Research Article

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Phytolith aided paleoenvironmental studies from the Dutch Neolithic

Abstract: There is increasing evidence for crop cultivation at sites of the Neolithic Swifterbant culture from ca. 4300 B.C. onwards. Presence of cereal fields at the Swifterbant S2, S3 and S4 sites has been corroborated from micro morphological studies of soil samples. Swifterbant sites with evidence for cultivated plants are still scarce though and only emerging, and have produced very low numbers of charred cereals only. The major aim of our work was to elucidate the environmental background of the Dutch Neolithic site Swifterbant S4 based on the investigation of phytolith remains retrieved from soil samples. In addition to find evidence for crop cultivation independently from other studies. Samples were taken at 1 cm intervals vertically from the soil section at the central profile of site S4. Additional samples were taken from pocket-like structures and adjacent horizons above and below. Pig coprolites yielded an astonishing phytolith assemblage which was compared to that of the soil samples. A pig tooth also yielded evaluable material via detailed investigation using SEM. The evaluation of phytolith assemblages retrieved from the soil horizons plus those ending up in the droppings of pigs feasting in the area enabled to draw a relatively reliable environmental picture of the area. All these refer to the presence of a Neolithic horticulture (cereal cultivation) under balanced micro-climatic conditions as a result of the vicinity of the nearby floodplain. These findings corroborate those of previous soil micro-morphological studies.

Keywords: Phytolith; monolith; coprolite; molar; Neolithic; Swifterbant; paleosol

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1 Introduction

One of the most significant transformations in human history is connected to the so-called neolithization process. It was the time when traditional hunting-fishing-gathering subsistence strategies were exchanged for by a new sedentary lifeway based on crop cultivation and animal husbandry. This process initiating from the area of the Fertile Crescent, expanded northward gradually reaching the area of the modern Netherlands as well [1].

The Mesolithic/Neolithic transition in the area hallmarked not only a shift in landscape utilization, but also in subsistence and the diet as well. A new broad spectrum subsistence emerged relying on terrestrial and freshwater resources [2–6] putting larger pressure on the landscape and the environment [7, 8]. Crop cultivation developed subordinately besides animal husbandry due to the unfavorable endowments [5–7, 9, 10]. It's still not clarified though whether or not the majority of settlements were temporary or permanent. The question of the spatial distribution of arable lands is also still open. One must think about a mixture of larger plots away from the wetlands and inundated areas and a wetland of small plots with minimal yields [5, 9, 11]. In order to better understand crop cultivation in a wetland setting during the Dutch Neolithic, a detailed study of a potential arable land would be truly helpful, as the majority of hard data is given by the analysis of allochtonous materials (pollen, seed, phytoliths) [5, 11]. There is increasing evidence for crop cultivation at sites of the Swifterbant culture from ca. 4300 B.C. onwards [5–8, 11, 12]. Presence of cereal fields at the Swifterbant S2, S3 and S4 sites has been corroborated from micromorphological studies of soil samples [12]. Nevertheless, Swifterbant sites with evidence for cultivated plants are still scarce.
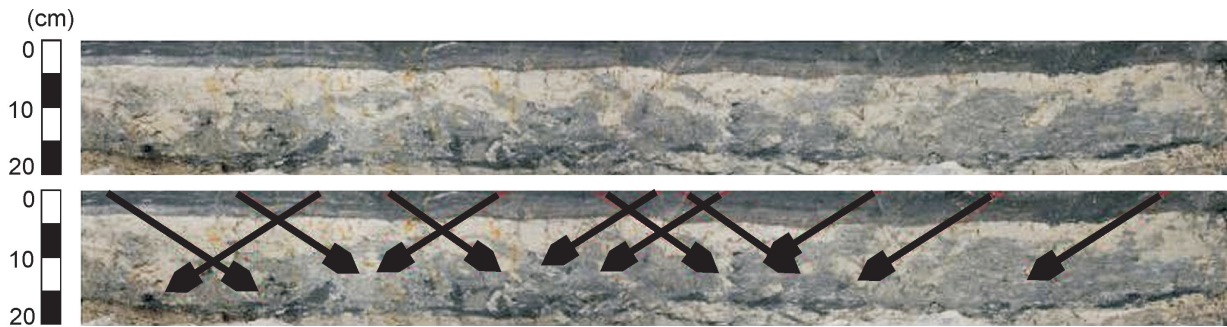
Our study site is one of the most significant in Dutch Neolithic related to the people of the so-called Swifterbant Culture, who settled in the area during the 5th millennium BC (4300 – 4000 cal BC). The site extensively studied and excavated by Daan C. M. Raemaekers exposes a multilayered profile of paleosols, embedding pocket-like structures highly resembling toolmarks left by digging sticks (Fig. 1

Figure 1: The studied paleosol monolith with pocket-like structures.

structures marked by arrows) [5, 6, 12]. The mere presence of these structures raised several issues regarding the prehistory of the site, important from the point of paleoenvironmental and geoarcheological research as well. Namely, if they are truly the outcome of agricultural activity implemented using digging sticks, then fossil plant remains embedded in the layers can reveal the variety of plants once cultivated by inhabitants of the site. Unfortunately, no pollen or macroplant remains could have been retrieved from these layers. So phytolith analysis seemed as an ideal tool for finding an answer to the problem. The study of plant opalites in geoarcheology and historical ecology [13] is less extensively used. The method is based on the identification of opalites precipitated in the derma of once living plants [14–17]. As these remains are highly resistant and preserved locally, it renders them ideal for reconstructing local vegetation patterns in contrast to pollen grains [17]. So if our study area was once under cultivation, then we may be able to find and identify these remains of the plants cultivated in the referred structures. Consequently, our aim was to attest plant cultivation at the site on the basis of the study of phytoliths, independently from the findings of other studies of macrobotanical remains and soil micro-morphology [5, 6, 12].
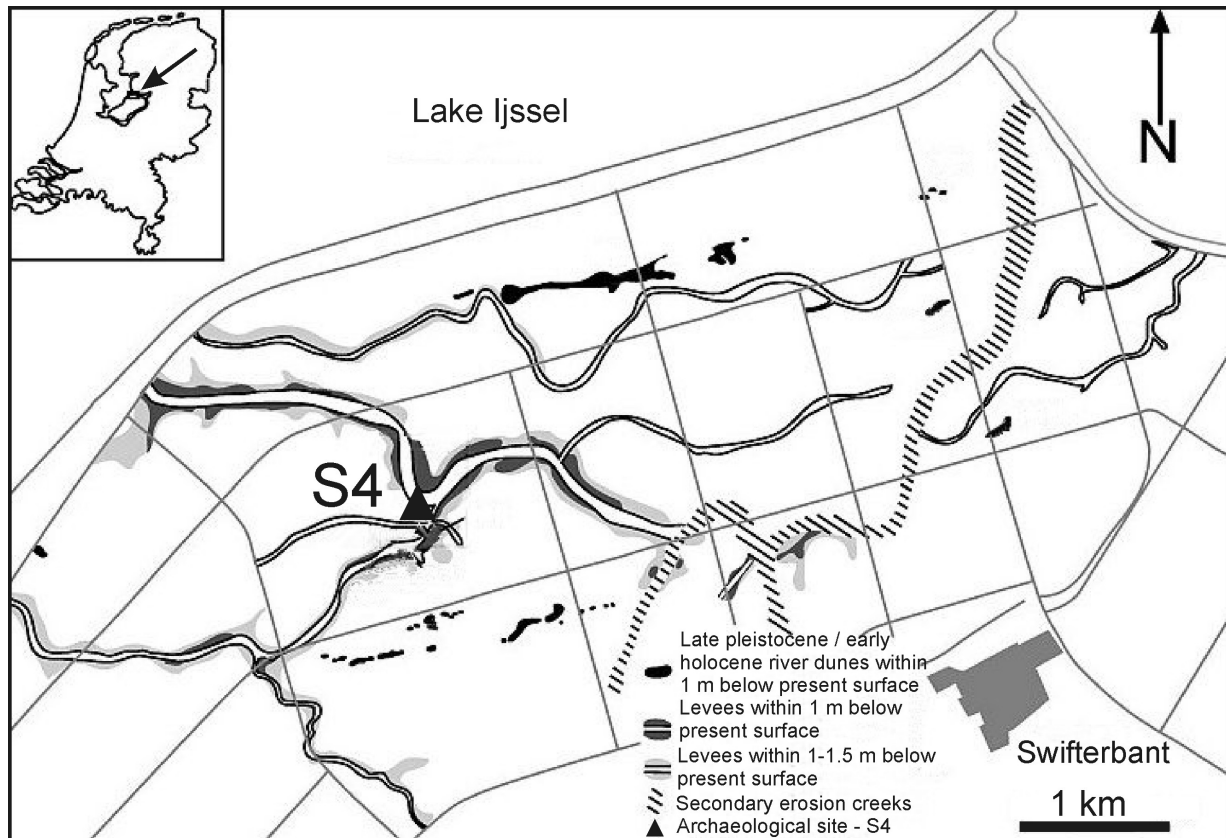
2 Regional setting

The study area is located in Flevoland county of the Netherlands about 3 km west of the village of Swifterbant, where numerous sites of Mesolithic and Neolithic age have come to light following the drainage of the Oostelijk Flevoland polder [5, 18, 19]. Our study material comes from the site of Swifterbant S4 (Swifterbant Culture as the first farming groups in the area) [2, 3, 5, 6, 11, 12, 20, 21]. During the Late Pleistocene the site was located deep in the heart of the continent several hundred kms away from the seashore southeast of the Doggerland Peninsula,

which occupied the North Sea at the time [22]. Certain researchers connected the inundation of the area of Doggerland to a catastrophic event: the Storega Slide tsunami (8200 cal BC) [23]. As a result of this event much of the originally dry areas were inundated by the sea transgressing as far as the Watt Sea. By breaching the coastal sands, the areas of the Dutch Lowland were also inundated [4, 5]. As a result of the southern disposition of the shoreline, the site itself developed in a near-shore tidal system of the North Sea around 6000 years ago [24]. The area was a mosaic of salty marshes studded by natural levees and creeks, as well as sand (Fig. 2) [5, 25]. Settlements are generally confined to the natural levees of the paleochannels. This mosaic of fluvial deposits was preserved by the overlying 1 – 2 m thick marine sequences related to the referred transgression event. The studied archeological features are found in an organic-rich, fine-grained deposit underlying the lacustrine/marine sequence. The feature-bearing level is underlain by a bluish-grey clay horizon often intruding into the referred fine-grained deposit as well [12]. According to the available data, sea level must have been 5.8 – 6 m lower than the modern value during the time of the Swifterbant Culture around the studied sites in Flevoland [21, 26, 27]. However, the more distant and lower lying sea must have been a continuous threat for these communities as well, as storm tides could penetrate deep into the continent [23].
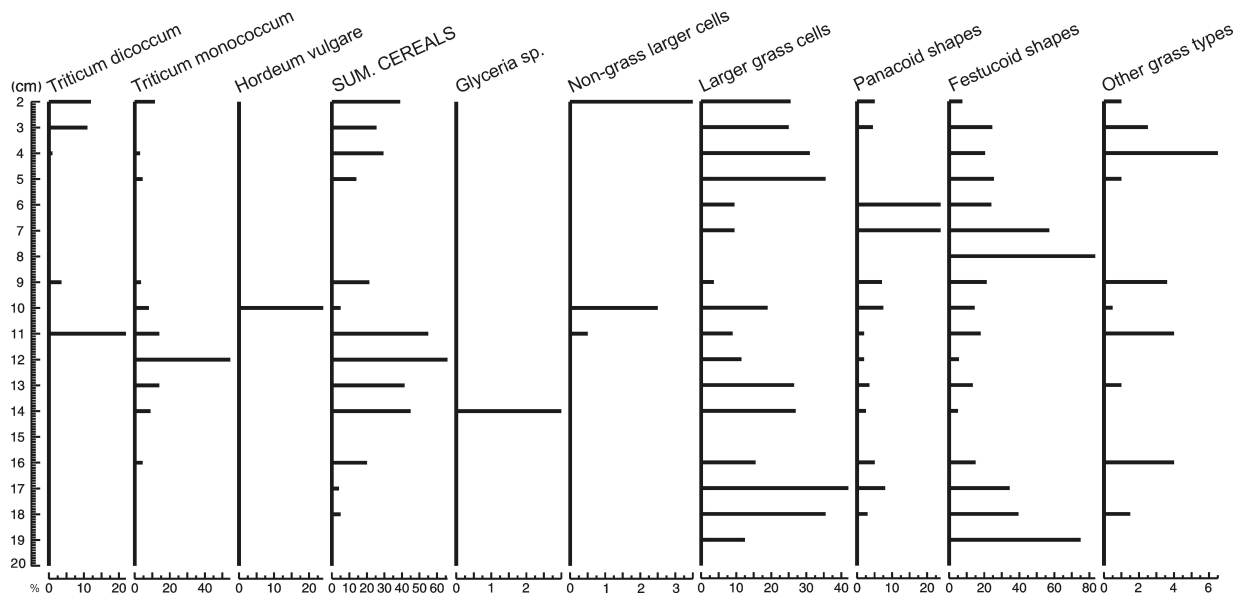
3 Material and methods

3.1 Sampling strategy

Samples for our study come from a soil monolith, a pig tooth and some coprolites from the Swifterbant S4 central site [5, 12]. In case of the soil monolith sampling was aimed to retrieve representative samples from the pocket-like infills and the layers directly underlying and overlying these

Figure 2: The location of the studied soil block and the site S4 [12, 50].
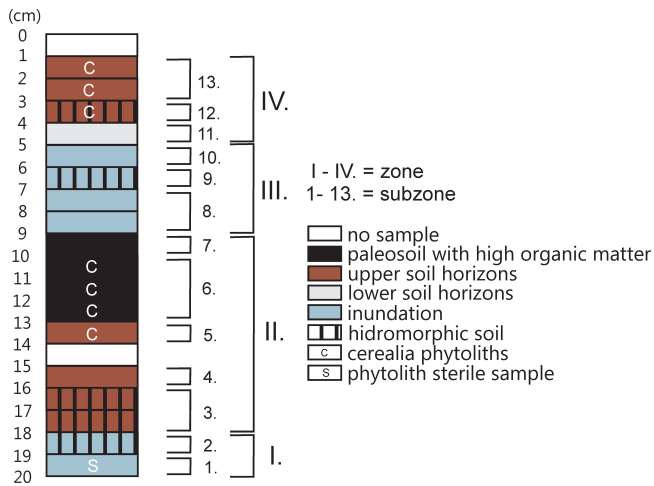

Figure 3: Phytolith diagram of the studied soil block.

observed features. In addition the entire monolith block was sampled at 1 cm intervals vertically (ca. 20 cm in total) (Fig. 6). Altogether 8 pocket-like infills were sampled. One yielded samples from all three sampling points, one

from the infilling material alone and 6 from two sampling points inside and below the observed pocket feature.

The general 1 cm sampling of the monolith enables us to get a general picture of the phytolith composition of the

Figure 4: Zonal and subzonal classification of the studied soil block on the basis of phytolith types and morphs identified.

soil. Sampling from and above as well as below the observed pocket features allow for a comparison with those of the vertical soil. Thus it helps to unravel the developmental history of these structures. Furthermore, we also aimed to test what kind of phytoliths, if any are present in the clearly distinguishable overlying eight grey sands and the underlying dark grey clay horizons. After the first preliminary results it became apparent to test the coprolites retrieved from the site thought to be coeval with the studied soil monolith as well. Finally, the study was complemented by the analysis of a pig molar to find phytoliths related to the feeding of these animals and look for correlation with the phytolith material of the studied soil block.

3.2 Phytolith extraction and determination

A personally modified version of the heavy-liquid extraction was adopted in the analysis of the soil and coprolite samples developed at the Department of Geology and Paleontology, University of Szeged [14, 15, 17]. 5 g of the samples were air dried and was shaken with the addition of Calgon solution to remove the organic matter and the carbonates from the samples. It was followed by the removal of the clay fraction and those of with a grain-size higher than 250 micron. A floation with a heavy liquid of 2.3 g/cm^3 enabled for the separation of plant opalites from other non-vegetal quartz grains. The retrieved phytoliths were stored in an Eppendorf tube in glycerine for further study. For the determination process individual slides were prepared and opalites were counted at a magnification of 500x under a biological stereomicroscope type Nikon Eclipse E600 line by line. All identified phytolith

types of the studied samples were also photographed. Altogether 200 counts were made and double-checked preceding final quantification of the results.

Besides the general morphological characterization, secondary features of the identified phytoliths have also been documented following the works of Golyeva [28]. This included such parameters as color and dominant size as the may shed light onto some characteristics of the reconstructed vegetation; *i.e.* woodland with large open patches. Abundance values aid the identification of soil horizons, while the proportion of Elongate LC types can provide us with information in the hydromorphic character of the soil. The observed variance of phytoliths tends to display good correlation with the speed of vegetation shifts. Burnt phytoliths and charcoal refer to burning in the area. Diatoms and sponge spicules on the other hand may hallmark inundation to the area.

The pig molar was investigated via SEM EDAX (Hitachi S-4700 with a RÖNTEC XFLASH detector). For the identification, the internationally accepted phytolith nomenclature has been systematically adopted [29]. For the identification besides the systematic collections of the University of Szeged, Department of Geology and Paleontology, the Colonial Williamsburg, the UCL Institute of Archaeology -Old World Reference Phytoliths (UCL OWRP) results published in various peer-reviewed journals has been used [28, 30–38]. For graphing the results the software PSIMPOLL [39] was utilized.

4 Results

4.1 Paleosol samples

According to the results of our analysis the studied paleosol monolith could have been divided into four phytolith zones (I–IV) with 13 subzones (Figs. 3 – 4, Table 1). Zones I and III correspond to the sandy sequences marking transgression to the area. Conversely, zones II and IV represent the paleosol layers hosting human activities and settlement. The identified zones are well in line with zones I–IV of the study of soil micromorphology at the site [12]. The indentified phytolith subzones are as follows:
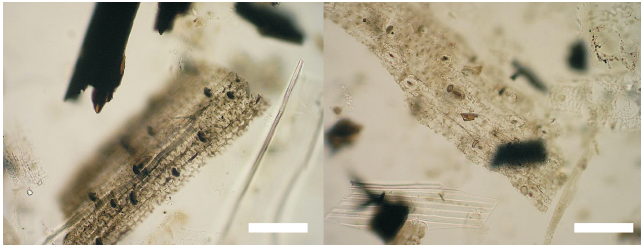
Subzone 1 (20 – 19 cm): free of phytoliths. Some scattered sponge spicules and the highest concentration of diatoms in the entire soil block was recorded here.

Subzone 2 (19 – 18 cm): dominantly transgressive deposits marking inundation and embedding phytolith types characteristic of hydromorphic soils [40], which must
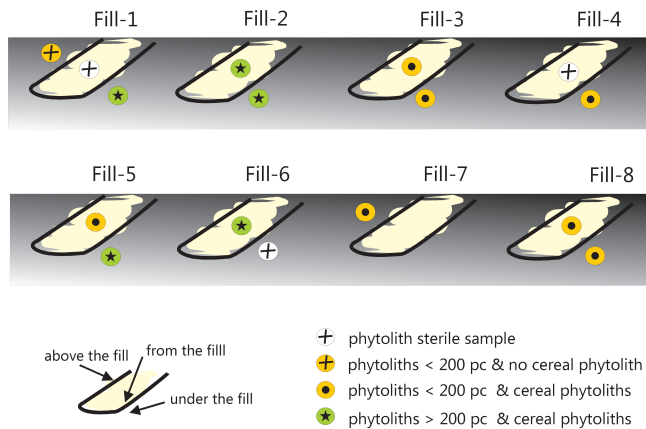
Table 1: Secondary parameters of the phytoliths retrieved from the studied soil block.

Sample (cm)	Dominant Size			Abundance	Elongate (%)	Mixed phytolith assemblages	Burnt phytolith	Charcoal	Sponge	Diatom
	Small (0–20 qm)	Medium (20–40 qm)	Large (40- qm)							
1–2	20,0	23,0	57,0	moderately abundant	23,5	no	-	xxx	xx	x
2–3	31	52	117	moderately abundant	50	no	-	xxx	xx	x
3–4	52	24	24	moderately abundant	26	no	-	xxx	x	x
4–5	21,5	21,5	57	few	30	no	-	xxx	x	x
5–6	7,2	9,5	83,3	very few	28,6	no	-	xxx	x	x
6–7	38,1	23,8	38,1	very few	9,5	no	-	xxx	x	x
7–8	83,3	0	16,7	very few	0	no	-	x	x	x
8–9	17,9	14,3	67,8	very few	1	no	-	xx	x	x
9–10	27	29	44	very abundant	16	yes	-	xxx	xx	x
10–11	31	25	44	very abundant	8,5	yes	-	xxx	xx	x
11–12	18,5	35	46,5	very abundant	7,5	yes	-	xxx	x	x
12–13	23,5	33	43,5	very abundant	26,5	no	-	xxx	x	x
13–14	20,5	31	48,5	moderately abundant	27	no	-	xxx	x	x
14–15	-	-	-	-	-	-	-	-	-	-
15–16	5	21,5	73,5	moderately abundant	13	no	x	xxx	x	x
16–17	54,5	28	17,5	moderately abundant	42	no	-	xxx	xxx	x
17–18	44	30	26	moderately abundant	33,5	no	-	xx	xxx	xx
18–19	7	12,5	0	very few	12,5	no	-	x	xx	xxx
19–20	0	0	0	phytolith sterile	0	no	-	x	xx	xxx

Figure 5: Selected phytoliths of the soil block (1 = *Triticum monococcum* L. 2 = *Triticum dicoccum* Schrank., scale = 50 micron).

Figure 6: Results of phytolith analysis of the pocket-like structures from the soil block.

have been removed from the overlying subzone. The proportion of types marking cool and humid conditions is high here.

Subzone 3 (18 − 16 cm): The upper A horizon of a hydromorphic paleosol. Subordinate, scattered presence of cereal phytoliths.

Subzone 4 (16 − 15 cm): Palosol level. The abundance of phytoliths is significantly reduced probably as a result of reworking into the underlying Subzone 3.

Subzone 5 (14 − 13 cm): A transitional subzone with elevated amount of cereal phytoliths but without concomitant increase in the organic matter.

Subzone 6 (13 − 10 cm): This zone is extremely rich in organic matter and cereal phytoliths, primarily emmer. Phytoliths of barley are also attested here. This zone corresponds to the cultivated A-horizon of the former soil. There is a concomitant increase in grass phytoliths as well an expansion of warm humid climate indicators and a reduction of cool, humid climate indicator elements. Phytoliths of bushes and smaller trees have also been attested in this subzone (Non-grass larger cells).

Subzone 7 (10 − 9 cm): Very similar to Subzone 6 with a reduced number of cereal phytoliths most likely at-

tributable to a downward redeposition of these promoted by the initiating and gradually strengthening inundation from Subzones 8 to 10.

Subzone 8 (9 − 7 cm): Signs of a minor, temporary transgression is inferred as the number of phytoliths is reduced but they still remain in the deposit. Must have ended up here as a result of reworking from the overlying paleosol.

Subzone 9 (7 − 6 cm): Reworked phytoliths characteristic of hydromorphic soils are present here similarly to Subzone 2.

Subzone 10 (6 − 5 cm): The uppermost layer of the transgressional sequence with reduced amount of reworked phytoliths, none of them being cereal types.
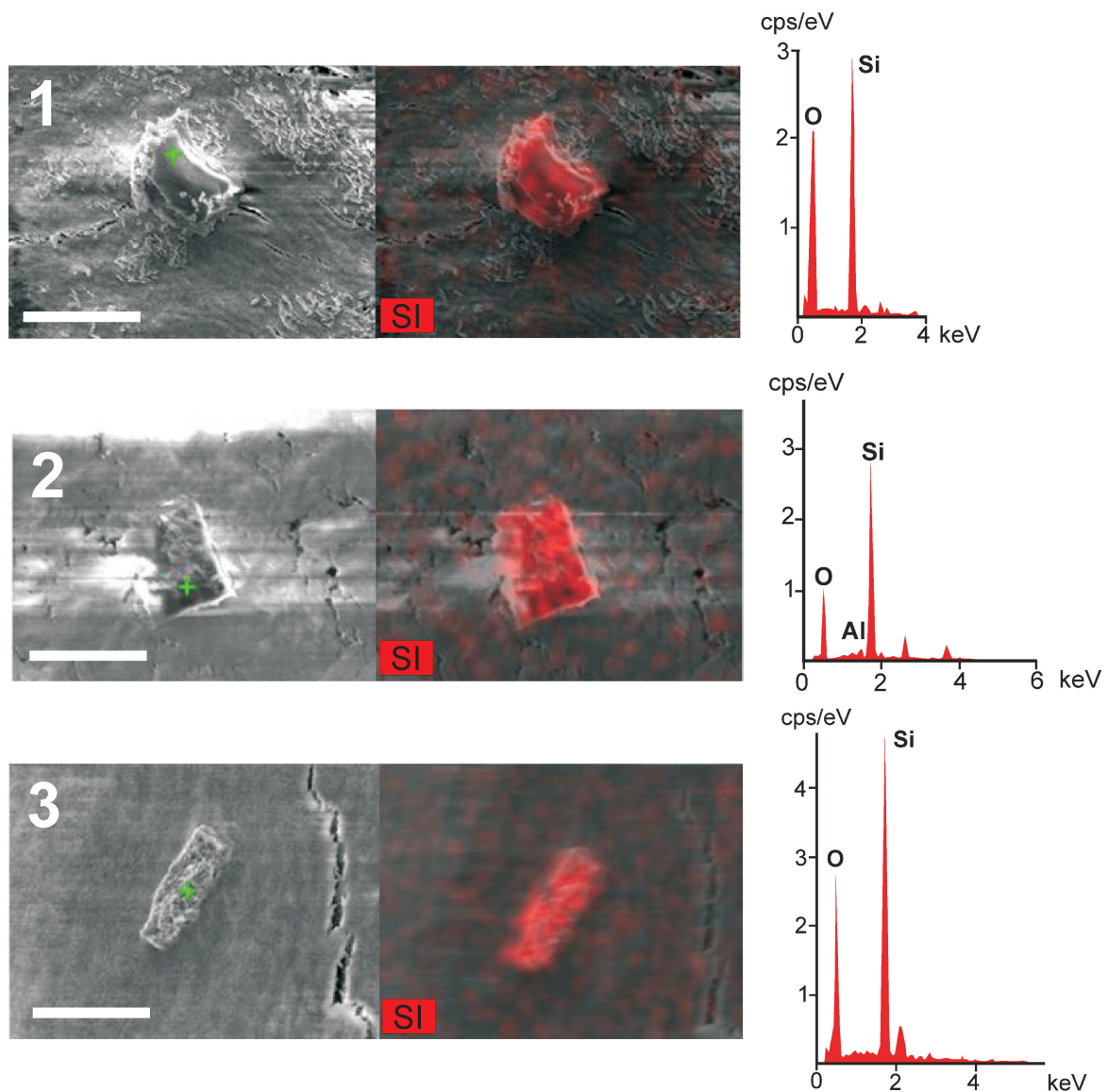
Subzone 11 (5 − 4 cm): This zone is located below the second cultivated paleosol level of the monolith representing the transitional AB horizon of the once cultivated soil. It contained a smaller amount of reworked emmer phytolith as well as Trichom types marking drier and warmer climate.

Subzone 12 (4 − 3 cm): Besides forms characteristic of hydromorphic soils, this subzone is dominated by cereal phytoliths attesting the presence of crop cultivation in the area. It's worth noting though that in contrast to the previous dominance of *Triticum monococcum* L. this zone is dominated by *Triticum dicoccum* Schrank besides the presence of the previous taxon (Fig 5).

Subzone 13 (3 − 1 cm): The previously observed trends are recorded here too without any hints on the hydromorphic nature of the soil.

Based on our findings crop cultivation could have been univocally attested at the site corroborating results of other studies of micromorphology [12] and plant remains [6].

The chosen sampling strategy helped us to add info to the origin of the pocket-like structures as well. If these are anthropogenic in origin marking the use of digging sticks, then the infills (Fig. 3) must contain cereal phytoliths in considerable proportions, while the adjacent areas must show a fairly contrasting picture. The results and interpretation is depicted on Fig. 6. The infills yielded only a highly reduced number of cereal phytoliths. Out of the 7 samples corresponding to the infills, 2 was completely free of phytoliths (Fill-1, Fill-4). Only two samples yielded at least 200 phytoliths, where cereal types could have also been attested (Fill-2, Fill-6). The remaining three samples contained cereal types, but phytolith abundance was very low, less than 200 in all cases (Fill-3, Fill-5, Fill-8) (Fig. 6). According to the findings of micromorphological studies, tillage for the growing of crops–including cereals– was possible [12]. This was not in line with our findings,

Figure 7: SEM photograph of the phytoliths of the studied pig tooth with elemental maps and curves (1 = Saddle 2 = Rectangle short cell 3 = Elongate long cell, scale = 20 micron).

but the lack of phytoliths inside these pockets could be the result of something else as well.

4.2 Pig coprolites

All but one of the 5 studied coprolite samples yielded phytoliths above 200 specimens per sample. All samples yielded phytoliths of emmer (*Triticum dicoccum* Schrank) attesting crop cultivation in the study area.

4.3 Pig molar

Only three phytolith specimens were identified (Fig. 7), none of these were cereals. The identified Rectangle short cell types refer to cool and humid conditions (Panicoid shapes). The Saddle type is typical warm and dry environment indicator (Festucoid shape). While the Elongate long cell types are common among grasses (*Poaceae*) [38, 41, 42]. This latter form was the most common in the studied sample. The third type was a damaged Cuneiform bulliform type most likely deriving from reed. However, the characteristic peak and a part of the grain was missing.

5 Discussion

5.1 Paleosol monolith

Two differing zones could have been identified. Signs of crop cultivation could have been attested on the basis of the general phytolith composition of the studied soil material. The overlying horizons of marine origin were relatively poor in phytoliths. The scattered remains identified here must derive from the underlying paleosol horizon.

The observed pocket-structures in the studied profile must have been closely linked to the evolution of the site and the cultivated paleosol horizons [12, 43–45]. This assumption is clearly justified by the fact that the proportion of phytoliths within the referred features was generally low. Furthermore, there is no sharp contrast in the abundance and composition of phytoliths between the referred feature and the directly adjacent deposits

5.2 Coprolite and tooth samples

The presence of cereal phytoliths in the studied coprolites posed further questions like was emmer used as a fodder for pigs during the Neolithic? Or was it for the fact that the arable lands were not suitably protected from domestic animals, who could simply wander into the cereal fields and devour the crops? Was there an excess of crops at the time which could justify the use of emmer as fodder? Or did the phytoliths end up in the digestive tract as a byproduct of nuzzling, which is generally characteristic of pigs? The highly variegated, riparian environment must not have provided endless plots suitable for crop cultivation [11]. The assumed average yields for the Neolithic must have been too low for a potential use of cereals as fodder. Rather as crop cultivation must have taken place in small, fenced plots similar to modern horticulture, animals could have gain access to the cultivated areas only if they were allowed to in general. According to ethnological records, pigs are often let into the croplands following the harvest to eat up the leftover grains and straw [46]. This approach is beneficial in several aspects. The treading of the hoofs loosens the soil, also pig drops are ideal fertilizers.

The continuous presence of reed phytoliths (Cuneiform bulliform) in the studied coprolite samples (2 – 12%) makes the exact determination of the feeding season difficult. The general waterside setting must have provided ideal conditions for the year-around presence of reed around the site. Pigs, both domestic and wild forms too, are well-known to dig up rhizomes of reed in times

when other food sources are scarce; *i.e.* during the late fall and winter. Considering the fact that both cereal and a low proportion of reed phytoliths could have been attested in the coprolites, we may assume a season of late summer, early fall following the general harvest at the site. This timing would conform to the idea of freely letting pigs onto the crop fields as well. Another important remark is that while in the paleosol samples reed phytoliths were intact, the majority of deriving from the coprolites were highly damaged probably marking the effects of chewing.

Phytoliths retrieved from the pig tooth have corroborated our presumptions regarding the presence of cool and humid climate indicator forms in the material. Finally, our new results were fully congruent with those of soil micromorphology and coprolite analysis implemented on the same profile of the site [6, 12].

6 Conclusions

On the basis of the new results gained some fundamental issues related to the economy of the site could have been corroborated. These included the question whether or not crop cultivation was actually present at the site. Due to the poor pollen preservation of the samples phytoliths offered an ideal tool to find an answer to these problems. The presence of cereal phytoliths and thus crop cultivation could have been univocally attested in one of the oldest Dutch Neolithic sites. This information is in line with the assumption that wetland areas could have been used for crop cultivation due to the complexity of the biotopes present besides foraging between 4300 and 4000 BC [6, 11, 12]. According to the literature, pollen analysis of coprolites from Dutch sites proved to be a useful tool in paleoenvironmental reconstructions [47–49]. Similar results were gained for phytoliths as well by our work.

Cereal types identified on the basis of phytolith remains (*Tr. monococcum, Tr. dicoccum, Tr. aestivum*) are congruent with data from the literature [6, 7]. Signs of inundation by the sea as inferred from the results of phytolith analysis corroborated the hypothesis according to which these wetland areas were not well-suited for agriculture and crop cultivation [5, 7, 8, 11, 12, 21].

Although the Neolithization of Northern Europe is generally connected to a warmer period known as the Holocene Climatic Optimum, almost all samples yielded cool and humid climate marker elements. This must be attributed to the effects of the local and regional microclimate of the seaside wetland areas, which offered ideal

habitats for plants with various ecological needs creating an environmental mosaic.

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