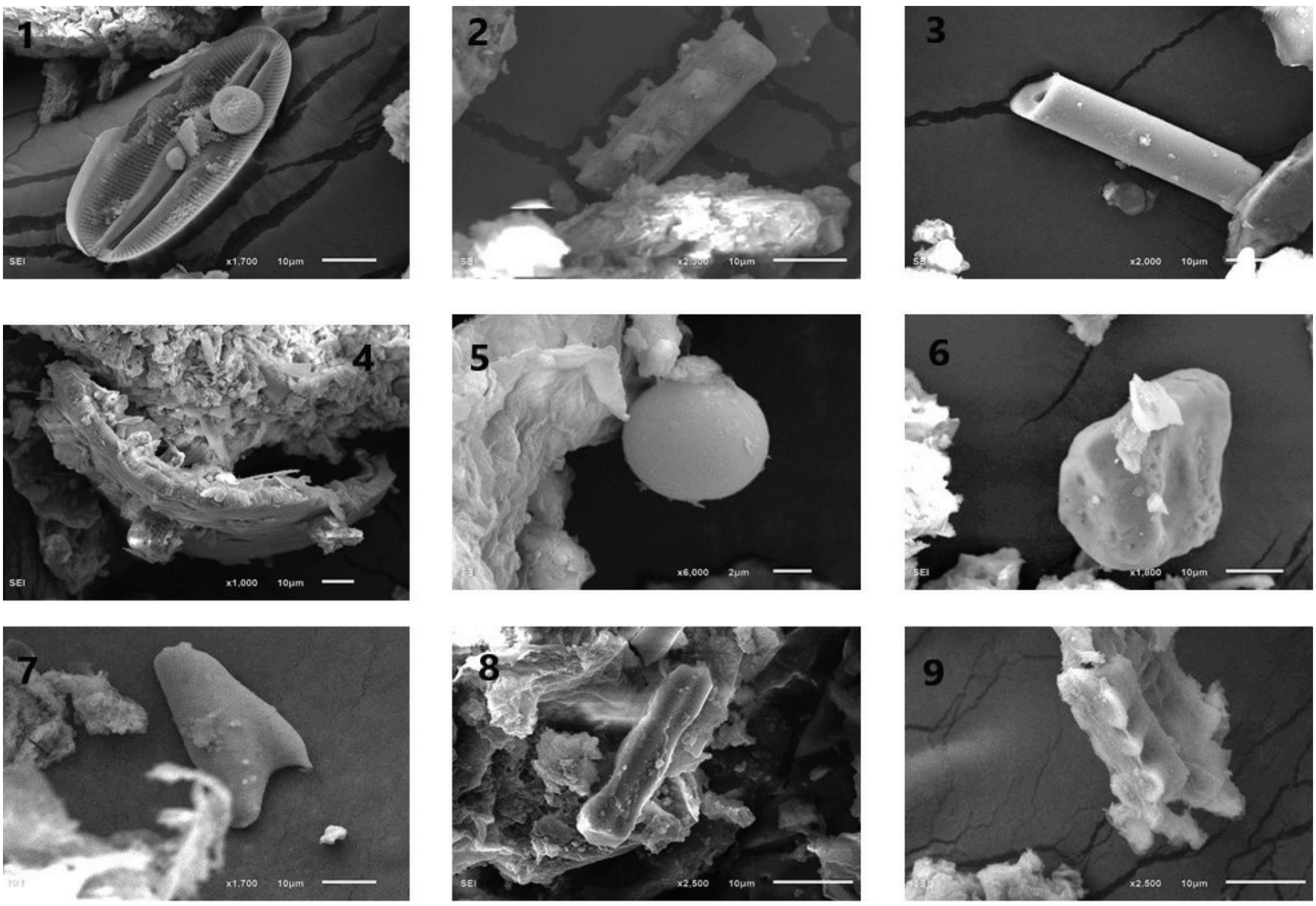

Figure 3. Microbiomorphs. Sample GR-1: 1 - diatom; 2 – phytolith of grasses (dry meadows); 3 – sponge spicula; 4 – plant detritus; 5 – phytolith of mosses; 6 – phytolith of reed. Sample GR-2: 7 – phytolith of grasses (forest habitats); 8 – phytolith of grasses (wet meadows); 9 – phytolith of grasses (dry meadows).

Table 1. The main categories of organic and silica microbiomorphs (in units).

Sample	Detritus	Amorphous organic matter	Sponge spicules	Diatoms	Phytoliths	Other microbiomorphs, present in the sample
GR-1	>100	>100	8	16	12	Cuticular casts, roots, pollen grains
GR-2	>100	>100	2	3	107	Pollen grains

Table 2. Results of phytolith analysis. The phytolith assemblages (in %).

Composition of the phytolith complex	Sample		ICPN 2.0. code
	GR-1	GR-2	
Dicotyledonous and several monocotyledonous herbs	62	29	ELO_ENT
Coniferous	13	7	BLO_VEL
Forest grasses	–	1	ACU_BUL_1
Meadow grasses	6	21	ACU_BUL_2; BIL; ELO_SIN; POL
Dry meadow grasses	–	14	RON_CON; RON_TRZ
Reed	13	1	BUL_FLA
Ferns and mosses	–	11	ELO_SIN
Mosses	6	16	SPH_PSI

Sample GR-1. The sample contains a large amount of plant detritus, amorphous organic material and the remains of grass roots. Pollen grains and the cuticular casts of plant cells are also present. Among the silica microbiomorphs, variably-preserved diatoms, clearly predominate (Table 1). In addition to diatoms, fragments of sponge needles with no signs of corrosion are well preserved.

Phytoliths are relatively scarce. The forms identified represent meadow grasses (68%), reed (13%), the needles of coniferous trees (13%) and mosses (6%) (Table 2).

Sample GR-2. The sample is enriched in herbaceous detritus, amorphous organic material and pollen grains. Sponge spicules and diatom shells are rare, while phytoliths clearly dominate among silica microbiomorphs (Table 1). Analysis has also revealed phytoliths that did not separate from the organic tissue (Figure 3/9).

The phytolithic complex is dominated by grasses, forms typical of wet and dry meadows (21% and 14%). Analysis shows the elevated representation of ferns (11%) and mosses (16%) in the sample (Table 2).

4.2 Non-pollen palynomorphs

The concentrations of pollen and spores, non-pollen palynomorphs, charcoal particles and fungi/plant/animal remains vary considerably from sample to sample (Figures 4 and 5; Table 3).

Sample GR-3 displays a high total pollen concentration and high algal (mainly those of the genus *Pediastrum*) and fungal concentrations. Charcoal particles, dominated by microcharcoal, are abundant. In contrast, sample GR-4 exhibits much lower palynomorph values and an almost complete absence of charcoal particles – the pollen

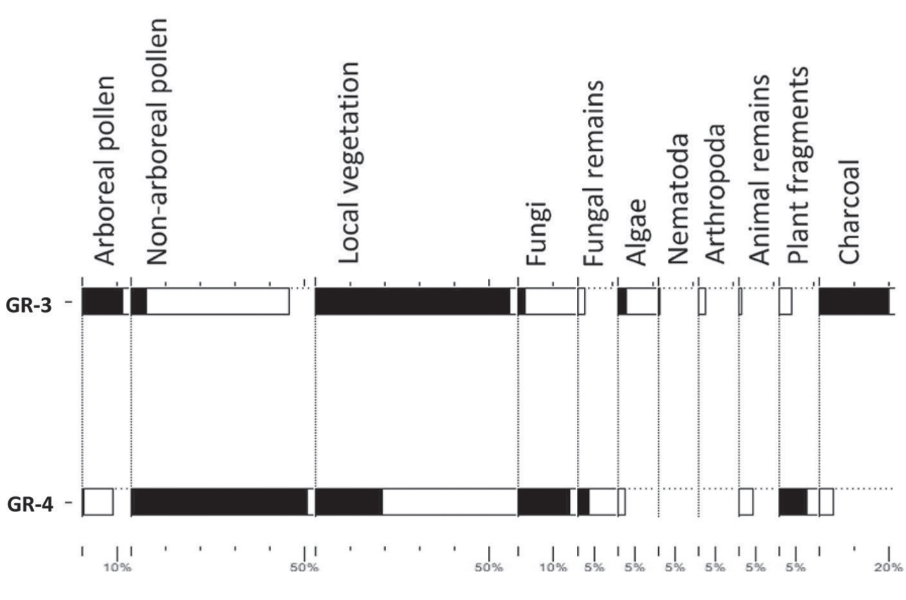

Figure 4. Percentage values of different palynomorph groups and charcoal particles in the samples of Graft.

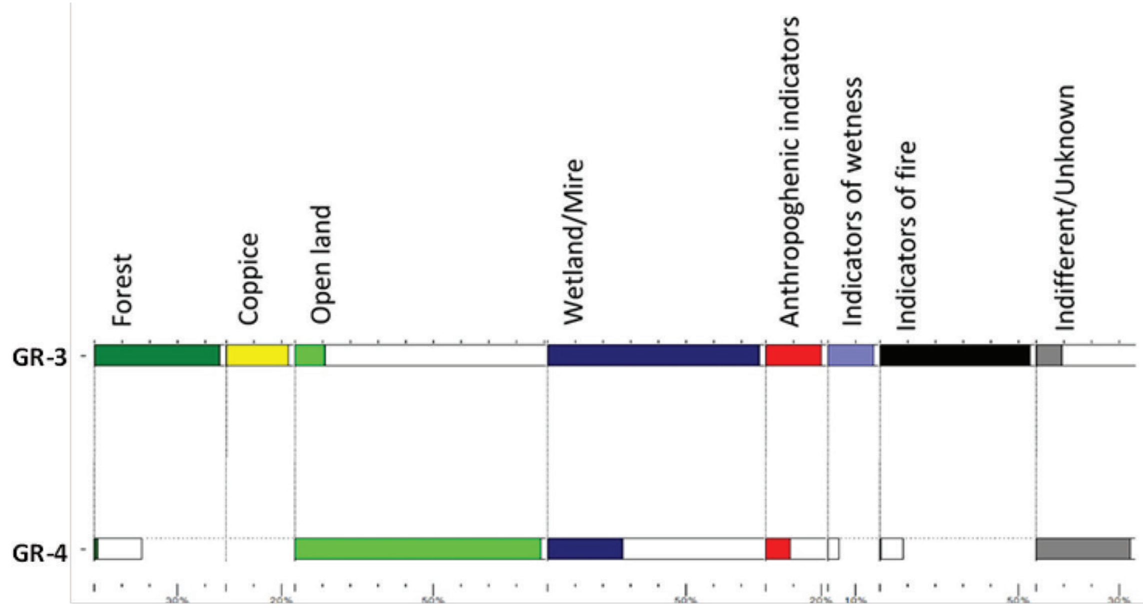

Figure 5. Percentage values of different vegetation types (FOREST: *Pinus*, *Fagus*, *Carpinus*, *Acer*, *Tilia*, *Quercus*, *Ulmus*, *Alnus*, *Betula*; COPPICE: *Corylus*; OPEN LAND: *Senecio* t., Caryophyllaceae, Plumbaginaceae, Fabaceae, Poaceae); WETLAND/MIRE: Ericaceae undiff., *Calluna vulgaris*, Cyperaceae, *Typha latifolia* t., *Sparganium* t., *Potamogeton/Triglochin*, Polypodiales, *Sphagnum*, *Hydrozetes* - Acari Oribatida (HdV-36), *Sphagnum* - leaf fragments, Moss – leaf, Moss-sporangium, Fern-sporangium fragments; ANTHROPOGENIC INDICATORS: *Humulus/Cannabis*, *Persicaria maculosa* t., *Artemisia*, Chenopodiaceae, *Polygonum aviculare* t., *Plantago lanceolata* t., Cerealia (cereals), *Podospora* (HdV-368), *Capillaria cf. putorii* egg; INDICATORS OF WETNESS: *Spirogyra*, *Pediastrum*, *Botryococcus*, Spermatophore of Copepoda (HdV-28), Chydoridae (copepods), *Entophlyctis lobata* (HdV-13), FIRE INDICATORS: macrocharcoal and microcharcoal particles; INDIFFERENT/UNKNOWN: *Meliola ellisii* (HdV-14), *Entorrhiza* (HdV-527), *Glomus* (HdV-207), ZAG-1, ZAG-2, ZAG-3; fungal tissue A (probably fruit body), fungal tissue B (probably fruit body), fungal tissue C (probably fruit body), animal remains (HdV-101), animal remains (probably eggs), plants-stomata, plants-vascular tissue (xylem elements), plants-epidermis (A), plants-epidermis (B), plants-epidermis (C).

concentration is almost four times lower, as compared to that of sample GR-3. It is accompanied by fungi and plant remains (mainly xylem vessels).

Sample GR-3. Non-pollen palynomorphs, such as algae, prevail. *Pediastrum* (especially the taxon *Pediastrum boryanum*) is much more abundant, as compared to *Spirogyra*, *Botryococcus* or Volvocaceae (Figure 6).

Within the fungi group, *Podospora* spores are most abundant, accounting for 4.5%. *Podospora* is followed by *Glomus* (3.4%) and the newly-found ZAG-3 (2.7%) fungus. Although *Glomus* seems to indicate erosion phenomena (van Geel *et al.*, 1989) related to anthropogenic activity and drought, this fungus is involved in arbuscular mycorrhiza and can colonise the roots of plants overgrowing the slab surface. *Meliola ellisii* (HdV-14) of the family Meliolaceae is an obligate and rather oligophagous parasite occurring on green plants. This fungus is a common parasite on *Calluna vulgaris* (van Geel *et al.,* 1981) and is often found on relatively dry *Calluna* bog (van Geel *et al.,* 1981).

Other groups (Nematoda, Arthropoda, animal remains, as well as plant and fungal fragments) are less common. The presence of an egg of *Capillaria cf. putorii*, a common parasite of the canine (Canidae) and marten (Mustelidae) families (Gomper *et al.,* 2003), is noteworthy.

Furthermore, analysis has revealed indicators of wet conditions and an aquatic environment, such as Copepoda (HdV-28) and Cladocera carapaces (Chydoridae) (van Geel, 1978; van Geel and Middeldorp, 1988).

Sample GR-4. Fungal spores and fungal remains (mostly tissue from, probably, fruit bodies) prevailed. Two unknown fungal forms, probably spores: ZAG-2 (~15%) and ZAG-1 (~11%), are most abundant; these are followed by plant vascular tissue – xylem vessels (~9%) and fungal tissue (~7%). Algae are almost completely missing in the sample, only one *Pediastrum* coenobia was found.

4.2.1 Short description of newly-found non-pollen palynomorphs

ZAG-1 – probably chytrid zoosporangia, operculated, appended, thick-walled (ca 0.3 μm). Variable in shape and size, from almost circular to, most often, irregularly piriform or reniform. Length 25–30 μm, width 10–15 μm, with opercula 17–25 × 7–12 μm in diameter (occupies approximately 4/5 of the sporangia surface). Colour yellow.

ZAG-2 – fungal ascospores, elipsoid to subspherical, 37–43.3 μm long and 25–30 μm wide. Single cells small, inaperturate, subspherical or lightly polygonal, 4–10 μm in diameter, thick-walled. Colour is dark-brown.

ZAG-3 – fungal ascospores, cylindric elongated with rounded ends, 57–63 μm long, 14–17 μm wide. Single cells rarely round, often angular, inaperturate, 4–7 μm in diameter, with muri ca 2.3 μm wide. Cells are mostly arranged in two rows. Colour is dark-brown.

Table 3. Basic categories and the total amount of palynomorphs (in units).

BASIC CATEGORIES OF MICROFOSSILS

Sample	ARBOREAL POLLEN	NON-ARBOREAL POLLEN	LOCAL PLANTS	FUNGI	FUNGAL REMAINS	ALGAE	NEMATODA	ARTHROPODA	ANIMAL REMAINS	PLANT FRAGMENTS	CHARCOAL
GR-3	183	71	871	38	4	46	1	4	2	6	316
GR-4	4	224	86	67	16	1	0	0	2	36	2

ARBOREAL POLLEN

Sample	*Pinus*	*Fagus*	*Carpinus*	*Acer*	*Tilia*	*Quercus*	*Ulmus*	*Alnus*	*Betula*	*Corylus*
GR-3	26	11	5	1	6	18	7	43	5	61
GR-4	1	1	0	0	0	2	0	0	0	0

NON-ARBOREAL POLLEN

Sample	*Senecio*	Caryophyllaceae	Plumbaginaceae	Fabaceae	*Humulus/Cannabis*	*Persicaria maculosa* t.	*Artemisia*	Cichoriaceae	Chenopodiaceae	*Polygonum aviculare* t.	*Plantago lanceolata* t.	Poaceae	Cerealia
GR-3	8	2	2	0	3	1	1	7	26	1	1	11	8
GR-4	5	1	0	4	0	0	0	0	0	0	1	193	20

LOCAL PLANTS

Sample	Ericaceae undiff.	*Calluna vulgaris*	Cyperaceae	*Typha latifolia* t.	*Sparganium* t.	*Potamogeton/ Triglochin*	Polypodiales	*Sphagnum*
GR-3	63	161	48	12	1	0	167	419
GR-4	0	0	80	0	0	2	1	3

FUNGI

Sample	*Entophlyctis lobata* (HdV-13)	*Meliola ellisii* (HdV-14)	*Podospora* (HdV-368)	*Enthorhiza* (HdV-527)	*Glomus* (HdV-207)	ZAG-1	ZAG-2	ZAG-3
GR-3	5	1	12	4	9	0	0	7
GR-4	0	0	0	0	1	27	39	0

4.3 Geochronology

All the samples contained a sufficient amount of carbon for accurate measurement and produced a sufficient ion beam during AMS ^{14}C measurement. The δ13C values are in the normal range for organic samples, indicating good reliability of the results.

AMS ^{14}C measurements gave the results in Table 4.

Despite the high measuring accuracy of carbon dating, a wide probability range of calibrated age, from the mid-17th to the 20th century, was obtained for 4 wood samples (posts with find nos. 38, 41, 42 and 44). This is due to solar activity fluctuations during the period discussed and, consequently,

Table 3. Basic categories and the total amount of palynomorphs (in units). (*Continuation*)

FUNGAL REMAINS				ALGAE		
Sample	Fungal tissue (fruit body) (A)	Fungal tissue (fruit body) (B)	Fungal tissue (fruit body) (C)	*Spirogyra*	*Pediastrum*	*Botryococcus*
GR-3	4	0	0	5	36	5
GR-4	0	5	11	0	1	0

NEMATODA		ARTHROPODA			ANIMAL REMAINS	
Sample	*Capillaria putorii* egg	Hydrozetes - Acari Oribatida (HdV-36)	Spermatophore of Copepoda (HdV-28)	Chydoridae	Animal remains (HdV-101)	Animal remains (probably eggs)
GR-3	1	1	1	2	2	0
GR-4	0	0	0	0	0	2

PLANT FRAGMENTS									
Sample	Sphagnum - leaf fragments	Moss - leaf	Moss-sporangium	Fern-sporangium fragments	Plants-stomata	Plants- vascular tissue	Plants-epidermis (A)	Plants-epidermis (B)	Plants-epidermis (C)
GR-3	2	0	1	2	0	0	0	1	0
GR-4	0	1	0	0	1	22	10	1	1

Sample	MACROCHARCOAL	MICROCHARCOAL
GR-3	88	228
GR-4	0	2

Table 4. Results of the AMS ^{14}C measurements.

Nr.	Laboratory code	Material	^{14}C age	Probability 68.3%	Probability 95.4%
13	FTMC-BV59-1	bulk sample	728±29	1268–1292 cal CE	1229–1379 cal CE
18	FTMC-BV59-2	wood	406±27	1445–1490 cal CE	1437–1621 cal CE
38	FTMC-HJ79-1	wood	133±27	1684–1930 cal CE	1675–1942 cal CE
41	FTMC-HJ79-2	wood	178±26	1668–1928 cal CE	1659–1915 cal CE
42	FTMC-HJ79-3	wood	104±26	1695–1916 cal CE	1686–1928 cal CE
44	FTMC-HJ79-4	wood	207±27	1655–1800 cal CE	1646–1925 cal CE

a decrease in the precision of radioactive signal calibration. It is clear, however, that the wood studied from the above four samples is not older than the mid-17th century.

5. Discussion

The results obtained provide valuable additional information on the oldest stages of anthropogenic activity in the region and the palaeoenvironmental background.

First of all, an essential conclusion regarding the function of the layers sampled can be drawn. Both microbiomorphs and NPP analyses indicate that the "dung layer" is a layer of organic matter consisting mainly of grasses from wet and dry meadows, as indicated by the phytolith analysis. The presence of phytoliths that have not separated from organic tissue could indicate "early" (summer) hay harvesting, when lack of the natural decomposition of grasses (*i.e.*, in autumn) would occur (Golyeva, 2008). In this case, the results of the NPP analysis do not support

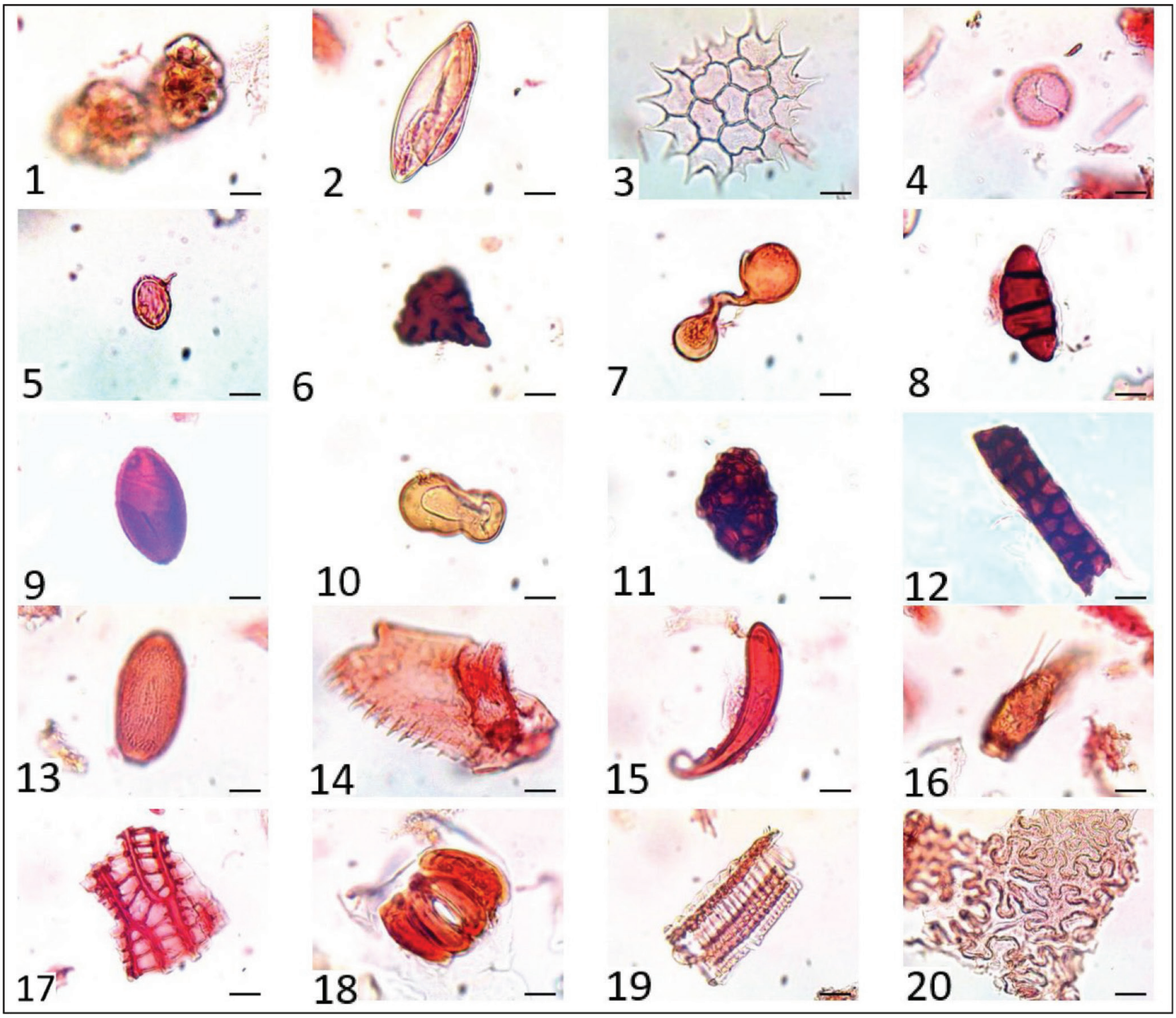

Figure 6. Some selected non-pollen palynomorphs found in the samples GR-11 and GR-10. ALGAE: *Botryococcus* (1), *Spirogyra* (2), *Pediastrum* (3), Volvocaceae (HdV-128) (4); FUNGI: *Entorrhiza* (HdV-527) (5), *Entophlyctis lobata* (HdV-13) (6), Glomeromycota - *Glomus* (7), *Meliola ellisii* (HdV-14) (8), *Podospora* (HdV-386) (9), ZAG-1 (10), ZAG-2 (11), ZAG-3 - very similar to EMA-85 (12); ANIMAL REMAINS: *Capillaria cf. putorii* (13), Chydoridae - Cladocera carapaces (14), Spermatophore of Copepoda (15), Hydrozetes (Acari: Oribatida) (16); PLANT FRAGMENTS: *Sphagnum* leaf (17), stomata (18), vascular tissue (xylem element) (19), epidermis (20).

the assumption that the layer is manure, because it contains no reliable coprophilous indicators, such as *Sporormiella*-type, *Sordaria*-type or *Podospora*-type (Baker *et.al.,* 2016). It is more likely that this layer consists of decomposed hay. Furthermore, a relatively high amount of moss, identified by phytolith analysis, could indicate that hay was used as part of the structure together with a moss interlayer (as well as a straw/reed interlayer found at the base of the organic mass).

In this case, that hay was used as cattle fodder, conclusions regarding the diet of the animals kept on the farm could be drawn. Phytolith analysis shows that hay was harvested from various wet and dry pastures. The presence of dry pastures is an important factor showing that, during the period discussed, parcels of land with dryer soil conditions still existed in the territory. Later, they were substantially influenced by the rising water level.

With respect to the function of the sandy layer, microbiomorph analysis has not revealed any clear evidence of human activities or foodstuffs, but the NPP analytical data suggest that the sand layer was part of the floor of a stable at some later stage of the farmyard. This assumption is based on the relatively high percentage of *Podospora* (HdV-368), which indicates the presence of manure on a very local scale (<10 m) and is a well-known indicator of grazing and related activities (Graf and Chmura, 2006; Cugny *et al.,* 2010; Baker *et al.*, 2016).

The radiocarbon data, together with the available finds of pottery and known historical sources, has led us to some conclusions regarding the habitation phases at the locality studied.

The earliest phase of activity began when people came to the region for soil reclamation in the 13th–14th century. This date is based on the pottery fragments found and the correlated AMS ^{14}C date (1229–1379 cal CE). The hay layer revealed could have been part of a haystack or a so-called "hallenhuis" – a type of a long-standing, one-storey farmhouse with a living area, a cowshed, and grain and hay storage, under one roof. This type of house was well-known in most of the Netherlands and Northern Germany in Medieval times (Waterbolk, 2009).

Probably, in the 16th – early 17th century, a restructuring of the farmyard took place. This assumption is supported by the dating of a wooden stake, which was part of the internal structure (1437–1621 cal CE). Historical records suggest that in 1607–1612 the reclamation of the Beemster, one of the biggest lakes in the study area, took place, triggering a new phase of economic activities in the region (Reh *et al.,* 2005). According to the archaeological data, a new type of house, so called "stolp boerderij", a regional common, square-shaped, pyramidicaly-roofed type of farm, which came into use in the mid-16th century, was built on the location (Waterbolk, 2009). It seems that while renewing the farmyard, a sandy layer was added to level the area for the new stage of living.

The third stage of activity at the farmyard is marked by the next renewal of the house in the 18–19th century, as indicated by the remains of brick walls built at this stage and found during excavation. The house is referred to in the cadastral archives as early as 1832, maintaining its "stolp boerderij" form up until 2019, when final reconstruction, followed by archaeological excavations, began (Kalverdijk, 2020).

The results of the microbiomorphic and NPP analyses illustrate the local palaeoenvironmental dynamics in the Medieval and Early Modern period. Thus, a variety of phytolith assemblages and the presence of pollen from cultivated cereals support the existence of wet meadow and dry grassland landscapes, as well as agricultural plots in the study area during the 13th–14th century. The presence of anthropogenic indicators, such as *Cerealia, Artemisia, Plantago lanceolata t., Polygonum aviculare, etc.*, as well as a high percentage of micro- and macro-charcoal particles revealed in the sand layer, indicate that in the 16th–17th century the area was considerably affected by human activities. *Humulus-Cannabis* type, found in the pollen spectrum (3%), seems to be related to rope making from *Cannabis* as used in sailing and known from historical sources (Kaptein, 1988), although this pollen type could just reflect the occurrence of *Humulus* as part of its natural dispersal. It is important to point out that the study area is situated in a peatland, where no sand deposits are available on the surface. Nothing is known so far about the logistics or trade connections of Graft as regards deliveries of sand, but such connections must have existed, as indicated by the intensive building and economic activity during the 16th–17th century. The probable nearest source of sand used at the farmyard was located to the west of Graft, most likely on the border between the inland edge of the dune area and the mire or lake, which at that time still existed. This conclusion is in good agreement with the data provided by the NPP and microbiomorphic analyses of the sand layer. This is evident both from NPP moisture indicators (*Spirogyra, Pediastrum, Botryococcus*, *etc.*) and from the predominance of diatoms and sponges among the microbiomorphs found in this layer. Analysis has also revealed the presence of well-preserved pollen, plant roots and detritus in the sample, which is also characteristic of surface sediment layers along the water line. The composition of the phytolith complex reflects the natural vegetation at a site of sand extraction: it originates from a coastal forest edge with meadow vegetation and reeds. The NPP data suggest that plant composition is indicative of alder, oak and pine-dominated forest (with, probably, the overgrowing of wetter areas), while the presence of Chenopodiaceae and Plumbaginaceae is an argument in favour of naturally-saline marshes that may have been close to the study area.

6. Conclusions

The study has shown that microbiomorphic and NPP analyses provide a deeper insight into archaeological findings. First of all, an essential conclusion regarding the function of the two sampled layers was drawn. NPP analysis has not supported the manure origin of the layer, as first interpreted as such solely by visual examination. Meanwhile, microbiomorphic analysis showed that the layer seems to be hay, as indicated by the predominance of phytoliths of meadow grasses as well as the presence of phytoliths that had not separated from the organic tissue in a natural seasonal manner. The hay could have been used either as fodder for cattle or as part of a structure.

Furthermore, microbiomorphic and NPP analyses were able to clarify the origin and function of the sand layer, and provided information on the location of sand extraction and its further function within the farmyard. Sand could have been brought from the region to the west of Graft in the farm renewal phase and had been used to level the surface. Part of the layer could have been used as a floor in the stable, as indicated by a relatively high percentage of coprophilous *Podospora* (HdV-368).

The research also provided important information on the local palaeoenvironmental dynamics and phases of economic activity at the farmyard in the Medieval and Early Modern periods.

To conclude, the study has demonstrated the informative value and effectiveness of microbiomorphic and NPP analysis in rescue excavations, especially when performed in combination, thus obtaining information which can be complementary and, to some degree, corroboratory to the results of each analysis.

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