

Archaeological phytoliths analysis on Rue des Boîteux (Brussels, Belgium).

**The evolution of the Holocene vegetation in the Senne Valley
and medieval urban horticulture**

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I solemnly declare that I have written the Master thesis, Archaeological phytoliths analysis on Rue des Boîteux (Brussels, Belgium). The evolution of the Holocene vegetation in the Senne Valley and medieval urban horticulture, myself. I am aware of the rules on plagiarism and have therefore ensured that these have been applied in this master thesis.

31/07/2019, Etterbeek

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A handwritten signature in blue ink, appearing to read 'Hermans', with a long horizontal stroke extending to the right.

Keywords: phytolith, peat, Dark Earth, methods, horticulture, urbanization, Brussels

Trefwoorden: fytolieten, veen, zwarte lagen, methodiek, tuinbouw, urbanisatie, Brussel

Abstract

In deze thesis wordt een fytolieten-analyse uitgevoerd op het bodemmateriaal van de archeologische site in de Kreupelenstraat, gelegen in het centrum van Brussel (België). In 2014 werd er op verschillende plaatsen in de profielwanden een dik pakket van veenafzettingen uit het Holoceen vastgesteld, dat gedateerd werd van tussen het 9^{de} millennium v.Chr. en de 12^{de}/13^{de} eeuw n.Chr.. Dit pakket werd afgedekt door een sequentie van zwarte lagen, die teruggaan tot de 13^{de} – 15^{de} eeuw n.Chr.. Deze zwarte lagen werden archeologisch geïdentificeerd als middeleeuwse tuinlagen. De huidige studie focust op twee onderzoeksthema's: 1) De studie over het veenpakket die toelaat om, in combinatie met andere archeobotanische proxy's, de evolutie van de vegetatie tijdens het Holoceen in de Zennevallei in kaart te brengen; 2) De studie over de zwarte lagen, die ons in staat stelt om, in combinatie met andere archeobotanische proxy's, onze archeologische kennis over middeleeuwse stadstuinen uit te breiden.

Summary

The present study focuses on the medieval urbanism in Brussels (Belgium) through a rather unknown archaeobotanical proxy called phytoliths. Phytoliths are opal microfossils that can occur in living plant tissues. Phytoliths can survive far longer than the organic plant tissues, as they have an inorganic character. It is possible to identify these fossil phytoliths under the microscope based on their shape, and to link them to their original taxon, even if the plant tissue itself has decayed.

In 2014, an almost complete Holocene peat sequence, dated between the 9th millennium BC and 12th/13th centuries AD, was uncovered. Directly on top of this peat sequence, two Dark Earth units dated between the 13th and 15th centuries AD were uncovered. Based on the geoarchaeological, palynological, carpological, anthracological, and zooarchaeological research these units were identified as medieval urban horticulture units. The peat sequence offered the chance to study the vegetational changes throughout the Holocene in the Senne Valley, the vegetational history of which is rather poorly documented compared to that of the Scheldt basin.

The Dark Earth units were valuable for gaining information on plants linked to urban medieval horticultural activities, which remain a little studied subject matter within the archaeological field. In spite of the important role urban horticulture played in the medieval city, most of our knowledge on medieval urban horticulture still derives from historical records rather than archaeological ones. New plots emerged from the 12th century AD onwards in medieval Brussels to provide for the town dwellers. The emergence of these plots and the horticultural activities are part of the spatial and vegetational developments within the medieval city. Therefore, the horticulture topic is closely linked to the story of medieval urbanism.

A phytolith analysis was executed on the samples from both the peat sequence and the Dark Earth units. This analysis was conducted within a complex methodological framework. Traditionally, phytoliths are extracted from the soil through a number of chemical steps and afterwards investigated under the microscope. For the peat sequence samples three different phytolith extraction methods were used, whereas for the samples from the Dark Earth units these same three methods were combined with a study of the phytoliths in soil thin sections. The thin section method is a less-frequently used method for phytoliths, but it has been repeatedly used in Brussels by Dr. Luc Vrydaghs.

The outcome of the phytolith analysis was different for the peat sequence and the Dark Earth units. Firstly, some issues arose while analyzing the peat sequence. In some parts of the sequence few to zero phytoliths were observed, while other parts yielded more significant results. Furthermore, the top of the peat sequence contained a lot of unknown phytolith material. These two issues should be

resolved in the future by examining more peat deposits in Belgium and by developing a reference collection of phytoliths for Northern-Europe based on present-day vegetation. On the other hand, the phytolith analysis of the Dark Earth units went very well. The phytolith record was able to contribute information to studies of the other archaeobotanical proxies (palynological, carpological, and anthracological studies).

In conclusion, one can state that 1) the phytolith study on Rue des Boîteux has proven to be valuable as it offers new research opportunities for phytoliths in peat, and has contributed information to the study of the Dark Earth units; 2) the integrative study of Rue des Boîteux has proven to be valuable as it was able to document the vegetational changes during the Holocene in the Senne Valley, and it enabled us to extend our knowledge on urban medieval horticulture in Brussels.

Samenvatting

De huidige studie focust op de archeologische site, de Kreupelenstraat (BR295), gelegen in het centrum van Brussel (België). Concreet benadert de studie deze site vanuit een eerder ongekennde archeobotanische proxy, namelijk fytolieten. Fytolieten zijn opale microfossielen, die aanwezig kunnen zijn in de weefsels van levende planten. Doorgaans kennen fytolieten een goede tot zeer goede bewaring in contrast tot de organische plantenweefsels. Dit komt door hun anorganisch karakter. De driedimensionale vormen van deze fytolieten zijn de sleutel om de fytolieten te identificeren onder de microscoop en ze vervolgens terug aan hun originele taxon te linken, ook als het plantenweefsel zelf helemaal vergaan is.

In 2014 werd er in de Kreupelenstraat een veenpakket uit het Holocene blootgelegd dat grote stukken tussen het 9^{de} millennium v.Chr en de 12^{de} / 13^{de} eeuw n.Chr overspant. Bovenop dit veenpakket werden twee zwarte lagen aangetroffen, die teruggebracht konden worden tot de 13^{de} – 15^{de} eeuw n.Chr.. Op basis van het geoarcheologisch, palynologisch, carpologisch, anthracologisch en zoöarcheologisch onderzoek werden deze lagen geïdentificeerd als middeleeuwse tuinlagen in de stad.

Het veenpakket bood de kans om de evolutie van de vegetatie in de Zennevallei tijdens het Holocene te bestuderen. Deze studie is relevant, aangezien de evolutie van de vegetatie in de Zennevallei een thema is dat nog niet uitgebreid bestudeerd werd. De evolutie van de vegetatie in de Scheldevallei tijdens het Holocene, daarentegen, werd reeds grondig bestudeerd.

De zwarte lagen zijn waardevol om informatie in te winnen over planten, die gelinkt kunnen worden aan de middeleeuwse stadstuinbouw. Vanuit een archeologisch hoekpunt is de middeleeuwse stadstuinbouw een eerder onderbelicht thema. Onze huidige kennis over middeleeuwse stadstuinbouw is voornamelijk afkomstig van historische bronnen. Toch is het relevant om dit thema onder de loep te nemen, aangezien tuinbouw een belangrijke rol speelde voor middeleeuws urbanisme. In Brussel verschenen er vanaf de 12^{de} eeuw nieuwe gebieden voor tuinbouw om aan de stedelijke voedselvraag te voldoen. De opkomst van deze nieuwe gebieden en de tuinbouwactiviteiten zijn deel van ruimtelijke ontwikkelingen in het middeleeuws stedelijk weefsel. Daarom kan men stellen dat de studie van middeleeuwse tuinbouw in de stad verweven is met het onderzoeksthema 'middeleeuws urbanisme'.

Een fytolietenstudie werd uitgevoerd op de stalen van het veenpakket en de zwarte lagen. De analyse werd uitgevoerd binnen een complex methodologisch kader. Normaal gezien worden fytolieten geëxtraheerd uit het bodemmateriaal met behulp van chemische reacties, waarna ze worden bestudeerd onder de microscoop. Voor de stalen, afkomstig van het veen, werden er drie verschillende

extractiemethodes gebruikt. Voor de stalen van de zwarte lagen werden dezelfde drie extractiemethodes gebruikt, maar werd er ook een andere methode toegevoegd, namelijk de studie van fytolieten in slijpplaatjes. Deze methode wordt niet frequent gebruikt voor fytolieten, maar heeft in het verleden reeds bewezen erg waardevol te zijn in fytolietenstudies in Brussel uitgevoerd door Dr. Luc Vrydaghs.

De fytolietenstudie van het veenpakket en van de zwarte lagen hadden verschillende uitkomsten. 1) Voor het veenpakket verhinderden enkele problemen de analyse. Sommige delen van het veenpakket bevatten slechts enkele tot geen fytolieten, terwijl andere delen juist heel veel fytolieten bevatten. Een tweede probleem dat zich voordeed was de aanwezigheid van veel onbekende fytolieten in het bovenste deel van het veen. Deze twee problemen kunnen opgelost worden door respectievelijk meer veenpakketten te bestuderen in Brussel en een referentiecollectie van fytolieten te ontwikkelen voor Noord-Europa op basis van hedendaags plantenmateriaal; 2) De fytolietenstudie over de zwarte lagen verliep wel vlot. De resultaten hebben, naast de andere archeobotanische proxy's (palynologisch, carpologisch en anthracologische studie), bijgedragen aan ons beeld van de site in de Kreupelenstraat.

Men kan concluderen dat: 1) De fytolietenstudie van de Kreupelenstraat waardevol is geweest, aangezien het enerzijds nieuwe onderzoekspaden geopend heeft voor de studie van fytolieten in veen en anderzijds bijgedragen heeft aan de studie van de zwarte lagen; 2) De volledige studie van de site in de Kreupelenstraat relevant was, aangezien de evolutie van vegetatie in de Zennevallei tijdens het Holoceen effectief in kaart gebracht is en onze kennis van middeleeuwse stadstuinbouw in Brussel aanzienlijk uitgebreid werd.

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Table of contents

Chapter 1: Introduction.....	1
1.1 Context.....	1
1.1.1 Phytoliths	1
1.1.2 Rue des Boîteux.....	1
1.1.3 Aim of the study	2
1.1.4 Relevance of the study.....	3
1.2 Research questions	4
1.2.1 Archaeological research questions	4
1.2.2 Methodological research questions.....	5
1.3 Methodology	7
1.4 Study	8
Chapter 2: Urban environmental archaeology.....	9
2.1 Urban archaeology: defining (ancient) towns)	9
2.1.1 Sociological and functional approach	9
2.1.2 Attribute-based approach	10
2.2 Medieval developments in Brussels	11
2.2.1 Spatial developments.....	11
2.2.2 Vegetational developments	16
2.2.3 The relevance of environmental studies.....	17
2.3 Dark Earth studies.....	20
2.3.1 Concept.....	20
2.3.2 Brussels	21
2.4 Medieval urban horticulture studies	22
2.4.1 Context.....	22
2.4.2 Scandinavian areas	22
2.4.3 Other areas in Europe	24
Chapter 3: Phytoliths as an archaeological proxy	25
3.1 Biological aspects.....	25
3.2 Taphonomical aspects.....	26
3.2.1 Preservation	26

3.2.2 Deposition	27
3.3 <i>Status Quaestionis</i>	27
3.3.1 History of phytolith research.....	27
3.3.2 Phytoliths as a proxy in medieval studies.....	28
3.3.3 Phytoliths in peat.....	30
3.4 <i>Archaeological research topics</i>	31
3.5 <i>Phytolith processing</i>	33
3.5.1 Sampling.....	33
3.5.2 Traditional extraction technique	33
3.5.3 Soil and sediment thin sections	35
3.6 <i>Limitations and challenges</i>	38
3.6.1 Biases in the phytolith assemblages	38
3.6.2 Modern phytolith reference collections.....	39
Chapter 4: Rue des Boîteux	40
4.1 <i>Site description</i>	40
4.2 <i>Historical background</i>	43
4.3 <i>Conducted research</i>	44
4.3.1 Natural peat sequence.....	44
4.3.2 Dark Earth units	46
Chapter 5: Material and methods.....	49
5.1 <i>Material for the phytolith analysis</i>	49
5.1.1 The natural peat sequence.....	50
5.1.2 The Dark Earth units.....	50
5.2 <i>Extraction methods</i>	52
5.2.1 Laboratory methods.....	52
5.2.2 Microscopic examination	54
5.3 <i>Thin section analysis</i>	56
Chapter 6: Results	57
6.1 <i>Results from the extraction method</i>	57
6.1.1 Taphonomical aspects.....	57
6.1.2 Number of phytoliths.....	58
6.1.3 Inventory	59

6.2 Results from the thin sections (US28, US27, and US26)	65
6.2.1 Taphonomical aspects.....	65
6.2.2 Number of phytoliths.....	67
8.2.3 Inventory	67
Chapter 7: Discussion and interpretation	69
7.1. Peat sequence (9 th millennium BC – 12 th /13 th centuries AD).....	69
7.1.1 Environmental changes.....	69
7.1.2 Anthropogenic signals.....	71
7.1.3 Identification issues	73
7.2 Dark Earth units (13 th – 15 th centuries AD)	76
7.2.1 The marks of horticulture in the Dark Earth units	76
7.2.2 Difference in the phytolith record from the peat and the Dark Earth units.....	76
7.2.3 Comparative analysis between Rue des Boîteux and the Hopmarkt (Aalst, Belgium)	80
7.3 Used methods.....	82
7.3.1 Phytoliths in peat.....	82
7.3.2 Combination of the phytolith extraction method with phytoliths in thin section	83
7.4 Recommendations for future research.....	85
7.4.1 Phytoliths in the peat.....	85
7.4.2 Identification issues	87
Chapter 8: Conclusions	90
8.1 Peat sequence.....	90
8.2 Dark Earth units.....	90
8.3 Methodology	90
Bibliography	92
Appendices	127
Appendix A: phytolith images.....	127
Appendix B: laboratory methods	144
Laboratory method 1 (Royal Belgian Institute of Natural Sciences).....	144
Laboratory method 2: Rapid phytolith extraction from Katz <i>et al.</i> (2010).....	145
Laboratory method 3: from R. M. Albert	145
Appendix C: Report on phytoliths in soil thin sections from Rue des Boîteux	148

List of Figures

Figure 1: 16 th century AD map of Brussels by Jacob Deventer (1555)	14
Figure 2: Map of Brussels showing the location of the studied Dark Earth sites	15
Figure 3: Detail of an illuminated letter from a manuscript from 1462	18
Figure 4: The gradual saturation of the city illustrated by three phases	19
Figure 5: Preservation of the phytoliths.....	26
Figure 6: Examples of morphological significant phytoliths	31
Figure 7: Microscopic view phytoliths: A) soil thin section; B) extraction method	37
Figure 8: Colored phytoliths	37
Figure 9: Global distributions of phytolith reference collections	39
Figure 10: Topographic 3D map of the relief of the Senne Valley based on LIDAR data	41
Figure 11: Location of the site 'Rue des Boîteux'	41
Figure 12: Map of the site	42
Figure 13: Drawing of section 7: North (profile) – Rue des Boîteux.....	42
Figure 14: Overview of the processed samples for phytolith analysis	51
Figure 15: Formation of aggregates	52
Figure 16: Perfectly preserved opaline microfossils in the peat	57
Figure 17: Absolute number of phytoliths	58
Figure 18: Inventory of the phytoliths.....	60
Figure 19: Presence of Poaceae, redundant and other phytoliths	61
Figure 20: Indicators for a wet environment per sample.....	62
Figure 21: Presences of ELONGATE DENTATE and ELONGATE DENDRITIC per sample	63
Figure 22: Non-identified and other phytoliths per sample	64
Figure 23: Relative frequencies of phytoliths preservation grades.....	65
Figure 24: Group of articulated phytoliths in excrements from US27	66
Figure 25: Relative frequencies of the ELONGATE, GSSCP and unidentified.....	67
Figure 26: Inventory of Elongate and the GSSCP in the isolated distribution pattern	68
Figure 27: Anthropogenic indicators in the pollen record for the last phase.....	72
Figure 28: Non-identified and non-classical phytoliths per sample.....	73
Figure 29: Examples of non-classical GSSCP	74
Figure 30: Examples of sedge phytoliths.....	75
Figure 31: Examples of non-classical RONDEL type 1	79

<i>Figure 32: Map with the sites in Brussels where peat has been uncovered.....</i>	<i>86</i>
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List of Tables

<i>Table 1: Relevance of the present study</i>	<i>3</i>
<i>Table 2: Overview on the methodology of the phytolith analysis and its relevance</i>	<i>5</i>
<i>Table 3: Sociological and functional definition of a city</i>	<i>9</i>
<i>Table 4: Set of criteria to evaluate (ancient) cities</i>	<i>10</i>
<i>Table 5: Archaeological sites in Brussels where Dark Earth has been uncovered and studied</i>	<i>21</i>
<i>Table 6: Radiocarbon dating of 12 samples from the natural peat sequence.</i>	<i>44</i>
<i>Table 7: Observed taxa from seeds and fruits, vegetables and oil and textile fiber plants</i>	<i>49</i>
<i>Table 8: Overview of the used laboratory protocols.....</i>	<i>53</i>
<i>Table 9: Classification scheme for phytoliths of ‘Rue des Boîteux’</i>	<i>54</i>
<i>Table 10: Added classification categories and their description</i>	<i>55</i>
<i>Table 11: Overview of the samples used for the inventory</i>	<i>59</i>
<i>Table 12: Number of isolated, clustered and articulated phytoliths per sample.</i>	<i>66</i>
<i>Table 13: Absolute numbers of phytoliths per sample</i>	<i>67</i>
<i>Table 14: Hypotheses for not observing phytoliths in the lower part of the peat.....</i>	<i>70</i>
<i>Table 15: Absolute number of phytoliths for several archaeological sites in Brussels</i>	<i>77</i>
<i>Table 16: Similarities and differences in the phytolith assemblages.....</i>	<i>77</i>
<i>Table 17: Absolute number of non-classical type 1 RONDEL for each sample</i>	<i>78</i>
<i>Table 18: Limitations and advantages per method</i>	<i>82</i>
<i>Table 19: Major complementary strength and limitation for both methods.....</i>	<i>84</i>
<i>Table 20: Extraction method for phytoliths in peat.....</i>	<i>86</i>
<i>Table 21: Wet oxidation and dry ashing processing method.....</i>	<i>88</i>

Chapter 1: Introduction

1.1 Context

1.1.1 Phytoliths

Phytoliths, meaning ‘plant stones’ in Greek, are plant microfossils. Although the term phytoliths can be used to cover all forms of mineralized bodies¹ produced by higher plants, archaeological and paleoecological studies mainly focus on phytoliths made out of opaline silica ($\text{SiO}_2 \cdot n\text{H}_2\text{O}$) (MULHOLLAND and RAPP 1992, p. 2). In archaeology, phytoliths are used as a proxy to provide information about ancient plants. This can be a key element towards understanding the relationship between humankind and its environment. Other archaeobotanical proxies that can help unravel this relationship are ancient pollen, seeds and fruits, charcoal, and remaining tissues of plants. In contrast to these, phytoliths are a lesser-used proxy among European archaeologists. However, a better understanding of these fascinating opal microfossils may be very valuable to archaeologists, as they can provide complimentary or even exclusive information in archaeological contexts. One major advantage of phytoliths is that they tend to remain preserved in places where other organic remains do not or poorly so². Sometimes, they may be the only available proxy for providing information on ancient plants.

1.1.2 Rue des Boîteux

In the present study, phytoliths from the archaeological site Rue des Boîteux- Rue d’Argent, located in Brussels, are studied. This site is located in the center of Brussels and was excavated in 2014 during a rescue excavation under the auspices of the Brussels Capital Region. A natural peat sequence ranging from the 9th millennium BC to the 12th - 13th centuries AD was uncovered in this excavation. On top, two anthropogenic units, more specifically two Dark Earth units from the 13th-15th centuries AD were uncovered. ‘Dark Earth’ is a descriptive term for dark, humus-rich, non-peaty, homogeneous units (DEVOS *et al.*, 2009, NICOSIA and DEVOS, 2014; NICOSIA, DEVOS and MAPCHAIL, 2017).

These Dark Earth units, mostly studied by geoarchaeologists, are commonly discovered during excavations in Brussels (DEVOS *et al.*, 2007; DEVOS *et al.*, 2013a; DEVOS *et al.*, 2017b; Devos, 2019). A wide range of human activities can be hidden behind these peculiar archaeological units such as

¹ including silica, calcium oxalate, calcite, aragonite, vaterite, amorphous calcium carbonate, and organic crystals

² Their study, however, should not be limited to such contexts: phytoliths are also observed in contexts where organic preservation is optimal.

ancient cultural or (semi-)natural processes like accumulation, mixing, and compaction of soils and ancient human activities such as pasture, crop growing, market activities, middening, and gardening (DEVOS, 2019, p. 110).

In the case of Rue des Boîteux several archaeological disciplines including the geoarchaeological, palynological, carpological and archaeozoological studies have pointed out that it is highly likely that these Dark Earth units should be seen as ancient gardens from the 13th – 15th centuries AD. For Brussels, these ancient gardens are mentioned in historical records, but from an archaeological point of view they have not yet been thoroughly studied (CHARRUADAS, 2011, p. 130-132).

1.1.3 Aim of the study

The present study draws on the preliminary study conducted in 2018 (HERMANS, 2018). A phytolith analysis was conducted on 16 samples from the Holocene peat sequence. The study aimed to evaluate the potential of phytolith analysis for the sequence as part of an integrative study of the Holocene evolution of the landscape in the Senne Valley in Brussels. The study concluded that due to potential laboratory issues the presence and identification of phytoliths could not be fully evaluated.

The study only focused on phytoliths in the peat and not on those from the Dark Earth units. Building on the preliminary study from 2018, the present study has three aims:

- 1) To refine the results of the peat analysis on the one hand and, on the other, to conduct new phytolith research on the Dark Earth units.
- 2) To perform a detailed literature study on the general principles of phytolith research and medieval urban horticulture in Europe.
- 3) To integrate the phytolith results with the other archaeological results and evaluate the integrative results from Rue des Boîteux.

1.1.4 Relevance of the study

The present study is contributive in the following ways:

	Phytolith analysis	Rue des Boîteux
The peat sequence (9th millennium BC - 12th / 13th centuries AD)	Complement information to the results from the other archaeobotanical proxies (palynological and carpological study) or provide exclusive information.	Reconstruct the vegetational evolution for Brussels and the Senne Valley during the Holocene. Provide environmental information on the early developments of Brussels (10 th - 13 th centuries AD) .
The Dark Earth units (13th-15th centuries AD)	Complement information to the results from the other archaeobotanical proxies (palynological, carpological and anthracological study) and/or provide exclusive information.	Provide information on urban medieval horticulture and its role in the spatial and vegetational developments of medieval Brussels.

Table 1: Relevance of the present study

Phytolith analysis

The phytolith analysis may complement existing research or provide exclusive information for Rue des Boîteux. For the peat micromorphological, palynological, carpological, and paleo-fire studies were previously conducted. As the site is located in the Senne Valley, the botanical remains had a good preservation. For the sites above the Holocene terraces the botanical remains are often less well preserved. Therefore, Rue des Boîteux is a good case study for an integrative study. For the phytolith study it is interesting to evaluate and compare the results with those from the other archaeobotanical studies.

Rue des Boîteux

The peat deposit offers the chance to evaluate the vegetational evolution in the Senne Valley during the Holocene. This is promising in two ways. Firstly, in contrast to the main basin of the Scheldt River, the evolution of the Holocene vegetation in the Senne Valley is rather poorly documented (MINNAERT and VERBRUGGEN, 1986; DEFORCE, 2011; DEFORCE, BASTIAENS and CROMBÉ, 2014; DEFORCE *et al.*, 2014;; CROMBÉ *et al.*, 2015). Therefore, this study facilitates the reconstruction of the Holocene environment of the Senne Valley and the study of human interaction with the environment there. Secondly, the vegetational record could serve as a reference for future studies in the local and regional environment (MARINOVA *et al.*, 2018).

The Dark Earth units are valuable for gaining information on plants linked to urban medieval horticultural activities. Medieval horticulture has not been thoroughly studied yet by archaeologists. For the moment, most of our knowledge on urban medieval horticulture derives from historical rather than archaeological records. Furthermore, urban horticulture played an important role in the medieval city. New plots emerged from the 12th century AD onwards in medieval Brussels to provide for the town dwellers CHARRUADAS (2011, p. 132). The emergence of these plots and the horticulture activities are part of the spatial and vegetational developments within the medieval city. Therefore, the horticulture topic is closely linked to the story of medieval urbanism.

1.2 Research questions

There are two types of research questions for the present study, namely archaeological and methodological ones.

1.2.1 Archaeological research questions

Based on the two different types of deposits in combination with their dating research questions can be divided into two subsets, questions on the natural peat sequence (9th millennium BC – 12th/13th centuries AD) and on the Dark Earth units (13th – 15th centuries AD).

Peat sequence (9th millennium BC – 12th/13th centuries AD)

The peat sequence offers the possibility to study the diachronic environmental changes from the 9th millennium BC until the 12th/13th century AD through phytolith research. The following specific questions of this diachronic process will be studied:

- Which environmental changes can be deduced from the phytolith record and how have they been recorded?
- At which point in time can anthropogenic influences be observed?
- Are there changes in the phytolith record that can be related to the urbanization process, such as a more intensive use of space?

Dark Earth units (13th – 15th centuries AD)

The phytolith study on the Dark Earth units can provide vegetational information on medieval horticulture in Brussels from the 13th- 15th centuries AD. Phytolith research could contribute to this story by answering the following questions:

- How can the phytolith study contribute to the understanding of horticultural practices?
- Are there differences in the phytolith record from the peat and the Dark Earth units? If so, what do these indicate?

1.2.2 Methodological research questions

The present study is also a methodological pioneering study in two ways. Firstly, phytoliths in peat have never been studied in Belgium and only limitedly so in Europe (BRAADBAART *et al.*, 2017). Secondly, the study combines two phytolith research methods for the Dark Earth, namely the extraction method and the thin section method³. In the phytolith community, the study of phytoliths by means of soil thin sections is not commonly applied; the combination of both methods even less so. Recently, the combination has only been used in three studies: DEVOS *et al.* (2017b), BORDERIE *et al.* (2018) and BANERJEA *et al.* (2019).

	Phytolith analysis: methodology	Relevance
The peat sequence (9th millennium BC - 12th / 13th centuries AD)	Three different extraction methods	To address the laboratory processing issues from the preliminary study (HERMANS, 2018). To extend our knowledge on the processing methods of phytoliths in peat.
The Dark Earth units (13th-15th centuries AD)	Three different extraction methods Phytoliths in soil thin sections	To gain more detailed results with the combination of methods as we are dealing with Dark Earth units. To extend our knowledge on the combination of these two methods.

Table 2: Overview on the methodology of the phytolith analysis and its relevance

³ The extraction method is the method traditionally used for studying phytoliths. Bulk samples are taken in the field. Afterwards, a process in the laboratory takes place to remove all soil particles except for the biogenic silica including phytoliths. Subsequently, the phytoliths are mounted onto a microscopic plate and investigated with a petrological microscope.

Soil and sediment thin section are less frequently used for phytolith research. The technique is mostly used by geoarchaeologists to study ancient soil or sediment. Oriented and undisturbed blocks are sampled in the field and afterwards impregnated (with epoxy resin for example) so that all soil or sediment is kept in place. Subsequently, this block is cut resulting literally in a thin section that afterwards is mounted onto a microscopic slide and studied with a petrological microscope.

The peat sequence (9th millennium BC - 12th / 13th centuries AD)

In 2018 a preliminary phytolith study was conducted on 16 samples from the peat sequence (HERMANS, 2018). This study highlighted complications on the study of phytoliths in the peat. For some parts of the peat, few to zero phytoliths were observed. These results do not necessarily mean that phytoliths were not present. The inability to evaluate the presence of phytoliths in peat possibly/likely originated in the laboratory processing⁴, an issue which is currently being addressed. The present study will use three different laboratory phytolith extraction methods and compare their results. This study of phytoliths in peat will extend our current limited knowledge about processing methods for phytoliths in peat. Following questions need answering:

- Do the three protocols yield the same results? If not, what causes the difference in results?
- Which protocol works best for the present study?
- Is it preferable to combine several extraction methods in the future for obtaining better results?

The Dark Earth units (13th-15th centuries AD)

To answer the research questions about the Dark Earth units in the best way possible, both extraction methods and the soil thin sections methods will be applied for the Dark Earth units. Dark Earth units are homogenized units which means that a clear stratigraphy is absent. This results in units that can contain phytoliths with potentially different depositional histories⁵ (VRYDAGHS, BALL and DEVOS, 2016). In this regard, the extraction method is limiting. As all soil particles, besides biogenic silica including phytoliths, are removed during the extraction process, all the depositional context of the phytoliths is lost as well. A method that tries to tackle this specific problem is studying phytoliths in soil and sediment thin sections. As these thin sections still preserve the surrounding archaeological context, a detailed picture of the depositional context of the phytoliths can be obtained. Following research questions are added to the present study concerning the relationship between both methods:

- Do both methods provide the same results (phytolith assemblages and amounts of phytoliths)? If not, in which way do both methods complement each other?
- What are the advantages and limitations of both methods?
- Is it interesting for future phytolith studies to combine both methods?

⁴ *It could be that the used protocol to remove the other soil particles in the laboratory also affected the phytoliths and that therefore other protocols should be tested.*

⁵ *If manure containing phytoliths (e.g. deriving from excrements) was used on an agricultural field (containing phytoliths from the processed crops) and the field was plowed, then phytoliths from different contexts could mix up. However, both groups of phytoliths tell another story. The phytoliths in the excrements can tell a story of human or animal diet. The phytoliths from the agricultural field give us information on the in situ vegetation.*

1.3 Methodology

The methodology aligns with the three aims of the present study. The aim to perform a detailed study on the *Status Quaestionis* of the general principles of phytolith research and urban medieval horticulture in Europe is accomplished by conducting a literature study.

The aim to refine the results for the peat sequence on the one hand and conducting new phytolith research on the Dark Earth units on the other hand, is fulfilled with the execution of a phytolith analysis including the three extraction methods and the thin section method. The first extraction method was executed in the chemical laboratory at the Geological Survey of Belgium (GSB) at the Royal Belgian Institute of Natural Sciences (RBINS) under the supervision of Dr. Alexandre Chevalier. The two other extraction methods were executed at the chemical laboratory situated at the Department of History and Archaeology at the University of Barcelona (UB) under the supervision of Professor Dr. Rosa M. Albert. The production of the thin sections was outsourced to the laboratory of Thomas Beckmann (Germany). The phytoliths from the three extraction methods were analyzed with a petrological microscope at the Center for Research in Archeology (CReA) situated at the Université Libre de Bruxelles (ULB). Although I had some micromorphological sessions with Dr. Yannick Devos on the thin sections from Rue des Boîteux, I was not yet able to analyze the phytoliths within the thin sections myself. The phytoliths in the thin sections were analyzed by my mentor, Dr. Luc Vrydaghs.

The third aim, to integrate the phytolith results with the other archaeological results and evaluate the results within a broader perspective, is accomplished in chapter 7: discussion and interpretation. Consequently, both the results from the peat sequence and the Dark Earth units are put in a broader perspective and compared to other cases.

1.4 Study

Chapter 2 focuses on urban environmental archaeology. Firstly, it evaluates the different archaeological approaches of studying ancient cities. Secondly, it presents the medieval spatial and vegetational developments in Brussels and the relevance of environmental studies for Brussels. Hereafter, a section on Dark Earth units is presented, including a presentation of the general concept and the research situation for Brussels. Finally, an overview on medieval urban horticulture studies is included.

Chapter 3 is an introductory chapter on archaeological phytoliths and discusses general aspects of phytoliths including the biological aspects and taphonomical aspects. Furthermore, it presents a *Status Quaestionis* on: 1) the history of phytolith research; 2) phytoliths as a proxy in medieval studies; 3) phytolith studies in peat. Next, the different archaeological applications of phytoliths are presented, followed by a section about phytolith processing. Finally, the limitations and challenges of phytolith research are discussed.

Chapter 4 presents three aspects of the site Rue des Boîteux: 1) a site description; 2) the historical background of the site; 3) a synthesis of the previously conducted research for the site including geoarchaeological, palynological, carpological, anthracological, zooarchaeological studies and radio-carbon dating.

Chapter 5 gives an overview on the materials for the phytolith analysis and on the methods used, including the extraction methods and the thin section method and the microscopic examination.

Chapter 6 presents the results in two sections: 1) the results from the extraction method; 2) the results from the thin section. Both sections discuss the three following aspects: taphonomical aspects, number of phytoliths, and phytolith inventory.

Chapter 7, discussion and interpretation, starts with the discussion of the results from the peat sequence and the Dark Earth units, followed by a discussion of the methods used. The last section of the chapter presents recommendations for future research.

Chapter 8 concludes this study with a synthesis of the answers to both the archaeological and methodological research questions.

Chapter 2: Urban environmental archaeology

2.1 Urban archaeology: defining (ancient) towns)

2.1.1 Sociological and functional approach

The first step in understanding urban medieval archaeology is understanding the concept of a city. The complex phenomenon of the city, be it ancient or contemporary, is a subject that has been widely studied by sociologists, archaeologists, historians, architects, and geographers. Urban literature used different approaches to identify cities. Here, three methods used in archaeology following SMITH (2016) will be presented. The first method is approaching cities through definitions. There are two dominant definition approaches, the sociological and the functional approach (**Table 3**). Sociological definitions are better fitted to contemporary cities than ancient ones. Not all ancient cities fit the description of the sociological definition⁶.

Sociological definition	Functional definition
Sociologist WIRTH (1938, p. 8) states that "For sociological purposes a city may be defined as a relatively large, dense, and permanent settlement of socially heterogeneous individuals".	Archaeologist TRIGGER (1972, p. 577) states that "It is generally agreed that whatever else a city may be it is a unit of settlement which performs specialized functions in relationship to a broad hinterland".

Table 3: Sociological and functional definition of a city

A second method is approaching ancient cities through urban typologies. An example of urban typology for European cities after 1000 AD is the two-dimensional typology from Fox (1977) that shows six types of cities. The combination of urban economy (autonomous/dependent) and state power (segmentary/bureaucratic) leads to four quadrant roles (ideological, administrative, mercantile, and industrial role). The ideological role includes (1) regal-ritual cities, the administrative role includes (2) administrative cities and (3) colonial cities, the mercantile role includes (4) mercantile cities and (5) city-states, the industrial role includes (6) industrial cities SMITH (2016, p. 157). Such a typology can help scholars narrow the scope of their research and focus on key aspects, but does not form a tool to identify or describe ancient cities.

⁶ To illustrate: SMITH (2016, p. 154) states that archaeologists SANDERS and PRICE (1968, p. 46) placed the capitals of Classic Maya into a non-urban settlement category.

2.1.2 Attribute-based approach

For the present study, working with a city definition or city typologies would not be optimal. Definitions fail to capture the dynamic character of the urbanization process resulting in the creation of terms like ‘proto-urban centers’ or ‘incompletely urbanized sites’. In order to tackle these issues, the present study will make use of a third approach, archaeological urban attributes. With this method, settlements are evaluated on a number of criteria, and will be considered more urban if they contain more of said attributes. Examples of such attributes are shown in **table 4**.

Categories of attributes	Attributes
Settlement size	high population; area; density
Built environment	Fortifications; gates; defenses; connective infrastructure; formal public space; planning of epicenter; royal palace; a mint; specialized building types for craftsmen and merchants; infrastructure facilities for the inhabitants; religious or sacred structures; plots and houses of the ‘urban’ type; a planned street system
Social impact (urban functions)	a complex religious organization; a judicial center, legal autonomy; a role as a ‘central place’
Social and economic features	lower elite burials/royal or high aristocratic burials; social differentiation; neighborhoods; agriculture within settlement and/or relationship with the hinterland; separation from the surrounding countryside; a diversified economic base; a concentration of trading and craft production; one or more markets

Table 4: Set of criteria to evaluate (ancient) cities

Note that the four classification categories of SMITH (2016, p. 159) are used and attributes from different scholars are included in these categories (WEBER, 1958; BIDDLE, 1976; FLANNERY, 1998; SCHOFIELD and STEUER, 2007; RENFREW, 2008).

The classification is to some extent artificial. In reality a lot of attributes can belong to different categories, and are related to each other. For instance, the role of a ‘central’ place can be either political, social, religious or economical and will most likely be all four simultaneously. However, this method makes it possible to capture and understand the complexity of ancient cities. It is useful for archaeologists as it is possible to investigate many of these attributes through archaeological data. This also counts for archaeobotanical data. The attribute ‘vegetation’ can be linked to agriculture, economy, openness of the landscape *et cetera*. The attribute ‘vegetation’ has been less thoroughly

studied in comparison to the architectural remains and other easily identifiable activity areas. Therefore archaeobotanical research holds great potential for further unravelling the complexity of ancient cities. Throughout the present study this attribute-based identification method is used.

2.2 Medieval developments in Brussels

2.2.1 Spatial developments

This section contains two maps on which all relevant places are indicated to illustrate spatial developments (in and around Brussels). The first map (**Fig. 1**) indicates the significant places (indicated in the text with A, B, C...) within the perimeter of the two city walls. The second map (**Fig. 2**) presents the locations of the sites where Dark Earth was uncovered and studied for Brussels. In addition, one can also take a look at the map (**Fig. 10**) included in Chapter 4 to understand the relief of Brussels.

Brussels is a so-called 'second generation city'. The city does not have Roman origins and only starts to appear in historical documents from the 11th century AD onwards (CHARRUADAS, 2012, p 256). From an archaeological point of view, Brussels is a city that starts to emerge from the 7th century AD onwards. From the 7th – 10th centuries AD settlements start to appear and the population size increases. Different sites illustrate this process:

- 1) the hilltops including the Treurenberg site (A) and the Coudenberg site (D);
- 2) the plateau including the site of Place de la Vieille Halle aux Blés (E);
- 3) the banks of the Senne Valley including the sites Riches-Clares (B), Saint-Géry chapel and the church Saint-Nicholas (F). It has been established that a port existed as early as the 11th century AD, and possibly even before that.

Currently, the time at which these settlements first emerged and subsequently developed, as well as their merging into one city are debatable subjects⁷ as archaeological research is still incomplete (PETIT, 2012, p. 15–29).

⁷ RÉGNIER (1932) and DES MAREZ (1935) mark *grosso modo* the same geographical cores that stimulated the local urbanization and that would consequently merge in the 12th and 13th centuries AD. In the lower part of town Régnier and Des Marez indicate a *castrum* and a merchant quarter (*portus*). In the upper part of town they indicate the church of Saint-Gudula and the Coudenberg palace. During the 1990s the historical department of the Université Libre de Bruxelles (ULB), including Claire Billen, Michel de Waha and Alain Dierkens started to reinvestigate the early urbanization of Brussels. This resulted in a changed vision on the origin of Brussels. Scholars started to believe that Brussels originated from polynuclear cores (DE MEULEMEESTER, 1992; DELIGNE, 2001;2003; CHARRUADAS 2007; 2009; VANNIEUWENHUYZE, 2008). Up until now, this hypothesis is generally accepted. However, this does not mean that there is consensus on the topic. The different areas that were merged and their chronology were and are still heavily debated.

In the Senne Valley, the settlements situated around the churches of Saint-Géry (C) and Saint-Nicholas (F) continued to develop. The port formed an opportunity for international trade. On the left bank of the Senne, the Saint-Catherine chapel (G) was established during the second half of the 12th century AD. On the hillside, the district near the Saint-Michael and Saint-Gudula collegiate church (A), the fortress at the Coudenberg palace (D) and the church of Saint-James (D) continued to develop. Halfway the slope a corn market hall (E) was established by the end of the 13th century AD and the area became more densely inhabited. The hospital of Saint-John (H) was founded at the end of the 12th century AD. Lastly, a new district developed in the south east around the church of Our Lady of the Chapel (I) (**Fig. 1**) (PETIT, 2012, p. 31–33).

From the 12th century AD onwards the city started to grow quickly and became a center for the Duchy of Brabant (CHARRUADAS, 2012, p. 256). During the 12th century AD we start to see the urban elite being present in the surrounding countryside. They operate as landowners and as tenants in fee in the network of the Dukes of Brabant. CHARRUADAS (2015, p. 293) states that there is a correlation between their urban economic success and their presence in the countryside, which was possibly a way of gaining prestige as urban elite, or their rural properties and social position may have been necessary for gaining urban success. This demonstrated that there was a strong connection between rural and urban elite.

An important marker in the urbanization process of Brussels is the development of the first city walls during the 13th century AD (**Fig. 1**). In the east the Coudenberg (D) was situated, while in the northeast the church of Saint Gudula (A) was located. Downtown the churches of Saint Géry (C) and Saint-Catherine (F) were located together with a range of economical infrastructures: the port and a commercial area (**Fig. 1**) (VANNIEUWENHUYZE, 2008, pp. 306–307).

During the 13th century AD, in the proximity of the Saint-Nicolas market (F) the marshland was drained for the purpose of trading. This is what is known today as 'la Grand-Place' (French) or Grote Markt (Dutch). It used to be called 'Gemene merct' (English: common market, or Nedermerct (English: Lower Market) (L) and was used as a meeting square for trading between merchants, peasants and craftsmen. The Duke of Brabant installed some market halls on the side of the square that were used for selling meat, bread, and cloth. In the proximity of the square there was a butchers district (M). The craftsmen also had their own district higher up, the Putterie (N) and ter Arken (O). Furthermore, emerging

monasteries from the 13th century AD include the Franciscans settling in the area of the Saint-Nicolas church (F) and the Senne and the Carmelites settling between the river and the corn market (E) (**Fig. 1**) (PETIT, 2012, p. 31–37).

During this period (13th – 15th century AD) the economy thrived. These economic activities attracted people into the city, resulting in a demographic growth that made Brussels the most densely populated city in Brabant at that time⁸. Religious institutes such as convents and monasteries, as well as a number of new hospitals were built. To the south east, the district of the Sablon (P) became inhabited from the 13th century AD. To the west several districts including Overmolen (Q), Dames Blanches (R) and Béguinage (S) emerged. In the northern areas the Orsental (J) and Marais (K) areas expanded. Several hospitals were established in different parts of the city. Furthermore, specialized markets were set up near the Grand Place (L), Saint John's hospital (H) and the Putterie district (N) to meet the demands of the town dwellers (**Fig. 1**).

The area of Our Lady of the Chapel (I) flourished as a center outside the first city wall. Craft work such as metal working, stone, leather, wood, cloth, cloth bleaching, tanneries, breweries, and tapestry (from the 15th century AD onwards) are situated in this district. A meat market and hospital (Saint-Julian) were established during the 14th century AD. To the east Bavendal (T), a work district, and Pré aux Laines (U), where dyed wool was being dried, were developed. More marshland was being drained in the southwest. The area called ten Cruysken (V) was inhabited by craftsmen working in the textile sector. Other districts emerged, namely Blanchisserie (W), an area for bleaching cloths, and Terre-Neuve (X), an area which was used for re-stretching wool in frames after it had shrunk after tucking (**Fig. 1**) (PETIT, 2012, p. 42–47).

The continuing urban developments led to the building of new city walls (8km) between 1357 and the end of the 1370s (**Fig. 1**). These included following city gates: Porte de Laeken, Porte de Schaerbeek, Porte de Louvain, Porte de Namur, Porte de Hal, Porte d'Anderlecht, and Porte de Flandre (VANNIEUWENHUYZE, 2008, p. 329–331) (**Fig. 1**). The second city wall enclosed the urban fabric, together with some spare uninhabited land for activities such as craft work and agriculture.

⁸ Estimation: between 20 000 – 25 000 inhabitations in the second half of the 14th century AD (PETIT, 2012, p. 44).



Figure 1: 16th century AD map of Brussels by Jacob Deventer (1555)

Scale bar: 500 meters / Blue dot indicates Rue des Boîteux situated between the first and the second city wall.

Legend

<i>City walls (black lines)</i>	<i>In the perimeter of the first city wall (red dots)</i>	<i>In the perimeter of the first and the second city wall (red dots)</i>
<i>Inner black line: first city wall (13th century AD)</i>	<i>A) Treurenberg / Cathedral of Saint-Michael and Saint-Gudula</i>	<i>I) Church of Our Lady of the chapel</i>
	<i>B) Riches-Clares</i>	<i>J) Orsental</i>
<i>Outer black line: second city wall (14th century AD) including the seven gates</i>	<i>C) Saint-Géry chapel</i>	<i>K) Marais aux Herbes Potagères</i>
	<i>D) Coudenberg and church of Saint-James</i>	<i>P) Sablon</i>
	<i>E) Place de la-Vieille-Halle-aux Blés</i>	<i>Q) Overmolen</i>
<i>1) Porte de Flandre</i>	<i>F) Hospital, church and market of Saint-Nicholas</i>	<i>R) Dames Blanches</i>
<i>2) Porte de Laeken</i>	<i>G) Saint-Catherine chapel</i>	<i>S) Béguinage</i>
<i>3) Porte de Schaerbeek</i>	<i>H) Hospital of Saint-John</i>	<i>T) Bavendal</i>
<i>4) Porte de Louvain</i>	<i>L) la Grand-Place</i>	<i>U) Pré aux Laines</i>
<i>5) Porte de Namur</i>	<i>M) Butchers district</i>	<i>V) ten Cruysken</i>
<i>6) Porte de Hal</i>	<i>N) Putterie</i>	<i>W) Blanchisserie</i>
<i>7) Porte d'Anderlecht</i>	<i>O) ter Arken</i>	



Figure 2: Map of Brussels showing the location of the studied Dark Earth sites

The green dotted line indicates the first city wall

Source: DEVOS (2019, p. 46)

2.2.2 Vegetational developments

Dark Earth studies indicate that the city had a rural character between the 10th and 12th century AD. Pasture and crop cultivation took place respectively in the whole city center and along the steep slope / on the plateau. The Treurenberg area had been a crop field between the 11th – 13th centuries AD. In the Rue de Dinant, Impasse du Papier and the Vieille-Halle-aux-Blés (**Fig. 2**) meadows and / or crop fields were observed for this period. During the 10th – 12th centuries AD, the site of the Court of Hoogstraeten (**Fig. 2**) was a meadow used for pasture and later on it was used as a crop field (DEVOS *et al.*, 2007, 2009, 2011, 2013a; DEGRAEVE *et al.*, 2010). On the site of the Petite Rue des Bouchers (**Fig. 2**) Dark Earth units from the 11th – 12th centuries AD were uncovered. These Dark Earth units are formed as a result of erosion processes higher up the hill. It is likely that this erosion can be linked to the presence of crop fields on the plateau and along the slope (DEVOS, 2015, p. 96). On the plateaus, crop cultivation took place under the auspices of wealthy rulers or abbeys. One example is Ossegem in Laeken, situated at the Heizel plateau (MEGANCK, 2009, p. 7). The need for construction material during this period is pointed out by the observations of stone quarries and sand and loam extractions (DEVOS, 2019, p. 131).

The 12th - 13th centuries AD were a period of agricultural expansion. This is a phenomenon observed not only in Brabant, but in other areas. The lords expanded their agricultural fields to provide food for the urban area. The rural economy was a key element in the development of medieval cities. From around 1250 the rural economy started to flourish as an intensification of the agricultural activities took place. The growth of the urban area demanded a higher productivity rate, which was accomplished by new techniques such as crop rotation (MEGANCK, 2009, p. 8). Dark Earth studies indicate that the presence of agricultural activity was expanded from within the perimeter of the first city walls to the area between the two city walls and into the Senne Valley. The open area in between the walls was used for crafts and agricultural activities. Furthermore, market activities have been observed for the Grand Place as well (DEVOS, 2019, p. 131–132).

The marshland area underwent some major changes. The area was drained and the banks were solidified to fight flooding. Consequently, the areas in the north were transformed into market gardens to keep up with the growing urban demand for food due to an increase in population. The advantages of this area were that the soil was suitable for market gardens and the proximity to the city for perishable products (fruits and vegetables). These areas were called Orsendal (J) and Marais aux Herbes Potagères (K) (**Fig. 1**) (PETIT, 2012, p. 36).

The interplay of population growth, a thriving economy and urban development led to a saturation of the area in the perimeter of the second city wall from the 13th – 15th centuries AD. Within the perimeter

of the first city wall, Dark Earth studies observe no more traces of agricultural activities such as cropland and pasture. However, they do indicate that in some open areas pleasure gardens and market gardens had been established. For the other areas (valley, along the slope, the plateau) agriculture was still present (DEVOS, 2019, p. 133–134).

An important observation for the 13th – 15th centuries AD is that the townscape, despite a saturation of the urban area, still kept a quite open character. VANNIEUWENHUYZE *et al.* (2012, p. 229) mention the study of a mid-16th century AD map of Brussels by Jacob Deventer presented in VANNIEUWENHUYZE (2008). A digital analysis of the map shows that 36% of the area within the second city wall was open space, 30% buildings, 17% road networks, 12% watercourses, and 5% green elements such as parks, trees and bushes. This shows us that even in the 16th century AD the city was characterized by 1/3th of its space being open.

2.2.3 The relevance of environmental studies

Urban environmental studies in Brussels date back to the 1990s (DUPONT, PEUCHOT and SCHUITEN, 1995; GAUTIER, 1995; LAURENT, 2001). These studies focused on animal and plant remains, mainly on (post-)medieval artisanal activities and food economy. However, the share of geoarchaeology and archaeobotany was limited and interdisciplinary projects and research were lacking. From the early 2000s a shift took place in favor of integrative research on urban development. This integrative research includes the following disciplines: geoarchaeology (field study, micromorphology, physico-chemical analyses), archaeobotany (palynology, phytolith study, carpology, anthracology), and archaeozoology (archaeozoology: mammals, fishes, birds; malacology, entomology, parasitology). These studies are conducted under the auspices of the Brussels Capital Region, the Royal Belgian Institute of Natural Sciences (RBINS), and the Université Libre de Bruxelles (ULB) (DEVOS and DEGRAEVE, 2018, p. 74-75; p. 80).

In contrast to many other European cities, such as London or Paris, whose history predates Roman times, Brussels is a second generation city that began to emerge in the 10th - 11th centuries AD. Previously conducted historical and archaeological studies in Brussels show that the process of early urbanization was completed in the 13th century AD⁹ (CHARRUADAS, 2012, p. 258). At first, historians did not understand this urbanization process completely and perceived medieval cities as dense, isolated

⁹ From the 13th century AD onwards the city is understood to be urbanized, although the urbanization process is a dynamic and ongoing process that also continues after the 13th century AD. After this early phase of urbanization a more densely build center started to develop.

places enclosed by city walls. Their image derived from the archaeological remains of the medieval city, together with the urban identity of the medieval citizens. VANNIEUWENHUYZE *et al.* (2012, p. 224–225) state that medieval citizens had an urban identity linked to a feeling of superiority that distinguished them from the countryside. They distinguished themselves by city walls, town rights, dense population, a concentration of buildings *et cetera*. They provide evidence for this urban identity with an illuminated letter depicting a dense, unrealistic urban landscape of Brussels (**Fig. 3**).

The problem with this initial paradigm is that it excludes the dynamic character of a town and that it considers it an isolated phenomenon (VANNIEUWENHUYZE *et al.*, 2012, p. 225). Over the last decades, archaeologists and historians are trying to address this shortcoming by taking into account the dynamic character of a town and studying towns from a new perspective (DELIGNE, 2003; DEVOS *et al.*, 2007; VANNIEUWENHUYZE, 2008). In the case of Brussels, archaeology is a key player in contributing information on early city developments that are not included in direct and reliable historical sources (HENNE and WAUTERS, 1845; RÉGNIER, 1932; BONENFANT, 1934; LEFÈVRE, 1934; BONENFANT, 1935, 1936, 1943, 1949; DES MAREZ, 1935; MARTENS, 1976; DE WAHA, 1976, 1979; DESPY, 1979, 1997; BILLEN, 2000; DELIGNE, 2001, 2003; DEMETER, 2003; CHARRUADAS, 2004, 2011; CHARRUADAS and DELIGNE, 2007; VANNIEUWENHUYZE, 2008). Since 1996, the Heritage Direction of the Brussels Capital Region is responsible for archaeological excavations conducted in Brussels, which has resulted in an increase of preventive excavations, and in an improved understanding of the urbanization process.



The letter was found in an inventory of the keeper of the ducal Charters. Nearly the complete initial is marked by an urbanized city showing no open space and focusing on the buildings depicting very little of the sky. It concentrates several elements from the urbanized city such as the tower of the Town Hall, the churches of Saint Michael and Saint Gudula, city gates, houses, and the ceremonial hall of Coudenberg (PETIT, 2016, p. 42).

Figure 3: Detail of an illuminated letter from a manuscript from 1462

Source: PETIT (2012, p. 7)

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Environmental studies have helped to tackle the traditional view. Currently, environmental studies, when combined with historical and geographical studies, elicit different themes in a complex way such as 1) the study of the openness of the urban landscape, for example studying the gradual saturation of the open space (**Fig. 4**) and; 2) the relationship between the city and its hinterland, for the study of the urban demand for rural products and the distributive systems of its hinterland (VANNIEUWENHUYZE *et al.*, 2012, p. 225).

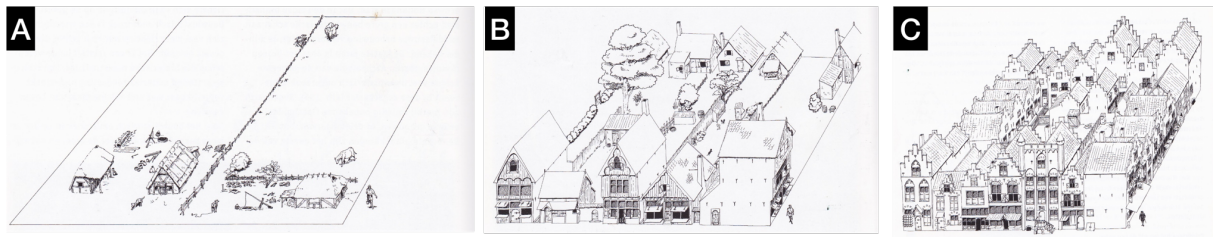


Figure 4: The gradual saturation of the city illustrated by three phases

A) 12th – 13th centuries AD – rural area; B) 13th – 15th centuries AD – saturation of open space; C) 15th – 16th centuries AD – dense city.

Source: Roos van Oosten

SCHOFIELD and VINCE (2003, p. 213) state that studies on the environment of medieval towns can be divided into four categories: 1) the study of physical factors such as climate regimes, air and water pollution and their influence on the town life; 2) the study of the interaction of mankind with its environment including the study of insects, plants, animals, woodland management, and the relationship between the town and its hinterland; 3) the study of biological factors such as changes in diet, diseases and viruses; 4) the study of social practices and their consequences on the environment such as overcrowding or urban living.

The present study is connected to three of these four categories (2, 3, and 4). Firstly, the relationship between mankind and its environment is studied. Rue des Boîteux consists of a natural peat sequence and anthropogenic Dark Earth units. This implies that at a certain moment, humans interacted with this environment. The study at hand contributes to the knowledge of vegetational changes and of the impact of this interaction. Secondly, the horticulture units can provide information on the diet of the 13th – 15th centuries AD. Finally, the location of the site Rue des Boîteux together with the surrounding areas, also referring to horticulture, show us that by the 13th century AD this area was used as a garden area in the city during the 13th – 15th centuries AD. The location, activity, and dating of the site are informative about the late medieval use of space in town.

2.3 Dark Earth studies

2.3.1 Concept

The present study uses the definition of Dark Earth as proposed by DEVOS (2019, p. 21–22) in his PhD dissertation: *“hick, dark colored, humic, homogeneous units covering large surfaces that are often rich in anthropogenic remains (charcoal, ceramic, brick, bone, mortar, coprolites, slag, etc.), regardless of their age or geographical location.”*¹⁰ The research was mostly based on urban contexts, often with a Roman past, and was applied to investigate the possible continuity in cities (FONDRILLON, 2009, p. 1–2). In Europe, Dark Earth units have been studied in Britain since the beginning of the 1980s (MACPHAIL, 1981, 1983; MACPHAIL and COURTY, 1985), in Italy from the late 1980 (BROGIOLO, CREMASCHI and GELICHI, 1988; CREMASCHI, 1992; CREMASCHI and NICOSIA, 2010; BROGIOLO, 2011; NICOSIA *et al.*, 2012, 2017), in France from the early 1990s (CAMMAS *et al.*, 1995; GEBHARDT, 1997; CAMMAS, 2004; BORDERIE, 2011; BORDERIE *et al.*, 2014; MACPHAIL, 2014), and in Belgium since 1996 in Ghent (ERVYNCK *et al.*, 1999; STOOPS, STOOPS and LALEMAN, 2001) and later in Brussels (DEVOS *et al.*, 2007, 2009; Y. DEVOS *ET AL.*, 2013a; VRYDAGHS, BALL and DEVOS, 2016) (NICOSIA, DEVOS and BORDERIE, 2013; NICOSIA, DEVOS and MACPHAIL, 2017, p. 331). Recently, the method has expanded to other sites in Belgium, including Antwerp (DEVOS *et al.*, 2013b), Lier (WOUTERS *et al.*, 2017) and Tongeren (WOUTERS *et al.*, 2019).

Dark Earth studies have proven to be a valuable working tool in environmental studies of town developments. They enable the study of the formation of urban soils and sediments and make it possible to identify ancient activities (DEVOS and DEGRAEVE, 2018, p. 73–75). WOUTERS (2011, p. 27) presents the following list of frequent interpretations for Dark Earth units: the abandonment of a site, occupation, plough land, horticulture, grassland or meadows, animal stables, artisanal activities, dug pits, and burials. WOUTERS (2011, p. 27) also notes that one should be careful when adhering to just one interpretation. These units have been affected both by natural and anthropogenic influences which can result in Dark Earth units conveying several contemporary or diachronic stories¹¹.

¹⁰ Originally, Dark Earth was used for units located in post-Roman and urban contexts. The definition also implies prior knowledge on the site chronology (DEVOS *et al.*, 2009, p. 270). Over the last years, scholars have tried to develop a new, non-biased definition, as Dark Earth can develop at any location, regardless of period, social context or initial condition (MACPHAIL, GALINIÉ and VERHAEGHE, 2003; HEIMDAHL, 2005; DEVOS *et al.*, 2009; MACPHAIL, 2010; C. NICOSIA, DEVOS and BORDERIE, 2013; NICOSIA and DEVOS, 2014; NICOSIA, DEVOS and MACPHAIL, 2017).

¹¹ To illustrate this: WOUTERS *et al.* (2019, p. 16) on Dark Earth units from Roman and early medieval times in Gallo-Roman town Atuatuca Tungrorum, Belgium observed that the Dark Earth units unravel a range of activities and events including cultivation, domestic activity and a backyard.

2.3.2 Brussels

The micromorphologist Y. Devos has extensively studied the Dark Earth units in Brussels for the past 20 years. His recent PhD dissertation is a synthesis of his research (DEVOS, 2019). The sites are divided into three main relief units: a valley floor, a steep slope on the right bank and the beginning of the Brabantian plateau. The Dark Earth units range from the 10th/11th centuries AD until the 17th century AD. Devos distinguishes two major periods and a transition period to classify the Dark Earth units. 42 units from 11 sites date from the 10th-12th / 13th centuries AD (the oldest period), 9 units from 5 sites date from the 13th – 14th centuries AD (the transition period) and 35 units from 9 sites date from the 14th – 16th / 17th centuries AD (the later period) (DEVOS, 2019, p. 45-49).

Area	Site
In the alluvial valley	- Rue des Pierres - The Poor Clares (Pauvres Claires) - Impasse de la Barbe (Place Fontainas) - Grand'Place - Rue des Boîteux
At the foot slope of the steep slope	- Petite Rue des Bouchers
Along the steep slope	- Treurenberg - Court of Hoogstraeten - Impasse du Papier - Relais Postal - Place de la Vieille-Halle-aux-Blés - Rue de Dinant - Rue du Chevreuil - Tour Anneessens
Near the plateau	- Rue de Bréderode

Table 5: Archaeological sites in Brussels where Dark Earth has been uncovered and studied

For the specific location of these sites see figure 2.

2.4 Medieval urban horticulture studies

2.4.1 Context

Medieval urban horticulture in Europe is studied using different methods: Geoarchaeological, archaeobotanical, geographical, and historical research. Each of these disciplines can provide unique and valuable information on this topic. A promising discipline to use for the study of the urban horticulture is geoarchaeology, and more specifically geoarchaeology on Dark Earth units. The present study adopts this approach. MACPHAIL and GOLDBERG (2017, p. 330-333) discuss ancient gardens through the study of Dark Earth. They mention that few studies on ancient and historic gardens¹² have been accomplished, although horticulture can be studied through urban sequences. Dark Earth studies on horticulture were already conducted for Roman times such as in Roman Colchester and London for the first century AD, and for early medieval times such as in Tours (Indre-Et-Loire, France) during the 4th - 8th centuries AD. In this regard, the study of the horticulture Dark Earth units for Rue des Boîteux may hold a promise to reveal new insights into the matter.

Although studies in disciplines such as history, geography and archaeology have already been accomplished for medieval horticulture in Europe, they have a fragmented character, and medieval urban horticulture in Europe has to date not been studied in an integrative way. Our current knowledge is too limited and fragmented to have an overall accurate picture of medieval urban horticulture in Europe. One recommendation for further research would be the integration of the different studies in Europe in a comprehensive overview. In the present section some of the literature is gathered on this topic in a preliminary fashion.

2.4.2 Scandinavian areas

At this moment, the most progressive studies on the subject have been conducted by scholars in Scandinavian areas. Between 2010-2013, four interdisciplinary seminars were arranged by the Nordic Network for the Archaeology and Archaeobotany of Gardening (NTAA). As an outcome 26 reports were published in a 2014 academic overview (ANDRÉASSON *et al.*, 2014). Among others the archaeological sources to the history of gardens and the cultural landscape were addressed. This theme focused on the relationship between archaeology and archaeobotany, and the recent development of garden archaeology. Embedded in this theme are the reports from HEIMDAHL (2014), focusing on soil science and archaeobotany in the field to identify garden soils in Sweden; from VIKLUND (2014), which goes

¹² In the category gardens, MACPHAIL and GOLDBERG (2017, p. 330) distinguish horticulture and ornamental gardens. In the present section, only the studies on horticulture are being taken into account.

into deeper detail on the relationship between archaeobotany and garden history; and from LINDEBLAD and NORDSTRÖM (2014), on the presence of horticulture in medieval towns and their everyday economic importance for town dwellers.

Archaeological studies have proven to be valuable to re-evaluate medieval Scandinavian horticulture (HEIMDAHL and LINDEBLAD, 2015, p. 2). The traditional and commonly held view of Scandinavian urban horticulture layers is no longer valid. For long academic literature insisted that Sweden was a poorly developed area that followed horticulture from central Europe during the medieval times. Instead, during the last decade, archaeology has proven that rich horticulture was already present in the first phase of the urban environment, such as Lund during the 10th century AD, Enköping during the 12th century AD and Skänninge during the 13th century AD. It was also made noticeable that Swedish archaeologists mainly focus on built-up areas. This entailed that little research had been conducted on ways of cultivation in the city such as orchards and kitchen gardens, although dominantly present in the medieval town¹³. Lastly, HEIMDAHL and LINDEBLAD (2015, p. 2) mention that LINDEBLAD (2006, 2010) has conducted studies that demonstrate that gardens and arable fields had a larger share in the medieval townscape than previously thought.

KRISTIANSEN (2018, p. 256–258) addresses another topic for Scandinavia: the cultivation of protein-rich plants on small plots in the town, while carbohydrate-rich crops were being grown on large fields in the hinterland. It states that large fields are more vulnerable to water scarcity or pest infestation, and such in contrast to small gardens where crop failure was combatted more easily. For the moment, the function of small gardens, which is to provide for the town dwellers, has not yet been studied thoroughly. However, they must have been vital to medieval life. The publication states that archaeological research has focused more on large fields in relation to the small plots that are enclosed around farms and urban yards.

These Scandinavian studies demonstrate that studying horticulture through archaeology is of great value to those trying to understand our urban past, as it offers new insights into the traditional matter and new information on aspects that have never been studied before. However, one must concede that apart from the studies in Scandinavia, archaeological studies on other geographical areas in Europa remain scarce. LYONS (2015, p. 115) mentions that archaeology will in the future be a key player in research on this subject, as historical sources are rare and generic.

¹³ *This statement goes along with the observation for Brussels from VANNIEUWENHUYZE et al. (2012, p. 229) that Brussels in the 16th century AD still has 1/3th open space in the townscape and that there was still significant open space for cultivation within the city.*

2.4.3 Other areas in Europe

GOODSON (2018, p. 339-340; p. 344) reports on early medieval gardening in Italy through historical records. She states that fruits and vegetables were cultivated in garden plots within the city walls. This is supported both by archeological and historical evidence. These plots are visible in the archaeological record and mostly, these plots go together with nearby properties. Historical documents record the buying, selling and exchanging of these properties. For early medieval times, evidence for market-scale gardening in the hinterlands of the urban area is rather small, while the scale of cultivation within the city is rather high. She mentions that attestations of gardens as part of properties started to appear for Rome in the late 6th century AD and for Ravenna in the mid-7th century AD. During the 8th century AD urban gardens are also frequently mentioned for Lucca. Goodman also analyzed the published property documents from 10th century AD Rome. 32 out of 186 documents involved urban properties. From these 32 urban properties, 8 did not mention a garden, while 26 did, which shows the marked presence of urban gardens.

VAN DER VEEN, HILL and LIVARDA (2013, p. 173) report on the horticulture from an archaeobotanical point of view with regards to medieval Britain. They mention that horticulture including the cultivation of fruits, vegetables and herbs was introduced by the Romans and that historical records mention the presence of small gardens located nearby the house for medieval times. However, they state that the information on the urban garden activities in early medieval times is limited. For example, they address the scarce information of regional variation or dissimilarities between rural and urban gardening.

For Belgium, the studies on medieval urban horticulture are few and far between. For Brussels, research has been conducted by the historian CHARRUADAS (2012, p. 258-259). He mentions the importance of urban gardens to supply the town dwellers with vegetables and other nourishment alongside grain from the 12th century AD onwards. The medieval horticulture in Brussels is further discussed in the section 'historical background' in chapter 4.

For Antwerp, a preliminary study on urban farming was conducted by VERMOESEN (2015). While this study focused on the early modern period rather than the medieval period, it does not exclude the relevance of the topic for medieval times, as there is a degree of continuity on urban farming from the late medieval period into the early modern period. The author states that the historical debate on food supply in early modern towns mainly focused on the food supply and the relationship with the hinterland. A less investigated topic is the fact that the town dwellers who lived within the city or near the edge of town also produced their own products.

Chapter 3: Phytoliths as an archaeological proxy

3.1 Biological aspects

Phytoliths are plant microfossils that are formed after the plant absorbs monosilicic acid $\text{Si}(\text{OH})_4$ from the soil and forms opaline silica ($\text{SiO}_2 \cdot n\text{H}_2\text{O}$) at specific intra- and extracellular locations and cell walls (BLACKMAN, 1969; GARRISON, 2003, p. 145; PIPERNO, 2006, p. 5; VRYDAGHS, BALL and DEVOS, 2016, p. 79).

Two mechanisms are responsible for the accumulation of solid silica and phytolith production. Its formation is on the one hand controlled by genetic and physiological mechanisms, and by local climate and growing conditions on the other. After the silica is deposited at different intra- and extracellular locations and cell walls, it will often take the shape of the location where the silica precipitates. As the morphologies of many phytoliths partially or totally reproduce shapes of plant cells, a variety in phytolith shapes will occur based on inter- and intra-plant¹⁴ taxonomic differences. These morphologies form the key factor for botanical identification of the phytoliths (PIPERNO, 2006, p. 12).

The reasons behind phytolith production in plants are currently the subject of debate.¹⁵ SANGSTER, HODSON and TUBB (2001) state that three major biological functions of phytoliths can be distinguished. First, they fulfill a structural function as they tend to increase rigidity and strength for the plant. Second, they fulfill a physiological function, which involves the interaction of silica with other processes taking place in a plant or growing environment. Third, phytoliths make plant structures less penetrable (PIPERNO, 2006, p. 12–13).

¹⁴ *Variety in phytolith morphologies that are situated in the stem, the leaves, the roots and the inflorescence parts of the plant*

¹⁵ *More information concerning the debate about the reasons behind phytolith production can be found in PIPERNO (2006, p. 12) .*

3.2 Taphonomical aspects

3.2.1 Preservation

A major benefit of phytoliths as an archaeological proxy is that overall they can very well survive over long periods of time thanks to their inorganic character. The most remarkable example is mentioned in JONES (1964) who described phytoliths from 60-million-year-old sedimentary rocks. On the other hand, this should not trick us into believing that phytoliths are indestructible, as phytoliths can suffer mechanical and/or chemical alteration (PEARSALL, 1989, p. 273; PIPERNO, 2006, p. 5; CABANES, WEINER and SHAHACK-GROSS, 2011, p. 2480). **Figure 5** presents a phytolith that is broken ensuing mechanical alteration, one that has been chemically altered, and one that has not fully formed within the plant. It is not always clear whether a phytolith was chemically altered or not fully formed within the plant.

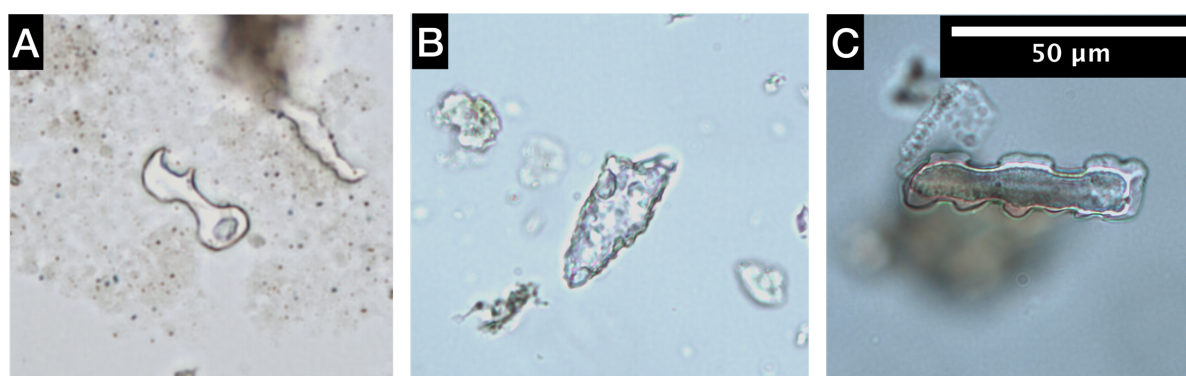


Figure 5: Preservation of the phytoliths

A) phytolith with erosion marks ; B) phytolith with corrosion marks; C) phytolith that has not been fully formed in the plant.

Source: Microscopic pictures of soil material deriving from Rue des Boîteux (taken by the author)

Following OSTERRIETH *et al.* (2009, p. 74), three major factors influence the preservation of phytoliths. Firstly, the particular type of phytolith, i.e. its shape and surface area, is of great importance. Secondly, the chemical composition and the degree of silicification play an important role. Finally, the natural context, including the climate, the vegetation and the soil, e.g. the pH-value, need to be taken into account. This implies the need for phytolith examinations to be conducted on a region-by-region and site-by-site basis if not case-by-case (PIPERNO, 2006, p. 21).

For archaeological studies, the preservation implies that when other archaeobotanical remains, such as pollen grains, seeds, fruits and charcoal, are present, phytoliths can operate complementarily with these proxies. However, if other archaeobotanical remains are poorly preserved or not preserved at all, phytoliths can be of great value as they may provide exclusive information (CHEVALIER and BOSQUET, 2017, p. 19).

3.2.2 Deposition

In contrast to pollen, the dispersion of phytoliths is not a requirement for plant viability. In general, phytoliths are characterized by a gravity-aided *in situ* decay and are therefore invaluable in the identification of localized plant materials, activities and the local plant environment (PEARSALL, 1989, p. 341; PIPERNO, 2006, p. 81; An, LU and CHU, 2015, p. 2).

Although *in situ* deposition remains the dominant deposition for phytoliths, it must be taken into account that this is not always the case. Due to depositional dynamics, phytolith assemblages can be composed of phytoliths deriving from multiple non-synchronous natural or anthropogenic inputs (ZURRO *et al.*, 2016, p. 2). Factors that influence phytolith dispersal can be ecological or cultural, such as human or natural (e.g. wind and fire) transportation of plants, excrements, agricultural fields *et cetera*. In order to not misinterpret the phytolith assemblages, it is crucial to have a clear grasp on the sample context and the taphonomic processes (PIPERNO, 2006, p. 21). This can be achieved by studying phytoliths in soil and sediment thin section.

3.3 Status Quaestionis

3.3.1 History of phytolith research

Comprehensive historical overviews have been published by several authors (PEARSALL, 1989, p. 328–340; FREDLUND, 2001; STRÖMBERG, 2003, p. 12–16; WALLIS and HART, 2003; MADELLA, 2008; HART, 2016, p. 4–13). However, most parts of these overviews are based on two significant articles about the history of phytolith research: 1) the chapter “Introduction: With a Short History of Phytolith Research” in *Phytoliths: a comprehensive guide for archaeologists and paleoecologists* from PIPERNO (2006, p. 1–4); 2) Powers’ “Great Expectations: a short historical review of European Phytolith systematics” as included in the book *Phytoliths Systematics. Emerging Issues* edited by S. C. Mulholland and G. J. Rapp (POWERS, 1992).

The history of phytolith research can be divided into three thematic phases: the botanical phase, the paleo-ecological and the archaeological phase. The botanical studies find their origin in 1835 in Germany, when phytoliths were mentioned in the dissertation from a German botanist named Struve (STRUVE, 1835). Other important German scientists were Ehrenberg, who found phytoliths in the dust collected on the deck of the Beagle, and Netolitzky, who conducted research on the production, taxonomy and intraspecific variation of phytoliths (EHRENBERG, 1841, 1854; Darwin, 1846, p. 27; NETOLITZKY, 1929; POWERS, 1992, p. 17). After 1936, when Germany fell under the Nazi Regime, phytolith research came to a standstill and Germany lost its position as a pioneer in the field.

The paleo-ecological research phase took off after WWII, from 1955 until *ca.* 1975, as soil scientists and botanists from the United States, the United Kingdom, and Australia began to exploit phytolith analysis as an index for environmental history (SMITHSON, 1956, 1958; BEAVERS AND STEPHEN, 1958; Baker, 1959a, 1959b). North America was the first geographical area where phytolith analyses were applied in order to study the vegetation history (JONES and BEAVERS, 1964; WITTY and KNOX, 1964; VERMA and RUST, 1969). Furthermore, several classical studies on grass phytolith morphology in modern plants were conducted (METCALFE, 1960; PARRY and SMITHSON, 1964, 1966; BLACKMAN and PARRY, 1968; TWISS, SUESS and SMITH, 1969).

The publication “Potential of Opal Phytoliths for Use in Paleoecological Reconstruction” from ROVNER (1971) marked the beginning of the archaeological research phase. Archaeologists started to use soil phytoliths as a proxy marker to investigate the origins and intensification of agriculture, for example the domestication processes of crop plants such as rice, wheat and maize. Other studies included the reconstruction of past plant communities, investigating ancient diets, and climates (PIPERNO *et al.*, 1985; HART, 1988; CUMMINGS, 1989; ROSEN and WEINER, 1994; FREDLUND and TIESZEN, 1997b; RUNGE, 2001).

For the last 20 years archaeological phytolith research has become increasingly popular. This growing interest brought about a need for standardization, and efforts were made to standardize phytolith terminology. Terminology in phytolith research includes the naming and describing of phytolith morphotypes. In 2005 the International Working Group on Phytolith Nomenclature published the International Code for Phytolith Nomenclature 1.0 (ICPN1.0) as a tool for researchers to maintain a standardized naming system. 2019, the system was revised (ICPN Working Group: MADELLA, ALEXANDRE and BALL, 2005). Furthermore, ZURRO *et al.* (2016) has provided an extensive overview on methodological guidelines and standards in phytolith research. Finally, digital technologies have proven very valuable to start sharing images of phytoliths. As phytolith scholars are based all over the world, the internet is an invaluable asset for them to exchange their knowledge. A specially advantageous aspect is the buildup of online phytolith databases, e.g. the Flora of Ecuador database (PEARSALL, s.d.) and the PhytCore 2.0 database (ALBERT, RUÍZ and SANS, 2016), both of which are exclusively dedicated to phytoliths.

3.3.2 Phytoliths as a proxy in medieval studies

Although phytolith studies can contribute to our understanding of medieval horticulture, few efforts have been made to use them as a archaeological proxy in studies of medieval times. In Europe, phytoliths have recently only been used systematically to investigate medieval urbanism for Brussels. Phytoliths are systematically studied as part of integrative Dark Earth studies. Since 1996, Vrydaghs

and Devos have headed the field by studying these phytoliths in soil thin sections from Dark Earth units from Brussels (VRYDAGHS, BALL and DEVOS, 2016; VRYDAGHS, DEVOS and PETŐ, 2017; VRYDAGHS and DEVOS, 2018b). The result of this systematic research is the identification of past human activities in Brussels and the study of the ancient urban landscape in Brussels (DEVOS *et al.*, 2007, 2009, 2013, 2017b). Besides the work executed for Brussels, there is a lack of comprehensive studies for medieval phytoliths studies.¹⁶ Based on the methods employed, the existing publications can be classified into three groups: studies using the thin section method, the extraction method, and those that use a combination of the extraction and the thin section methods. Most results from phytoliths in medieval studies derive from thin sections and are included into the observations of the micromorphologists (SIMPSON, BARRETT and MILEK, 2005; LISÁ *et al.*, 2018). However, they only note the presence of phytoliths and/or include a limited description following the system elaborated by VRYDAGHS, BALL and DEVOS (2016). Morphotypes are in these studies not identified by a phytolith specialist, nor do they contain a closer examination of the phytolith results in thin section. Therefore these articles are not taken into account in this section. Examples of phytolith studies are:

(1) Extraction method

- HART (2007) evaluating the usefulness of phytoliths found on medieval sherds from Wicken, Northamptonshire, England.
- GOLYEVA (2012) studying medieval animal dung deposits from the Moscow Kremlin; Russia.
- DEJMAL *et al.* (2014) applying a multi proxy Interdisciplinary research on a medieval horse stable from the 13th century AD in the Czech Republic in South Moravia;
- SVIRIDA and GOLYEVA (2016) investigating medieval ploughing in Moscow;
- LAZZATI *et al.* (2016) on the diet of three medieval individuals from Caravate (Varese, Italy).

(2) Extraction method & Thin section

- DEVOS *et al.* (2017b) studying Dark Earth from the alluvial valley of the Senne river (Brussels, Belgium).
- BORDERIE *et al.* (2018) about the early Middle Ages houses of Gien (France) dating from the 9th to the 11th century AD;

¹⁶ *The Oxford Handbook of Later Medieval Archaeology in Britain* even states that for late medieval Britain there are currently no published studies of phytoliths, but that there is potential (McParland pers. comm.), as phytoliths may be preserved where other remains are not (MOFFETT, 2018, p. 118).

- BANERJEA *et al.* (2019) integrating phytolith results of two 13th century AD Teutonic Order castles at Karksi (Livonia), and Elbląg (Prussia).

Based on the existing literature three final comments can be made on the study of phytoliths in medieval archaeology:

- Phytoliths clearly have not been studied thoroughly for medieval times. If studied, it is mostly concerned single case studies rather than systematic research. The only systematical medieval phytolith research so far is for Brussels;
- Phytoliths have often been observed and registered in medieval studies using the thin section technique phytoliths. However, most of these studies lack profoundness;
- The combination of the extraction method and the thin section has only been applied in three studies (2017, 2018, and 2019). This shows that combining both techniques for studying medieval times is still in its infancy. In this regard, this study will hopefully contribute.

3.3.3 Phytoliths in peat

From a chemical and geological point of view, different aspects of biogenic silica in peat were studied including the origin of the mineral matter, the silicification process, the chemical composition, and characteristics of biogenic silica (ANDREJKO, 1977; ANDREJKO, COHEN and RAYMOND, 1983; ANDREJKO, RAYMOND and COHEN, 1983; UPCHURCH, STROM and ANDREJKO, 1983; DAVIS *et al.*, 1984; MCCARTHY *et al.*, 1989; Ruppert *et al.*, 1991; TSUTSUKI *et al.*, 1993; LOPEZ-BUENDIA *et al.*, 2007). A key publication is the book 'Mineral Matter in Peat: Its Occurrence, Form, and Distribution' from 1983 edited by Raymond and Andrejko. Both men are authorities on the study of biogenic silica in peat.

In archaeology, the aim of studying phytoliths in peat is to aid in the reconstruction of the paleo-environment. During the 1970s and 1980s, Cohen and Andrejko conducted studies (COHEN, 1974; ANDREJKO and COHEN, 1984) in which phytoliths were extracted together with other biogenic microfossils such as sponge spicules and diatoms from the Okefenokee swamp, situated on the border between Georgia and Florida, USA. These groundbreaking studies demonstrated that studying phytoliths in peat can be an important source for paleo-ecological data in relation to other archaeobotanical proxies¹⁷ (PIPERNO, 1988, p. 211–212). In the following decades studies were

¹⁷ Traditionally, pollen studies were seen as the dominant provider of paleo-ecological information. However, pollen can degrade in alkaline anaerobic conditions and fires occurring in the peat often destroy the organic compounds, including pollen and macro-remains of plants (PIPERNO, 1988, p. 211–212).

conducted for Argentina (BENVENUTO *et al.*, 2013) , Brasil (SILVA *et al.*, 2016), Australia, New Zealand (TAYLOR, 2010), the USA (COHEN *et al.*, 1999), Russia (RUHLAND *et al.*, 2000), Japan (SUGIYAMA, 1993; KARIYA, SUGIYAMA and SASAKI, 2004), and China (JIE *et al.*, 2011; LI *et al.*, 2011, 2017). Especially in China, phytoliths in peat were the subject of extensive research by Zhang (ZHANG *et al.*, 2005, 2007, 2010, 2015; ZHANG, HU and LIU, 2005; ZHANG, HU and JIE, 2006; ZHANG, HU and WANG, 2007). For Northern Europe, phytolith studies on peat have not yet been conducted with exception of the study by BRAADBAART *et al.* (2017) on phytoliths as evidence for hearths used by Iron Age farmers in the Netherlands. Rue des Boîteux is the first study of phytoliths in peat for Belgium.

3.4 Archaeological research topics

As this study aims for phytolith contributions to archaeology it is important to understand what types of information phytoliths can convey. Phytoliths can provide information on plant taxonomy, differentiation of plant parts and/or on ecological circumstances (WEINER, 2010, p. 139–140). Here is one example of each type of information:

- *Plant taxonomy*: Cone shaped phytoliths derive from Cyperaceae (sedges) (OLLENDORF, 1992) (**Fig. 6**);
- *Differentiation of plant parts*: Primarily, ELONGATE DENDRITIC phytoliths are formed in the long cells of the epidermis of the inflorescence bracts (palea, lemma and glume) of Poaceae (grasses) (ICPT: NEUMANN *et al.*, in press). (**Fig 6**);
- *Ecological circumstances*: A high production of silicified bulliform cells is usually related to high water availability (SANGSTER and PARRY, 1969; ROSEN and WEINER, 1994; BREMOND *et al.*, 2005; STRÖMBERG *et al.*, 2007; FISHER *et al.*, 2013; ICPT: NEUMANN *et al.*, in press.) (**Fig. 6**).

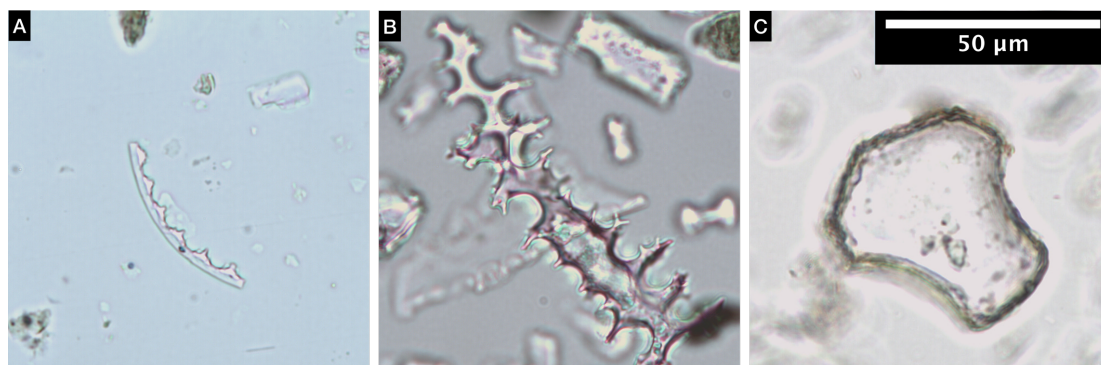


Figure 6: Examples of morphological significant phytoliths

Phytoliths from Rue des Boîteux. A) Cone shaped phytolith deriving from Cyperaceae; B) ELONGATE DENDRITIC phytolith; C) BULLIFORM FLABELLATE

Source: Microscopic pictures of soil material deriving from Rue des Boîteux (taken by the author)

These types of information are useful for the following research topics:

- *Diet*: Phytoliths research from dental calculus, fossil feces and residues in cooking pots in order to identify the plant aspects from the animal and human diet.
- *Water availability*: Combined with other criteria, phytolith analysis can provide information on whether agriculture used irrigation and/or rain-fed methods (ROSEN and WEINER, 1994; MADELLA *et al.*, 2009; JENKINS, JAMJOUM and AL NUIMAT, 2011; SHILLITO, 2011b; WEISSKOPF *et al.*, 2015; JENKINS *et al.*, 2016).
- *Fire activity*: High amounts of burned phytoliths can be an indicator of fire. This can be useful in ecological studies to identify the paleofire activity and/or in archaeological studies to identify burned plant material with an anthropogenic origin (EVETT and Cuthrell, 2017). Another application of fire activity is fuel use. Phytolith studies can help identify whether the fuel used on an archaeological site derived from wood, peat, dung *et cetera*¹⁸ (BRAADBAART *ET AL.*, 2017; LANCELOTTI, RUIZ-PÉREZ and GARCÍA-GRANERO, 2017; ESTEBAN *et al.*, 2018).
- *Spatial division*: Phytolith analysis is being used to identify intra-site spatial differences such as building construction, house roofs, house floors, streets, storage rooms, enclosures of domestic animals *et cetera* (TSARTSIDOU *et al.*, 2009; SHILLITO and RYAN, 2013).
- *Agricultural processes*: Phytoliths can help identify ancient agricultural processes such as the domestication processes of rice, maize, wheat *et cetera* (PIPERNO *et al.*, 1985; SHILLITO, 2013; BALL *et al.*, 2016; BATES, SINGH and PETRIE, 2017; MEISTER *et al.*, 2017).
- *Paleo-environmental studies*: Although paleo-environmental studies mainly pertain to the paleontology discipline, they can be interesting for archaeologists as well. In archaeology, the relationship and interaction between humans and their environment forms a complex research matter. Understanding the diachronic vegetational changes can help unravel this relationship. Phytoliths form a tool for these deep-time paleo-environmental studies (BARBONI *et al.*, 1999; BORBA-ROSCHER *et al.*, 2006; CALEGARI *et al.*, 2017; ESTEBAN *et al.*, 2017).

The present study focuses on diet, agricultural processes, and paleo-environmental studies.

Phytolith studies are often combined with other proxies such as pollen, seeds and fruits, starch grain, diatoms, micro-charcoal, use wear, isotopes, lipid analysis, protein analysis, mineralogical analysis, ancient DNA *et cetera* (PIPERNO *et al.*, 1985; KEALHOFER, TORRENCE and FULLAGAR, 1999; ZUO *et al.*, 2016;

¹⁸ There is some debate about phytoliths as a proxy for the composition of fuel use. According to GUR-ARIEH *et al.* (2014), phytoliths do not allow researchers to distinguish between dung- or wood-dominated fuel material.

BATES, SINGH and PETRIE, 2017; GARCÍA-GRANERO, LANCELOTTI and MADELLA, 2017; JENKINS *et al.*, 2017; MUSAUBACH and BERÓN, 2017; PETÓ *et al.*, 2017).

3.5 Phytolith processing

3.5.1 Sampling

The sampling procedure differs from site to site, as it is designed to answer specific research questions. This implies that the sample size¹⁹, sample amount and the sampling strategies will vary on a site-by-site base. For archaeological contexts there are five sampling strategies for phytoliths: vertical (also column) sampling, horizontal, contextual, and artifact sampling. The vertical sampling occurs from an exposed and profiled wall, taking soil sediment samples from different strata or heights. As a sequence contains different *strata*, from each *stratum* samples at different heights are taken to evaluate changes in the phytolith record from a diachronic perspective. The present study used vertical sampling. Secondly, horizontal samples provide information on synchronically, spatially discrete areas of a site. It can provide information on the horizontal distribution such as the function of the site, intra-site variability, the use of construction material (ancient house floors, roofs collapse...) *et cetera*. Contextual sampling is a strategy where specific features such as ash deposits, ovens, floor areas, collapsed roofs, burials, fireplaces *et cetera* are being sampled. Although contextual sampling offers an insight in specific areas, it is preferably combined with a comprehensive strategy covering all parts (horizontally and vertically) of an archaeological site. Furthermore, artefact sampling is used on artefacts such as stone tools, ceramic vessels and dental remains (PIPERNO, 2006, p. 81–84).

3.5.2 Traditional extraction technique

Lab processing

Phytolith extraction is a physico-chemical process that takes place in a laboratory. The extraction process is completed in three main steps (STRÖMBERG *et al.*, 2018, p. 262).

First, through application of chemical processes, the phytoliths are disaggregated from other elements and the soil particles that could obscure the microscopic visibility are eliminated. This step includes the removal of carbonates, organic compounds, residues of incompletely decayed plant and animal, clays and silts.

Secondly, the phytoliths are isolated and concentrated. To this end, heavy liquid at a specific gravity of 2.3 sg is added. Since biogenic silica has a gravity around 2.2-2.3 sg, it will rise to the top, while other

¹⁹ Normally, the sample weight varies between 30 – 50 grams per sample.

mineral fractions (~2.65 sg or heavier) will sink to the bottom. Consequently, phytoliths and other elements consisting of biogenic silica, including diatoms, sponge spicules and chrysophycean cysts, can be pipetted off and be transferred to another tube (STRÖMBERG, 2003, p. 40–41).

Thirdly, the phytolith-rich fraction is mounted onto microscopic slides before being covered with a coverslip. For the mounting of the slides, a distinction can be made between two procedures: semi-permanent mounting and permanent mounting. For the semi-permanent technique, the phytolith fraction is placed on a slide with a few drops of water and sealed with nail polish. For the permanent technique, the phytolith fraction is placed on the slide with a few drops of Permout, Canada Balsam, Histoclad, Benzyl Benzoate or Glycerine. Hereafter, a coverslip is placed on top of it, which will stick to it as glue (PIPERNO, 2006, p. 93).

Although every protocol consists of these three steps, much variety exists throughout the steps in different kinds of protocols. Papers continue to report on extraction techniques, including experiments and comparative studies (ROVNER, 1971; POWERS and GILBERTSON, 1987; BUCKLER, PEARSALL and HOLTSFORD, 1994; MUNSTERMAN and KERSTHOLT, 1996; ZHAO and PEARSALL, 1998; LENTFER and BOYD, 1998, 1999, 2000; MADELLA, POWERS-JONES and JONES, 1998; ALBERT *et al.*, 1999, 2003; WEINER and ALBERT, 2001; PARR, 2002; ZUCOL and OSTERRIETH, 2002; COIL *et al.*, 2003; KATZ *et al.*, 2010). The main reason for examining extraction techniques is the crucial role of a correct protocol to achieve reliable results.

Microscopic examination

After the recovery of phytoliths, the microscopic plates are ready to investigate with the help of a petrological microscope under plain polarized (PPL), crossed polarized (XPL) and fluorescent light starting from a magnification of 200x. On the slides, phytoliths are randomly counted in order to reach an amount representative for the whole phytolith assemblage. Following ZURRO (2017) the estimates for the minimum sum of phytoliths can be divided into three groups: counting a minimum number of phytoliths; counting a minimum number of significant morphotypes; and counting a minimum number of phytoliths in relation to a standard such as amount of phytoliths in relation to a fixed number of grass silica short cells or amount of phytoliths in relation to diatoms (PIPERNO, 2006, 1988; FREDLUND and TIESZEN, 1997a; MADELLA, POWERS-JONES and JONES, 1998; BARBONI *et al.*, 1999; GRAVE and KEALHOFER, 1999; LENTFER and BOYD, 1999; ALBERT *et al.*, 2000, 2003; PARR and CARTER, 2003; PORTILLO, ALBERT and HENRY, 2009; PORTILLO *et al.*, 2014; ALEMAN *et al.*, 2014). The most commonly used method is the first one, where a minimum amount of phytoliths is counted. Different articles use different minimum sums, varying from 100 to 800 phytoliths per sample (PIPERNO, 1988, 2006; MADELLA, POWERS-JONES and JONES, 1998; ALEXANDRE *et al.*, 1999; LENTFER and BOYD, 1999; WALLIS, 2001; STRÖMBERG, 2002; OSTERRIETH *et al.*, 2009; LANCELOTTI *et al.*, 2014).

Over the years several phytolith scholars have set up their own nomenclature and classification systems (BERTOLDI DE POMAR, 1971; BROWN, 1984; OLLENDORF, 1992; PEARSALL and DINAN, 1992; FREDLUND and TIESZEN, 1994; RUNGE, 1999; BOWDERY *et al.*, 2001; ZUCOL and BREA, 2005; PEARSALL, 2016). However, standardizing the nomenclature on a universal level is essential for phytolith scholars to communicate and compare findings. In 2005 a code (ICPN1.0) was published under the auspices of the former International Phytolith Society (IPS) and it set a standard among phytolith scholars for naming and describing phytoliths. In 2014 the International Phytolith Society (IPS) set up a new committee, The international Committee for Phytolith Taxonomy (ICPT) to revise the ICPN1.0 and develop a list of descriptors. The outcome was ICPN2.0 which was published in 2018 (ICPT: NEUMANN *et al.*, in press).

3.5.3 Soil and sediment thin sections

Phytolith recovery

Oriented and undisturbed soil and sediment samples are taken in the field. These samples are dried and impregnated with resin. Afterwards, these polished blocks can be cut into thin sections. MURPHY (1986) addresses all aspects of soil and sediment thin section preparation. Within thin sections phytoliths are still situated in their original soil context.

Microscopic examination

In order to analyze phytoliths in thin sections Vrydaghs and Devos propose 1) a systematic recording of the distribution patterns of phytoliths; 2) morphotype inventory; 3) and phytolith counting within each distribution pattern (DEVOS *et al.*, 2013b; VRYDAGHS, BALL and DEVOS, 2016; VRYDAGHS, DEVOS and PETÓ, 2017).

- 1) Within thin sections, the distribution of phytoliths can be divided into three patterns, isolated, clustered or articulated phytoliths. Isolated phytoliths are phytoliths that are disarticulated and separated from each other. They can be oriented in any way. Their origins cannot be confirmed. It is possible that these (parts of) phytoliths derived in the soil matrix as a result from bioturbation, windblown material, dung fragments *et cetera*. Clustered phytoliths are groups of random phytoliths that are disarticulated and potentially observed under various orientation. These phytoliths can be intrusive and should be viewed as a sign of disturbance. Articulated phytoliths can be either contiguous, fan shaped or silica skeleton. They are characterized by the preservation of their anatomical distribution. Contiguous and fan-shaped distributions indicate an *in situ* decay with no or limited post-depositional disturbance.

- 2) Subsequently, all the morphotypes in the distribution patterns are registered. Just as with the extraction method, the morphotype registration follows the international guidelines for morphotype descriptions (ICPT: NEUMANN *et al.*, in press).
- (3) Within each distribution pattern, phytoliths are counted.

Apart from distribution patterns, the visibility, the preservation and the color of the phytoliths merit examination. In order to investigate these aspects of phytoliths in soil and sediment, VRYDAGHS and DEVOS (2018b) developed a descriptive system:

- *As to visibility*, **figure 7** shows two microscopic views: A) from a soil and sediment thin section B) from the extraction method. Within thin sections, phytoliths do not always have a clear visibility as they can be (partially) masked by (fine) surrounding particles. The visibility level indicates how masked the phytoliths are.
- *As to preservation of phytoliths*: Phytoliths can suffer chemical and/or mechanical alteration. Phytoliths can be categorized individually into five preservation levels, including a perfect preservation (labelled as A), almost perfect preservation (labelled as B), good preservation (labelled as C), moderate preservation (labelled as D), and a bad preservation (labelled as E).
- *As to color of phytoliths*, generally, phytoliths are colorless microfossils. However, sometimes phytoliths can be colored due to carbon inclusions or coating from charring of the organic materials surrounding the phytoliths (**Fig. 8**). Furthermore, dark-colored phytoliths can be an indicator of combustion (EVETT and CUTHRELL, 2017). Phytoliths are categorized individually into two groups, namely colorless (labelled as A) and colored (labelled as B).

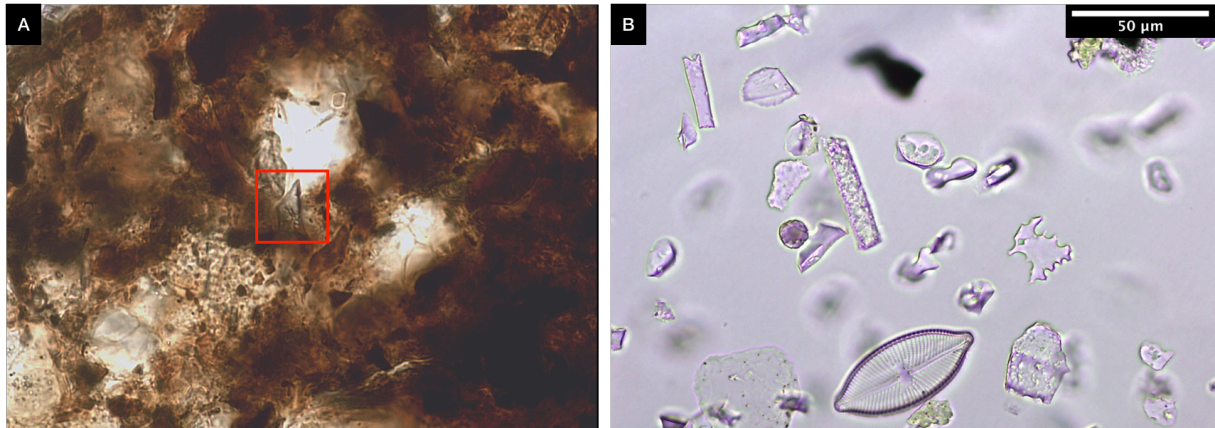


Figure 7: Microscopic view phytoliths: A) soil thin section; B) extraction method

A) Phytolith in thin section. Note that the phytolith is partially obscured by other soil particles; B) phytoliths and a diatom (lemon shape at the bottom) processed with the extraction method. Note the clear visibility of the phytoliths.

Source: Microscopic pictures of soil material deriving from Rue des Boîteux (taken by the author)

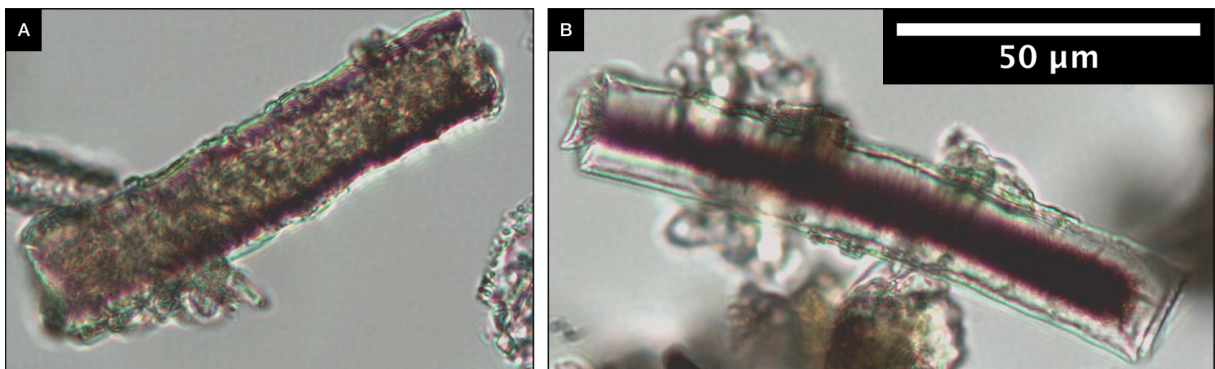


Figure 8: Colored phytoliths

A) Phytolith with a purple color labelled as A: colored phytolith; B) Although the phytolith is colored, it is not labeled as A, but as B: colorless phytolith as the color derives from occluded carbon.

Source: pictures of Rue des Boîteux taken by the author

3.6 Limitations and challenges

3.6.1 Biases in the phytolith assemblages

The first limitation in phytolith research is a representational bias. The phytolith record will not always provide a complete picture of the past vegetation²⁰. Following PIPERNO (2006, p. 141) four factors account for this phenomenon: over- or underrepresentation of species in the phytolith record, taxonomic significance of morphologies, the dispersal of phytoliths, and preservation.

1) The representation of the taxa in the phytolith assemblages is problematic as the production of phytoliths is not equally high in all species, and some taxa are even entirely devoid of phytolith production. Therefore, phytolith assemblages that over- or underrepresent certain taxa will come into play. Phytolith production also depends on the variation in silica rates among different kinds of environments. (FREDLUND, 2001, p. 338; HYLAND, SMITH and SHELDON, 2013, p. 342).

2) The phenomenon of multiplicity and redundancy of phytoliths can hinder the identification and interpretation of phytoliths. Multiplicity refers to different phytolith morphotypes that are produced within a single taxon, while redundancy refers to the same phytolith morphotypes that are produced within several taxa. In case of multiplicity it can be hard to link the several morphotypes in the phytolith record to only one taxon, while in the case of redundancy it is sometimes impossible to ascribe a phytolith morphotype to only one taxon, as this specific morphotype can occur in several taxa (ROVNER, 1971, p. 349; WEINER, 2010, p. 137; VRYDAGHS, BALL and DEVOS, 2016, p. 79). VRYDAGHS, BALL, and DEVOS (2016) report on this matter and try to tackle these two issues by studying phytoliths in soil thin sections.

3) The dispersal of phytoliths can be problematic as well. It is vital to be aware of both pre- and post-taphonomic processes of the phytoliths, making it important to distinguish between different groups of phytoliths in one context that tell different stories. For instance, if an agricultural field was fertilized with excrements containing phytoliths, the phytoliths in the excrements provide insight in the ancient animal or human diet, while the phytoliths on the field can grant information on the *in situ* (cultivated) vegetation. When the phytoliths are processed in bulk samples, all contextual information is lost and mixed phytoliths can potentially have different histories. Studying phytoliths in thin sections may allow to avoid this issue altogether.

²⁰ *This is also the case with other plant microfossils. Taking pollen as an example, these studies usually rely on pollen that are transported by wind, while those transported by insects are not observed (Luc Vrydaghs, pers. comm.).*

4) Phytoliths are not always well preserved as they can suffer mechanical or chemical alterations. Phytoliths can break up when placed in dynamic environments or can dissolve partially or completely in acid environments ($\text{pH} > 7$). This can result in phytoliths that are not preserved at all, or heavily altered phytoliths that are difficult to identify (CABANES, WEINER and SHAHACK-GROSS, 2011, p. 2480).

3.6.2 Modern phytolith reference collections

From an archaeological point of view the most critical problem is the lack of regional modern phytolith reference collections in Europe. Modern reference collections can be plant- or soil based, with soil-based reference collections containing phytolith assemblages extracted from modern superficial soils. These phytolith assemblages reflect contemporaneous vegetation and can give insight into over- and underrepresentation of taxa or can be used to compare ancient phytolith assemblages. Modern plant-based reference collections consist of phytoliths extracted from modern plant tissues that were taxonomically identified in advance. Archaeological phytoliths can be compared with these modern phytoliths in order to identify the ancient ones and link them to certain plant parts or taxa.

As plants differ region-by-region, regional reference collections play a distinctive role. **Figure 9** shows all the work globally accomplished on reference collections. The map shows a lack of reference collections for the Northern part of Europe as there is only a modern plant-based reference collection for the Swiss Alps (CARNELLI, MADELLA and THEURILLAT, 2001; CARNELLI, THEURILLAT and MADELLA, 2004) and two soil-based reference collections for France (DELHON *et al.*, 2003; BREMOND *et al.*, 2004).

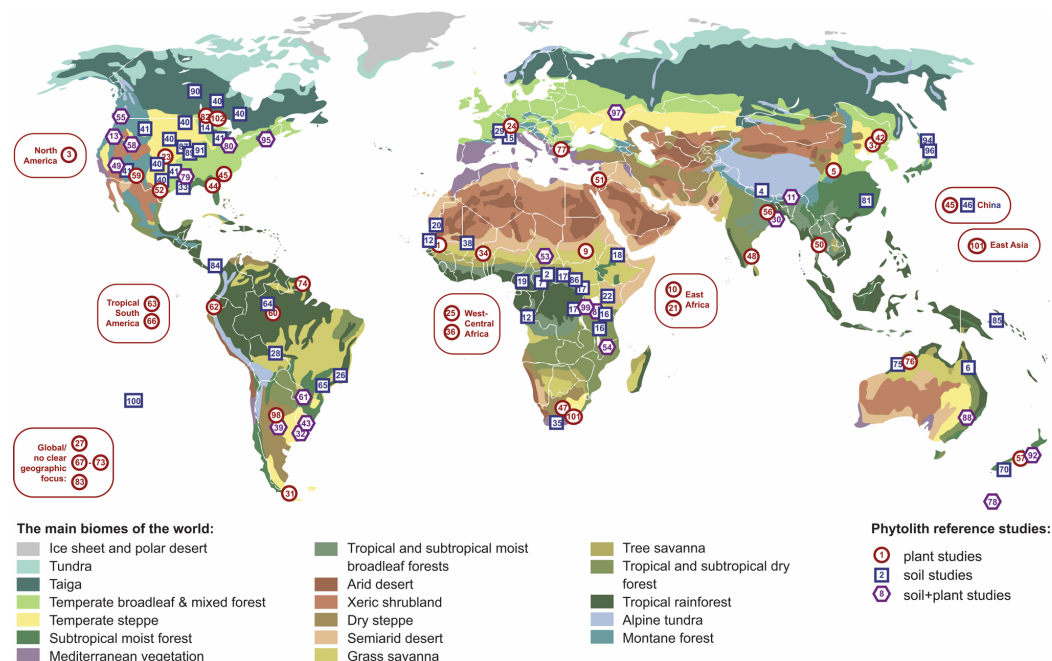


Figure 9: Global distributions of phytolith reference collections

Global distributions of phytolith reference collections. For references as presented on the map see appendix 12.4 in STRÖMBERG *et al.* (2018, p. 270–273).

Source: STRÖMBERG *et al.* (2018, p. 265).

Chapter 4: Rue des Boîteux

4.1 Site description

In the summer of 2014 an archaeological intervention headed by Modrie²¹ was carried out on a construction site situated between Rue des Boîteux and Rue d'Argent in Brussels (**Fig. 12**). The site is located between the first and the second city wall (**Fig. 11**). The site is situated in the lower part of town at the base of a steep hill in the alluvial Senne valley. The elevation of the site is 17 m above sea level (**Fig. 10**) (DEVOS, 2014, p. 6).

The archaeopedological field study carried out by Devos²² confirms the information deriving from the geotechnical map of Brussels from *DAM et al.* (1977) The site is located in a zone characterized by the following geological sequence: a primary base, followed by Landenian sands, clayey sands (Tertiary), and finally alluvial deposits (Quaternary). These alluvial deposits consist of -bottom to top - sands and gravels, silt, peat and clay. The most remarkable discovery in the field was the presence of an almost complete Holocene natural peat sequence dating from the 9th millennium BC to the 13th century AD . Different bulk samples covering the peat sequence were taken for paleoenvironmental studies (palynological and carpological research). On top of this peat sequence, two anthropogenic Dark Earth units dating from the 13th-15th centuries AD were uncovered. **Figure 13** shows the top of the peat sequence (US28) covered with the Dark Earth units (US26 and US27). US26 is covered with a dark grey, silty unit that is a bit clayey (US32). These Dark Earth units (US26 and US27) were sampled for physico-chemical, archaeozoological, palynological, and carpological analyses. For US32 no bulk sample was taken as this did not contain significant material, and the available time in the rescue excavation was limited. Furthermore, undisturbed oriented blocks were sampled from US28, US27, US26, and US32 for micromorphological studies (DEVOS, 2014, p. 19).

²¹ *Heritage Direction, Brussels Regional Public Service, Belgium*

²² *Centre de Recherches en Archeologie et Patrimoine, Université Libre de Bruxelles, Belgium*

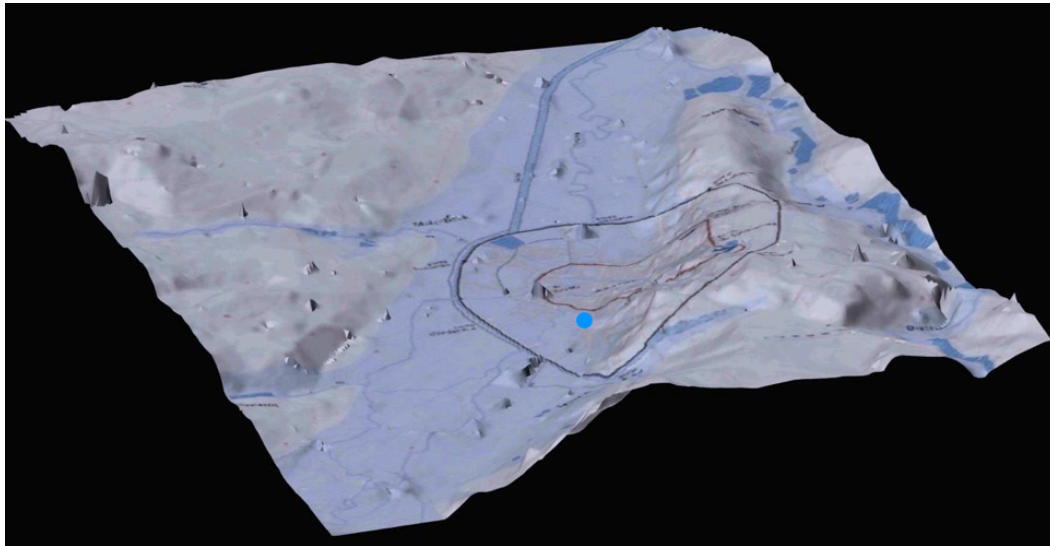


Figure 10: Topographic 3D map of the relief of the Senne Valley based on LIDAR data

Blue dot indicates the location of Rue des Boîteux

Source: MARINOVA et al. (2018)

© CIRB

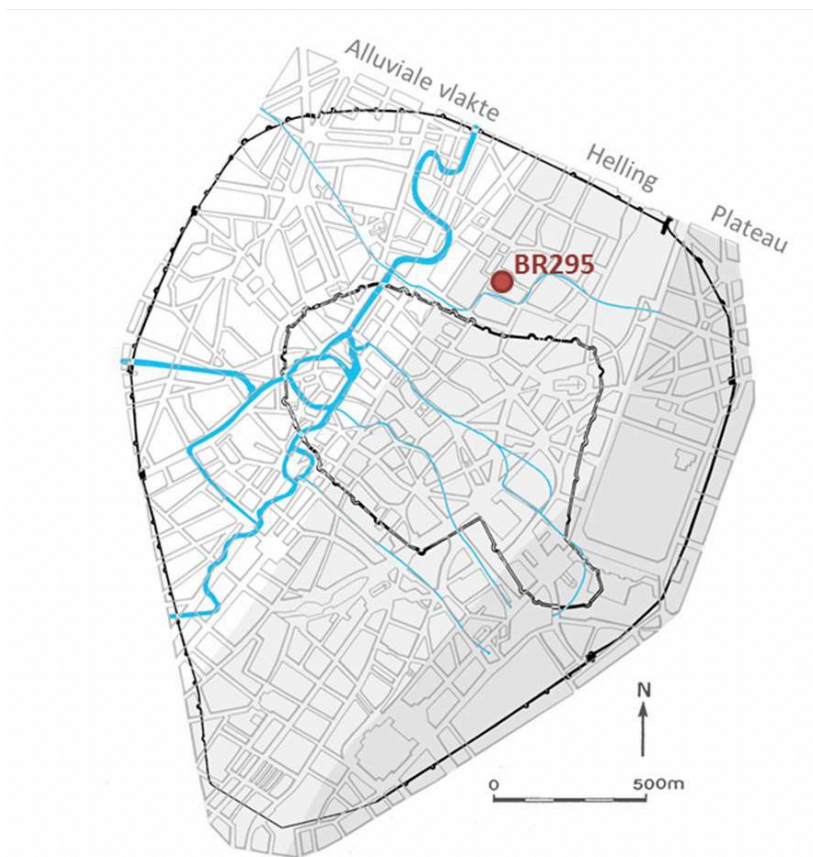


Figure 11: Location of the site 'Rue des Boîteux'

The red dot indicates the location of Rue des Boîteux

Source: SPELEERS (2017, p. 1)



Figure 12: Map of the site

The different sections are indicated on the map in red.

The drawing was produced by Sylvianne Modrie and Denis Willaumez.

Source: DEVOS (2014, p. 8).

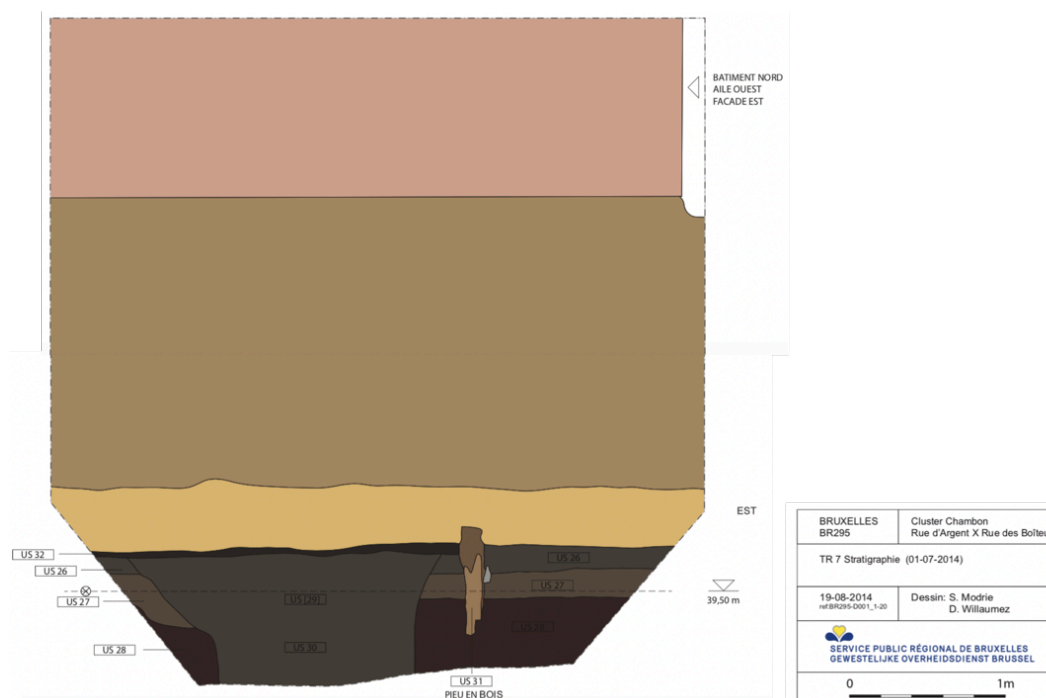


Figure 13: Drawing of section 7: North (profile) – Rue des Boîteux

Section 7 contains the studied units: US28 (peat), US27 and US 26 (Dark Earth)

Source: DEVOS (2014, p. 13)

4.2 Historical background

Rue des Boîteux can be linked to the history of two areas, namely Orsendal (J) and Marais aux Herbes Potagères (K).²³ Orsendal is first mentioned in the 12th or 13th century AD²⁴. VANNIEUWENHUYZE (2008, p. 1038) states that it is hard to locate Orsendal precisely. However, one can assume that it is located *grosso modo* in between the 'Broekstraat' and the 'Schaarbeekse weg'. Marais aux Herbes Potagères was probably situated between the Senne and the 'Broekstraat' (VANNIEUWENHUYZE, 2008, p. 1191). Sometimes, historians mention Orsendal and Marais aux Herbes Potagères together as one area. However, Marais aux Herbes Potagères was situated in a low-lying marshland, while Orsendal was situated in the valley. He concludes that it is likely that Orsendal would have been situated more uphill than Marais aux Herbes Potagères. Some of the present surrounding current street names still refer to the gardening area: Koolstraat (English: Cabbage Street), Warmoesberg (English: Hill of the Chard), and Peterseliestraat (English: Parsley Street) (SPELEERS, DEFORCE and DE CUPERE, 2018).

The development of these two areas coincides with the town developments that took place from the 12th century AD onwards. As mentioned in chapter 2, the 12th – 13th centuries AD designated a period of agricultural expansion from within the perimeter of the first city wall to the area in between the first and the second city wall. Rue des Boîteux was part of a marshland area in the North that underwent major changes during these times. The major advantage of its location is the proximity to the center allowing for the cultivation of more perishable food products such as fruits and vegetables.

The inhabitants of Orsendal and Marais aux Herbes Potagères were called the '*broeckoisien*' (medieval Dutch word for gardeners) during medieval times. The gardeners brought their products to town through the Warmoespoort (English: Gate of the Chard) to go to the center. The city wall contained another gate, the *Keulsepoort* (the Gate of Cologne) through which the products were moved to the countryside for outside trading. It seems that the gardeners did not have a fixed location to sell their products. However, some local ordinances do mention that the gardeners sold their products on the *Nedermarkt* (English: Lower Market, currently: la Grand-Place). During the 15th - 16th centuries AD the toponyms such as *Grasmarkt* (English: Grass Market) and *Hooimarkt* (English: Hay Market) start to appear in historical sources. These places indicate the locations where grass and hay were sold, but probably indicate the products of the gardeners as well (VANNIEUWENHUYZE (2008, p. 244-245)).

²³ **Figure 1** in chapter 2 shows that Rue des Boîteux is situated within/nearby these two areas.

²⁴ It is mentioned for the first time in an original copy in 1227. However, it is also mentioned in a copy that goes back to 1180.

Another historian that mentions the *broeckoisien* is CHARRUADAS (2011, p. 132). The *broeckoisien* were responsible for cultivating vegetables, fruits and herbs. The author mentions that the Orsendal area was a very characteristic sight. The parcels were compact and small. It is likely that they could be linked to several small individual plots which emerged during the 12th – 13th centuries AD. Several documents from the second half of the 13th century AD mention the garden activities, the presence of meadows and the partition of the areas by hedges and ditches. These documents mention the toponym ‘from Bloc’. The Middle Dutch word ‘Bloc’ is used to indicate an agricultural parcel that is enclosed by hedges and ditches that reflect the individual character of the parcels. Some records dating from 1270-1280 mention that the cultivation of grapevine was also present in the area.

4.3 Conducted research

4.3.1 Natural peat sequence

MARINOVA (2015, 2016, 2017) has conducted a comprehensive pollen study on the sequence. The results are divided into four ‘local pollen assemblage zones’ (LPAZs), which reflect successive stages of vegetation history. The pollen assemblages from Rue de Boîteux are typical for alluvial valleys of North-Western Europe. SPELEERS (2017) looked into the seeds and fruits from the peat sequence. Speleers used the ‘local pollen assemblage zones’ and slightly adapted the dates of these zones. Both palynological and carpological studies use the radiocarbon age of 12 samples that was determined at Brussels (RICH) laboratory. **Table 6** shows the dating results. The sequence starts in the 9th millennium BC and ends in the 13th century AD. Furthermore, paleofire studies²⁵ have been executed. These will not be taken into account in this study.

Date	Calibrated ranges BC/AD (with 95.4% probability)	Block	Relative depth [cm]	Composite profile depth [cm]	Dated material
833±35BP	1125 - 1270	US 27-28	10-15	82-87	Chenopodium polyspermum (seeds=12), Urtica dioica (seeds=3), Rubus sp. (fruits=3)
1166±33BP	770 - 970	US 28	15-20	97-102	Mentha (seeds =11), Carex sp. (seed=1), Polygonum hydropiper (seeds=1), Chenopodium polyspermum (seeds=5), Urtica dioica (seed=1), Lamium sp. (seed=1)
1751± 62BP	130 - 409	US 28	0-5	111.5-116.5	Mentha (seeds=4), Urtica dioica (seeds=7), Alnus (catkin bract=2, twig=1)
2805±36BP	1050 - 840	US 2	12.5 - 15	127.5-130	Alnus sp. (twig and catkin)
3073±33BP	1420 - 1230	US 3	12.5 - 15	150-152.5	Alnus (twigs=2)
3210±34BP	1550 - 1410	US 20	0 - 2.5		Rubus sp. (seeds=3)
3319±33BP	1690 - 1510	US 4	17.5 - 20 cm	167.5-170	Alnus (twigs=5)
5822±37BP	4790 - 4550	US 5	5-7.5 cm	205-207.5	Alnus (twigs=2, bud scales=9, catkins =4), Urtica (seeds=11)
6218±41BP	5300 - 5050	US 6	17.5 - 20	215-217.5	Urtica dioica (seeds =70)
8803±52BP	8250 - 7650	US 8	0 - 5	270-272.5	cf. Urtica (seeds=22)
8923±39BP	8250 - 7960	US 12	17.5-20 cm	277.5-280	peat bulk sample
9428±44BP	8820 - 8600	US 12	7.5 - 10	287.5-290	Menyanthes trifoliata (seeds=15)

Table 6: Radiocarbon dating of 12 samples from the natural peat sequence.

The calibration (95.4% probability) performed with the OxCal v4.3.1 program (BRONK RAMSEY, 2009).

²⁵ F. Augustijns (KU Leuven, Belgium) has studied the Early Holocene fire activities in the vegetation, while S. Hautekiet (KU Leuven, Belgium) has studied the anthropogenic and natural factors influencing the Mid to Late Holocene fire activities in the vegetation (AUGUSTIJNS, 2017; HAUTEKIET, 2017).

Given the study's focus on the vegetation history in the Senne Valley during the Holocene, the results from the palynological and carpological study are presented:

The first phase dates from ca. 10900 and 9700 cal BP (palynological report) / ca. 11100 and 9300 cal BP (carpological report). The pollen report indicates that the regional vegetation is dominated by birch (*Betula*) forests and stands of pine (*Pinus*) and juniper (*Juniperus*). This vegetation composition is typical for the beginning of the Holocene. The carpological study also reports the presence of birch (*Betula alba/pendula*). Furthermore, both the palynological and the carpological study observed hazel (*Corylus avellana*). The local vegetation, on the other hand, is characterized by a marshy environment with heliophilous herbs, grasses, nutrition-rich habitats with nettle (*Urtica*), aquatic plants, and organisms which are indicators for shallow water. These include algae (*Chara* sp.), water fleas (*Daphnia* sp.), water-crowfoot (*Batrachium* sp.), white water lily (*Nymphaea alba*), bogbean (*Menyanthes trifoliata*), and duckweed (*Lemna* sp.). There were also willow trees (*Salix*).

The second phase ranges from ca. 9700 to 7800 cal BP (palynological report) / ca. 9300 and 7800 cal BP (carpological report). The environment that had been dominated by pine and birch changed to one dominated by temperate trees. At the beginning of the phase, the pollen proportion of hazel increased rapidly. Simultaneously, oak (*Quercus* sp.), elm (*Ulmus* sp.) and alder (*Alnus* sp.) occurred in percentage values that suggest their migration to the proximity of the study area. At the end of this period the dominance of birch decreased. The observed sporangia indicate an undergrowth with ferns. Locally, the marshy environment area was evolving into a drier area, a development indicated by the presence of sedges (*Carex* spp.). At this point the palynological and the carpological reports contradict each other. The palynological report suggests that there still must have been some open water stands, as indicated by the presence of aquatic plants, while the carpological report indicates the absence of aquatic plants. However, Ehippia (winter or dry-season eggs) from water fleas indicate shallow water in some seasons.

The third phase ranges from ca. 7800 and 3400 cal BP (palynological report) to ca. 7800 and 3400 cal BP (carpological report). Only in the two oldest samples from this phase, were water fleas observed, as well as the disappearance of birch trees. This period was characterized by the development of mixed, oak-dominated woodland. A decreased amount of hazel and grass pollen at the beginning of this phase marks an increase in density of the forests and the establishment of mixed deciduous woodland. In the second half of this phase elm trees started to decrease followed by an increase of lime (*Tilia*) and a slight increase in the oak curve. Locally, alder carr dominated the area with nettle (*Urtica dioica*) as undergrowth. Furthermore, blackberry (*Rubus fruticosus*) and creeping buttercup (*Ranunculus repens*) were observed.

The last phase, dating from ca. 3400 and 2700 cal BP (palynological report) / ca. 3400 and 1050 cal BP (carpological report) was marked by a decrease in arboreal pollen and a slight increase in light-demanding trees such as *Corylus*. Beech (*Fagus sylvatica*) became clearly established in the study area. In the first half of this phase, alder (*Alnus* sp.) was still present, but carpological research reports that from ca. 1600 alder (*Alnus* sp.) ceased growing in the local environment which resulted in a more open landscape. This phase was also characterized by a change in herbal vegetation. Several species were observed that were not observed in previous phases. Watermint (*Mentha aquatica*), gypsywort (*Lycopus europaeus*), lesser water-parsnip (*Berula erecta*), St. Peter's wort (*Hypericum tetrapterum*), water mannagrass (*Glyceria fluitans*) indicate an open or light shaded, nutrition-rich habitat and the proximity of water. Furthermore, an increase in rushes (*Juncus* sp.) took place and species characterizing places with changing water levels such as brown galingale (*Cyperus fuscus*) and common spike-rush (*Eleocharis palustris*) were introduced.

Both palynological and carpological studies notify an anthropogenic signature in this last phase. In the palynological assemblage anthropogenic indicators (*Plantago lanceolate*-type, *Polygonum aviculare*, *Cirsium*-type, Cichorioideae) were continuously present for this phase. These plants are mostly indicators for secondary anthropogenic activities such as pasture, trampling and opening of the forest vegetation. In the carpological assemblage manyseed goosefoot (*Chenopodium polyspermum*) and henbane (*Hyoscyamus niger*) were observed for the upper part of the samples. They tend to grow on places impacted by human activity, but can also occur in a natural environment, e.g. along riverbanks.

4.3.2 Dark Earth units

DEVOS (2018) conducted micromorphological research on the top of the peat sequence (US28) and both Dark Earth units (US26 and US27). Based on the humic character, in combination with the presence of mesofaunal activity²⁶ and root galleries, both units were identified as ancient topsoil. Furthermore, evidence was found that this topsoil was cultivated. Characteristics such as the presence of fragmented, randomly distributed anthropogenic elements and peat fragments in combination with other geoarchaeological observations indicate the physical working of the soil. In turn the intense working suggests on-going horticulture. Finally, the presence of omnivore/carnivore excrements indicates the addition of manure to the soil. Part of the bone fragments showed clear phosphate staining, suggesting ingestion, which is also an indicator for excrements (possibly added to the

²⁶Witnessed by the abundant organo-mineral excremental aggregates

manure). The hypothesis of ancient horticulture units was supported by the other proxies. The results of the carpological, palynological, anthracological and archaeozoological studies is presented in two parts: firstly, the information on the *in situ* vegetation; secondly, the information on the content of the manure (SPELEERS, DEFORCE and DE CUPERE, 2018; DEFORCE, 2019).

***In situ* vegetation**

The carpological study, conducted by SPELEERS (SPELEERS, DEFORCE and DE CUPERE, 2018), states that for both units, remains of plants growing in nutrition-rich grapples are well represented. They tend to grow at places that mark the transition between forests or zones with shrub vegetation to zones with low growing or no vegetation. It is likely that these remains were part of plants that were growing at the side of the ancient garden. The most dominant species in the assemblage is nettle (*Urtica dioica*). Possibly, a part of these seeds derive from the peat sequence.

The remains of the anthropogenic vegetation and the ruderal plants are probably representing *in situ* vegetation, but it should not be excluded that a part of them was added to the soil through manure. Purple dead-nettle (*Lamium cf. purpureum*), sun spurge (*Euphorbia helioscopia*), black nightshade (*Solanum nigrum*), fumitory (*Fumaria officinalis*), manyseed goosefoot (*Chenopodium polyspermum*), lamb's quarters (*Chenopodium album*) were present and are commonly found in cultivated places such as kitchen gardens. The remains of dwarf nettle (*Urtica urens*), nettle-leaved goosefoot (*Chenopodium murale*), henbane (*Hyoscyamus niger*), and dyer's rocket (*Reseda luteola*) can be subscribed to ruderal plants, but can also occur in kitchen gardens. Furthermore, the indicator for trampling and pasture activities, *Plantago lanceolata*-type, is abundant in both Dark Earth units and at the top of the peat sequence.

The carpological report mentions that the remains of wild plants are well-presented in the assemblages for both Dark Earth units. It should be marked that that a part of wild plant remains may be intrusive and belong to the peat, especially those from wild plants that tend to grow in wet environments. Rushes (*Juncus* sp.), statoblasts from moss animals (*Bryozoa*) and resting eggs from water fleas (*Daphnia* sp.). These remains were only present in the older part of the peat sequence. It is likely that they got into the soil through the addition of water. In line with this, DEFORCE (2019) mentions that a notable part of the pollen and non-pollen palynomorphs (NPP) probably derives from the underlying peat. Pollen from alder (*Alnus*), sedges (Cyperaceae), aquatic plants such as the simple stem bur-reed (*Sparganium erectum*) and broadleaf cattail (*Typha latifolia*) likely derive from the peat. Besides the pollen of plants that can be linked to a humic environment, some other pollen from the Dark Earth units could have belonged to the peat such as birch (*Betula*), Hazel (*Corylus avellana*), and oak (*Quercus*).

Addition of manure

The archeozoological, anthracological, palynological and carpological study all help unraveling the history of the content of the manure.

Decupere (SPELEERS, DEFORCE and DE CUPERE, 2018) conducted the archeozoological research. The assemblages of both units indicate that the manure contains waste of consumption. Fish bones from both marine fish and to a lesser extent from local freshwater fish were observed. Furthermore, a few bone fragments from pig and sheep/goat, also regarded as waste of consumption, were observed. The non-determined bone fragments support the hypothesis of manure as these fragments show traces of the digestion process in the body. This implies that these fragments were part of excrements.

The anthracological study, conducted by DEFORCE (2019), points out that it is likely that the charcoal particles were part of the manure as well. The charcoal originally derives from hearths, but it is known that ashes and charcoal were used in cesspits and latrines to banish the bad smell and keep flies away. Afterwards these excrements and charcoal could be used as manure. For both units beech (*Fagus sylvatica*) dominated the assemblage. Furthermore, oak (*Quercus* sp.) and birch (*Betula* sp.) were observed as well. Charcoal from maple (*Acer* sp.), alder (*Alnus* sp.), common hornbeam (*Carpinus betulus*), hazel (*Corylus avellana*), the apple subfamily (Maloideae), willow (*Salix*), willow/populus (*Salix/Populus*) was observed in small amounts. All identified taxa belong to local flora and may have grown in Brussels or the surrounding area.

The palynological study, conducted by Deforce (DEFORCE, 2019), shows that part of the observed pollen can likely be linked to latrine materials. The presence of eggs of intestinal parasites such as whipworm (*Trichuris*) and roundworm (*Ascaris*) is often related to the filling of medieval and post-medieval latrines. In addition, the presence of a pollen grain from gum rockrose (*Cistus Ladanifer*) also indicates the use of human excrements as manure. The gum rockrose is native to the western Mediterranean region. Their pollen are frequently observed in (post)medieval latrines in the Low Countries which is likely the results of the consumption of honey or products that contain honey from the Southern part of Europe. Furthermore, the presence of pollen from cereals, beet (*Beta vulgaris*), spinach (*Spinacia oleracea*), very likely come from (post)medieval latrines. In addition, remains of coprophil fungi such as *Arnium*, *Podospora*, and *Sordaria*, were present in the Dark Earth units (DEFORCE, 2019).

The carpological research, conducted by Speleers (SPELEERS, DEFORCE and DE CUPERE, 2018), reports on the observation of several charred cereals. The identified species are oat (*Avena* sp.), barley (*Hordeum vulgare*), rye (*Secale cereale*), and wheat (*Triticum aestivum/durum/turgidum*). As these cereals were charred, it is likely that they derive from burned household waste or waste from hearths. The pollen study also indicates the presence of cultivated cereals (*Cereal*-type) and weeds (*Orlaya*-type,

Scleranthus annus), but could not determine whether they belonged to *in situ* vegetation whereas the carpological study can (DEFORCE, 2019). It is hard to determine for the other consumable plant remains whether they were part of the *in situ* vegetation or of the added manure. A dominant presence of fruit seeds is a typical feature of latrine material. Furthermore, both the vegetable group as the oil plants and textile fiber plant can be found in latrines. **Table 7** details the observed taxa for the three groups.

Category	Taxa
Seeds and fruits	fig (<i>Ficus carica</i>) wild strawberry (<i>Fragaria vesca</i>) blackberry (<i>Rubus fruticosus</i>) elder (<i>Sambucus nigra</i>) grapevine (<i>Vitis vinifera</i>) medlar (<i>Mespilus germanica</i>) hazel (<i>Corylus avellana</i>) cherry (<i>Prunus cerasus/avium</i>) the apple subfamily (<i>Maloideae</i>)
Vegetables	very small amounts ²⁷ of beet (<i>Beta vulgaris</i>) celery (<i>Apium cf. graveolens</i>) turnip (<i>Brassica rapa</i>)
Oil plants and textile fiber plants	Opium poppy (<i>Papaver somniferum</i>) hemp (<i>Cannabis sativa</i>)

Table 7: Observed taxa from seeds and fruits, vegetables and oil and textile fiber plants

Classification according to Speleers (SPELEERS, DEFORCE and DE CUPERE, 2018)

Chapter 5: Material and methods

5.1 Material for the phytolith analysis

There was no explicit bulk sampling for phytoliths during the excavations. First, bulk samples from the peat sequence and the Dark Earth units were taken in the field. Hereafter, E. Marinova took

²⁷ Vegetables are mostly underrepresented in the carpological assemblage as they are harvested before they produce seeds.

subsamples of these bulk samples for the pollen analysis. The material for the phytolith analysis derived from the remaining material of these subsamples.

5.1.1 The natural peat sequence

The main research design for the peat sequence was to assess the diachronic changes in phytolith assemblages and phytolith quantities in order to investigate the relationship and interaction between humans and their environment. The selection was made in order to form an overview on the peat sequence rather than generating a detailed picture of every sample. This choice was based on the research design, which was conceived to investigate if there are temporally related changes in phytolith records instead of forming a detailed paleo-environmental picture and if these changes originated from human impact. **Figure 14** details the samples that were processed for phytolith analysis. Section 4 (US12) forms the base of the peat, followed by section 1 (US2, US3, US4, US5, US6, US7, US8). The samples from section 6 (US20) overlap in chronology with section 1. The top of the peat (US28) was sampled in section 7. These 22 samples were selected based on two criteria:

- At least one and maximum three samples per US;
- Samples with a usable quantity of remaining material after the pollen analysis.

5.1.2 The Dark Earth units

The Dark Earth units were sampled in section 7 (**Fig. 12**). In order to evaluate the phytolith assemblages and quantities as precisely as possible, all usable samples were processed. Two samples from US26 and 8 samples from US27 were processed. Following samples were not deemed usable as they were situated at the transition between US26 and US27 or between US27 and US28 and thus do not provide exclusive information for US26 or US27: US26-27_14.5 (US26 or US27), US26-27_12 (US26 or US27), US26-27_9.5 (US26 or US27), US27-28_4.5 (US27 or US28), US27-28_2 (US27 or US28).

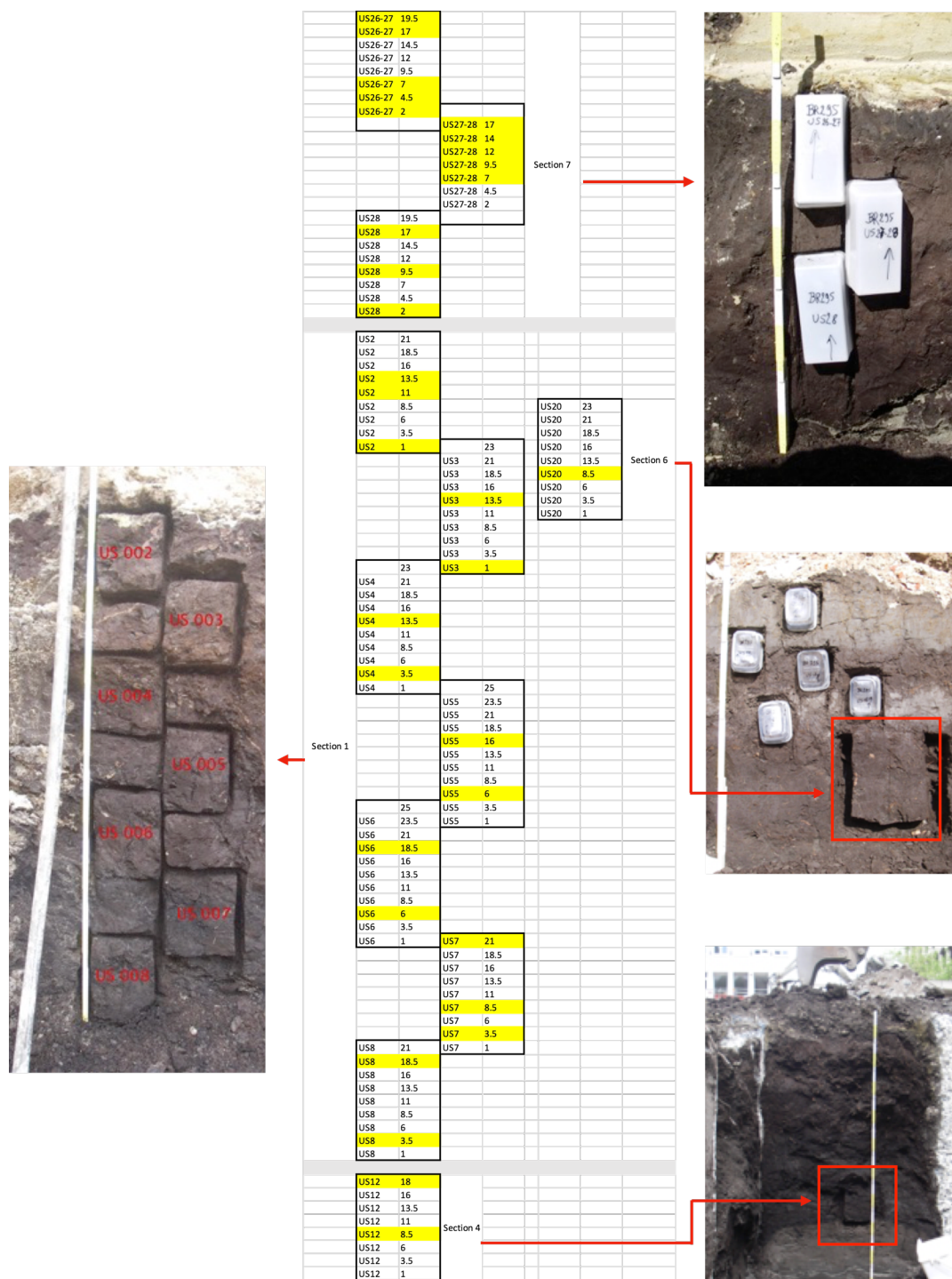


Figure 14: Overview of the processed samples for phytolith analysis

Processed samples are indicated in yellow. They were sampled in 4 different sections (Fig. 12). Section 4 is the oldest section, while section 7 is the youngest (for the radiocarbon dating see table 6). The numbers in the right column indicate the relative depth in centimeters per block. Note that section 6 overlaps with section 1. This overlap is based on radiocarbon dating.

Source images: DEVOS (2014)

5.2 Extraction methods

5.2.1 Laboratory methods

In the preliminary study 16 samples of the peat were processed using laboratory method (1). Laboratory method (1) is the phytolith protocol from the Royal Belgian Institute of Natural Sciences (RBINS). This a standard, traditional, profound procedure where all other soil particles are removed in order to have an almost pure biogenic silica fraction. It takes 1-2 weeks to process the samples. The absence of the phytoliths in some samples from the preliminary study raised the question if phytoliths were absent or not observed. Following processing issues could have been responsible for not observing phytoliths:

- The formation of aggregates obscuring the visibility of phytoliths (**Fig. 15**)
- The dissolution of phytoliths during the chemical processing

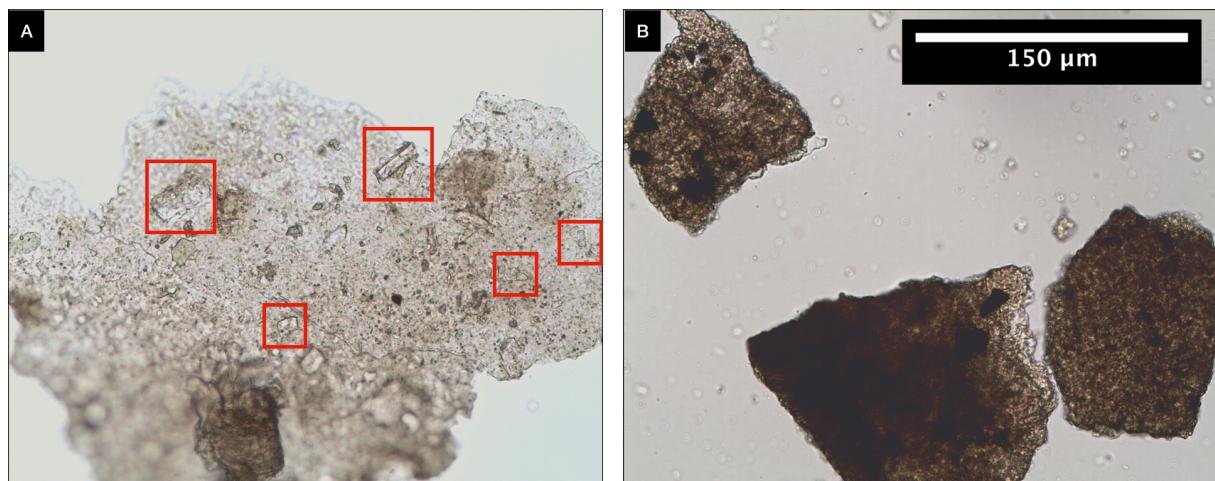


Figure 15: Formation of aggregates

Are phytoliths trapped in the aggregates or absent? A) Trapped phytoliths within a transparent aggregate; B) Dark aggregate possibly obscuring the visibility of the trapped phytoliths

Source: Microscopic pictures of soil material deriving from Rue des Boîteux (taken by the author)

In order to tackle these issues two extra extraction protocols were used beside the traditional method (laboratory method 1). Laboratory procedure (2) is a rapid phytolith extraction method based on KATZ *et al.* (2010). It takes a few hours to process the samples. However, it does not eliminate all soil particles and it is a non-permanent²⁸ method. Laboratory procedure (3) is an adaptation of procedure (2), founded by R. M. Albert²⁹. It takes about 1-2 days to process the samples. The main difference with

²⁸ Slides can only be investigated within 24 hours after preparation as the heavy liquid (SPT) is not rinsed and turns opalescent, thus negatively affecting visibility.

²⁹ ICREA, Barcelona, Spain

the second procedure is that after ‘the addition of heavy liquid (SPT)’ samples are rinsed with water and dried before they are mounted onto a microscopic slide. This results in slides that are permanent, in contrast to the second method. **Table 8** details the various steps of each protocol. ‘Appendix B: laboratory methods’ explains the different protocols and their steps in more detail and presents which samples were processed with each protocol.

These two methods can help tackle the issues of the presence of aggregates and dissolution of the phytoliths in following ways:

- Both methods contain fewer chemical reactions than method 1. This can resolve the question about the possible dissolving of phytoliths during the chemical process. However, it must be noted that adding acid could cause the phytoliths to dissolve;
- Method 2: Mounting the slides with water can keep aggregates from appearing.

	Laboratory method (1)	Laboratory method (2)	Laboratory method (3)
Step 1: Disaggregation and elimination of soil particles	- Removal of carbonates - Removal of organic matter - Breaking metallic bonds - Eliminating organic and humic colloids - Deflocculation and elimination of silts	- Removal of carbonates - Removal of organic matter	- Removal of carbonates - Breaking metallic bonds - Removal of organic matter
Step 2: Floatation and recovery of the phytoliths	- Using SPT - Rinse and dry	- Using SPT - No rinse and wet	- Using SPT - Rinse and dry
Step 3: Mounting of the slides	- Using Canada Balsam	- Using Entellan	- Using Entellan

Table 8: Overview of the used laboratory protocols

5.2.2 Microscopic examination

All observations were made with a petrological microscope under plane-polarized light (PPL) and crossed polarizers (XPL) at magnifications of x200, x400, x500, and x750.

Laboratory method (1) Two slides per sample were made. 150 phytoliths per slide were counted. This means that for each sample 300 phytoliths were registered. The morphotype naming follows *the international nomenclature of the ICPN 2.0* including minor adaptations (ICPT: NEUMANN *et al.*, in press). Following classification scheme was used:

ICPN2.0							
ACUTE BULBOSUS	BLOCKY	BULLIFORM FLABELLATE	ELONGATE				TRACHEARY
			ENTIRE	SINUATE	DENTATE	DENDRITIC	
ICPN2.0							
BILOBATE	POLYLOBATE	CROSS	CRENATE	RONDEL	TRAPEZOID		
Classical		Classical	Classical	Classical	Classical		
Non-classical		Non-classical	Non-classical	Non-classical	Non-classical 1	Non classical	
	Non-classical 2						
Addition							
CELL WALL	Cyperaceae		Non-identified		Unidentifiable		

Table 9: Classification scheme for phytoliths of ‘Rue des Boîteux’

Two major adaptations from the ICPN 2.0 took place. First, most of the Grass Silica Short Cell Phytoliths (BILOBATE, CROSS, CRENATE, RONDEL, and TRAPEZOID) have each been divided into two categories, namely a classical category and a non-classical category. This decision was made in order to distinguish between a group of known – classical – types and unknown – non-classical – types. Classical types are types that correspond to the description provided by the ICPN 2.0. Non-classical types contain phytoliths that, in spite of their clear morphological analogies with GSSCP, also testify of marked morphological differences such as lobes and / or a wavy outline.

Secondly, four additional categories were included. These include CELL WALL, Cyperaceae, Non-Identified and Unidentifiable phytoliths.

Category	Additional Information
CELL WALL	- Predominantly of epidermal origin; - Extremely variable shape and size; - Cell wall fragment (KLEIN and GEIS, 1978, p. 152).
Cyperaceae	- Phytoliths with more distinct central apices in Cyperaceae and Orchidaceae; - The phytoliths in these families may have more pronounced surficial relief (i.e., from the apex to the base of the cone) than hat-shaped phytoliths (OLLENDORF, 1992, p. 92).
Non-identified	- Phytoliths with non-damaged morphologies that cannot be or were not ascribed to a morphotype category (ZURRO <i>et al.</i>, 2016, p. 3).
Unidentifiable	- Phytoliths which are too damaged to be assigned to a specific morphotype category (ZURRO <i>et al.</i>, 2016, p. 3).

Table 10: Added classification categories and their description

Laboratory method (2) Laboratory method (2) was used to quantify the phytolith results. During the laboratory process the used amount of material is closely monitored. Per sample one slide was prepared. On each slide the amounts of phytoliths on 20 fields at a magnification 400x were registered. After the microscopic examination, algebraic formulas are used to calibrate the results and estimate the amount of phytoliths per gram of sediment.

Laboratory method (3) For each sample one slide was prepared. Laboratory method (3) was used as a control assessment. The slides were closely observed, but phytolith counting or morphotype registering was not executed systematically.

5.3 Thin section analysis

A series of block samples have been taken in the field following DEVOS (in press). The air-dried blocks have been impregnated and cut to 30 µm thick thin sections (60 x 90 mm) following the standard laboratory procedures of T. Beckmann in Germany (see BECKMANN (1997)).

The phytolith analysis was executed after the micromorphological study. Vrydaghs studied three thin sections covering the Dark Earth units (US26 & US27) and the top of the peat / transition to the Dark Earth units (US28). Based on these observations one square of 5×5mm was selected in each studied unit. This selection served to target the phytolith content of the soil matrix and to avoid compiling these phytoliths with those with other depositional histories (e.g., phytoliths within pottery, coprolites, etc.). All observations were conducted under PPL and XPL at a magnification of 100x and 400x.

The phytolith analysis contained the following four steps:

- First, a recording of all opal microfossils of biological origin (phytoliths, diatoms, sponge spicules, and chrysophyceae) was made (KACZOREK *et al.*, 2018);
- Then, a systematic recording of the phytolith distribution pattern (Isolated, Clustered and Articulated) as well as an inventory of all phytoliths composing each distribution pattern was made (VRYDAGHS, BALL and DEVOS, 2016; VRYDAGHS and DEVOS, 2018a).
- Next, the phytoliths within the distribution patterns distribution were recorded (VRYDAGHS and DEVOS, 2018a). The applied nomenclature follows the ICPN 2.0 (ICPT: NEUMANN *et al.*, in press).
- Lastly, the visibility, aspect and color of each type of microfossil of biological origin were recorded (VRYDAGHS and DEVOS, 2018b).

The report of Vrydaghs can be found in 'Appendix C: Report on phytoliths in soil thin sections from Rue des Boîteux'. The results of the thin sections in chapter 6 are predominantly based on the results of this report.

Chapter 6: Results

6.1 Results from the extraction method

6.1.1 Taphonomical aspects

Concerning the taphonomical aspects, following observations were made:

- Both the phytoliths from US26 and US27 have similar preservation grades, ranging from perfect to bad preservation.³⁰ Corrosion and erosion processes for phytoliths and other microfossils (diatoms, sponge spicules, and chrysophycean cysts) were observed in both units. Considering the fact that the pH value³¹ of the samples is not detrimental to the preservation of phytoliths, this could be evidence of post-depositional perturbations.
- The preservation grades of the phytoliths from the upper part (US2) and top (US28) of the peat do not differ significantly when compared to the ones of the Dark Earth units. However, one major difference is noted for sample US2_1. In contrast to the other samples, the erosion grade for all microfossils (phytoliths, diatoms, sponge spicules, chrysophycean cysts) is much lower. **Figure 16** presents a perfectly preserved diatom and sponge spicule.

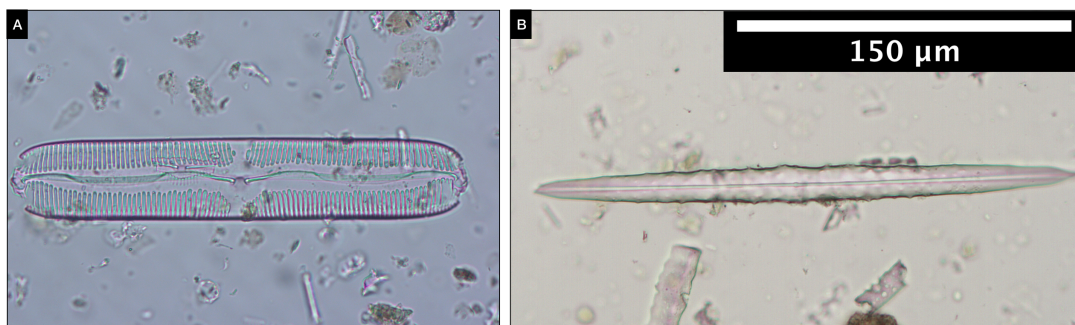


Figure 16: Perfectly preserved opaline microfossils in the peat

Sample US2_1: A) diatom; B) sponge spicule

Source: pictures of Rue des Boîteux taken by the author

³⁰ In contrast to the study of the preservation grades of the phytoliths in the soil thin sections, the preservation grades were not systematically recorded for the samples deriving from the extraction methods.

³¹ pH value around 7, tested in H₂O

6.1.2 Number of phytoliths

In order to investigate the amount of phytoliths, laboratory protocol (2) was used as this method takes quantification into account. One sample from US26, seven samples from US27, and one sample per US for US28, US2, US20, US5, US6, US7, US8, US12 were used. **Figure 17** shows the results of the samples. Here, the mean of the results of the 7 samples from US27 was used. The red chart shows the individual results of the samples from US27. For the peat sequence, most of the samples contained few to zero phytoliths except for US20, US2, and US28 respectively estimating 100 000, 50 000 and 550 000 phytoliths per gram of sediment. For the Dark Earth units an increase in amount of phytoliths is noticed. US27 and US26 contain respectively 1 300 000 and 350 000 phytoliths per gram of sediment.

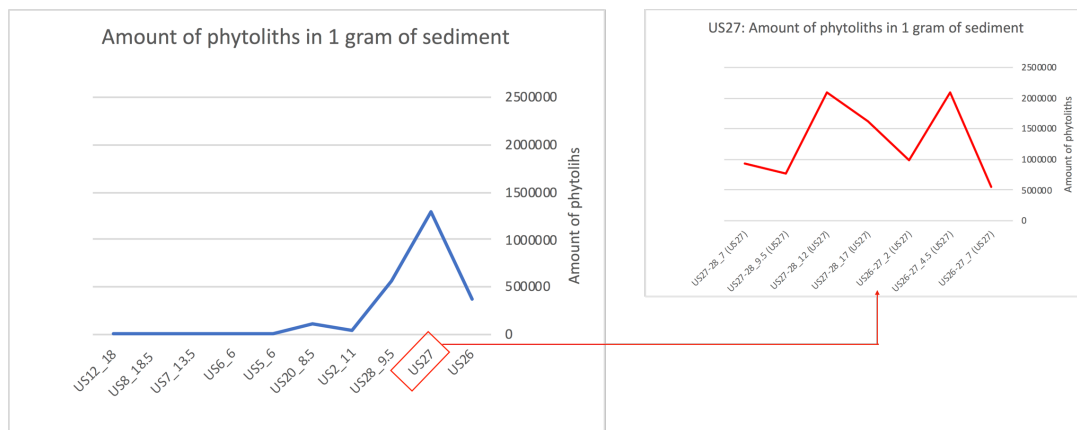


Figure 17: Absolute number of phytoliths

The blue chart presents the amount of phytoliths per unit. The red chart details the individual results of the samples from US27. Note that the number of phytoliths in the sample from US26 is significantly lower than from US27. In fact, only one sample from US26 was available for this analysis. Consequently, based on one sample it cannot be stated with certainty that US26 contains less phytoliths than US27.

Based on these amounts, the studied material can be divided into three parts:

- The lower part of the peat sequence (US12, US18, US7, US6, and US5) where phytoliths were not observed at all;
- The upper part of the peat sequence (samples US20, US2) and the transition to the Dark Earth units (US28) which contained small amounts of phytoliths. The transition to the Dark Earth units records an increase in the amount of phytoliths;
- The Dark Earth units where the amount of phytoliths was much higher. In archaeological contexts, a high amount of phytoliths is usually considered to be an anthropogenic signal (MADELLA, 2007).

6.1.3 Inventory

For each sample two slides were prepared with laboratory method (1). Only slides with at least 150 phytoliths were used for the inventory. This means that 300 phytoliths per sample were obtained. If it was unattainable to reach 300 phytoliths per sample, the morphotypes were not registered. **Table 11** gives an overview of the samples:

Sample	Slide 1	Slide 2
US26-27_19.5 (US26)	150	150
US26-27_17 (US26)	150	150
US26-27_7 (US27)	150	150
US26-27_4.5 (US27)	150	150
US26-27_2 (US27)	53	147
US27-28_17 (US27)	150	150
US27-28_14 (US27)	150	150
US27-28_12 (US27)	150	150
US27-28_9.5 (US27)	150	150
US27-28_7 (US27)	150	150
US28_17	150	150
US28_9.5	150	150
US28_2	0	0
US20_8.5	0	0
US2_13.5	± 50	± 80
US2_11	0	0
US2_1	150	150
US3_13.5	0	0
US3_1	0	0
US4_13.5	0	± 5
US4_3.5	0	0
US5_16	0	± 15
US5_6	0	0
US6_18.5	0	± 5
US6_6	0	0
US7_21	0	± 5
US7_8.5	0	0
US7_3.5	0	0
US8_18.5	0	0
US8_3.5	0	0
US12_18	0	0
US12_8.5	0	0

Table 11: Overview of the samples used for the inventory

The samples marked with green indicate the qualified samples. The samples marked with gray indicate samples that contained zero phytoliths, while the orange marked samples indicate slides where less than 150 phytoliths per sample were observed.

Table 11 indicates that for the Dark Earth units almost every slide contained at least 150 phytoliths. For the peat sequence, however, only three samples out of 22 were eligible for further analysis. In addition, for sample US26-27_2 (US27) 300 phytoliths were counted, but one of the two slides contained significantly less phytoliths than the other slide.

As Dark Earth units are homogenized units, they cannot be considered as a sequence. Therefore, the results from the subsamples of US26 on the one hand and US27 on the other hand were merged in order to acquire one inventory result per Dark Earth layer. As mentioned before US28 forms the upper, and youngest part of the peat sequence followed by US2. This indicates that the qualified peat parts to work with are situated at the top. The results of the inventory are presented in **figure 18**. One notes:

- Presence of BILOBATE, POLYLOBATE, CROSS, RONDEL, CRENATE, TRAPEZOID, ACUTE BULBOSUS in each sample (will be presented in 'presence of Poaceae')
- Presence of BULLIFORM FLABELLATE for US28_9.5, US28_17 and Cyperaceae phytoliths for US2_1, US27 and US26 (will be presented in 'wet environment indicators')
- The appearance of ELONGATE DENDRITIC from US28_17 on that go along with an increase in ELONGATE DENTATE (will be presented in 'presence of cereals')
- The marked presence of non-identified phytoliths for all samples, and especially for US2_1 (will be presented in 'non-identified cereals').
- The presence of BLOCKY, ELONGATE ENTIRE, ELONGATE SINUATE, TRACHAERY, CELL WALL and unidentifiable phytoliths. These will not be further presented into detail as they are morphologically insignificant phytoliths.

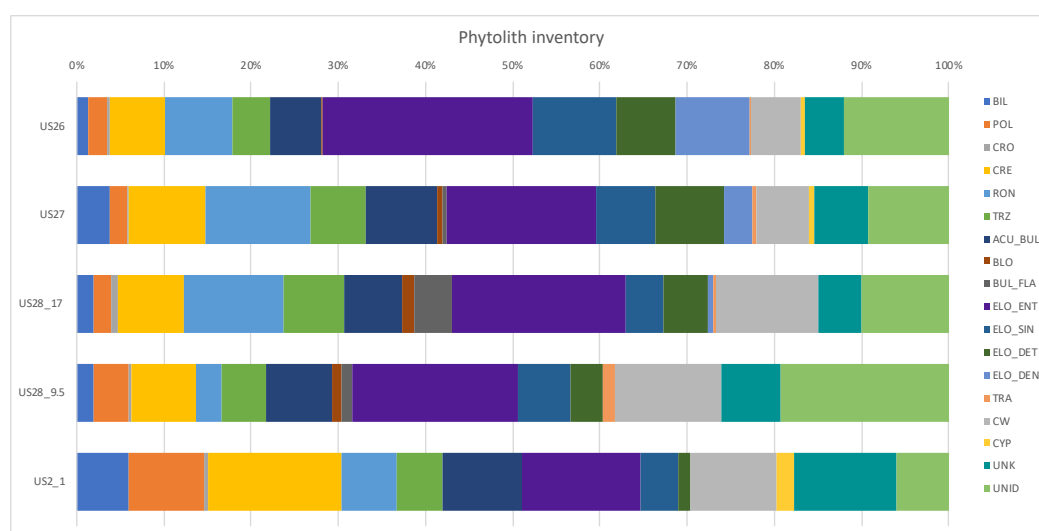


Figure 18: Inventory of the phytoliths

List of abbreviations: BIL = BILOBATE; POL = POLYLOBATE; CRO = CROSS; CRE = CRENATE; RON = RONDEL; TRZ = TRAPEZOID; ACU_BUL = ACUTE BULBOSUS; BLO = BLOCKY; BUL_FL = BULLIFORM FLABELLATE; ELO_ENT = ELONGATE ENTIRE; ELO_SIN = ELONGATE SINUATE; ELO_DET = ELONGATE DENTATE; ELO_DEN = ELONGATE DENDRITIC; TRA = TRACHAERY; CW = CELL WALL; CYP = Cyperaceae; UNK = Non-identified; UNIN = Unidentifiable.

Presence of Poaceae (grasses)

The phytolith record can be reorganized into three groups: grass silica short cell phytoliths (GSSCP), redundant phytoliths, and other phytoliths (**Fig. 19**):

- **Poaceae** This group is formed out of the grass silica short cell phytoliths (GSSCP) and ACUTE BULBOSUS phytoliths. The GSSCP consists out of following morphotypes: BILOBATE, POLYLOBATE, CROSS, CRENATE, RONDEL, and TRAPEZOID. BILOBATE, POLYLOBATE AND CROSS are morphotypes frequently found in Panicoideae and other PACMAD grasses. CRENATE, TRAPEZOID AND RONDEL are mostly found in the Pooideae subfamily (BEP grasses) (ICPT: NEUMANN *et al.*, in press).
- **Redundant phytoliths** are “identical types appearing in related as well as taxonomically unrelated species” (ROVNER, 1971, p. 349). In other words, there is a possibility that they derive from Poaceae. This group consist out of following morphotypes: ELONGATE ENTIRE, ELONGATE SINUATE, ELONGATE DENTATE, and ELONGATE DENDRITIC.
- **Other phytoliths** are the remaining phytoliths from the assemblage. We know for sure that this group of phytoliths did not derive from Poaceae.

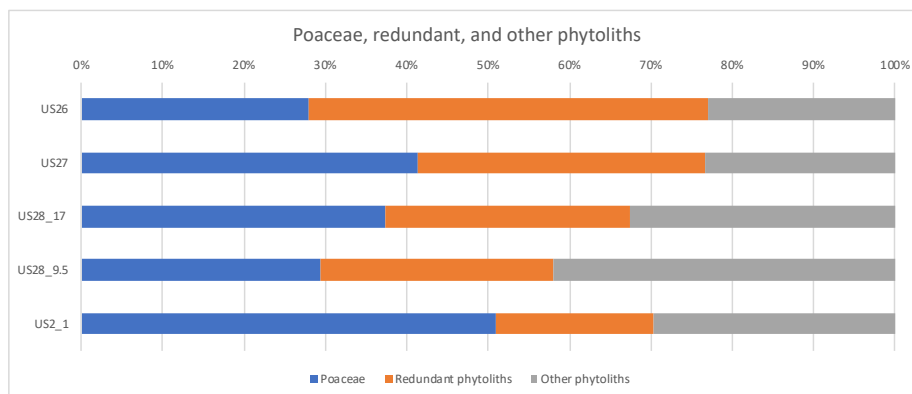


Figure 19: Presence of Poaceae, redundant and other phytoliths

The presence of phytoliths deriving from Poaceae is marked for both the peat and the Dark Earth units, but with a decrease in GSSCP for the transition and Dark Earth: 50% for US2_1 and no more than 40% for US28, US27, and US26. If we consider GSSCP and redundant phytoliths together, we reach frequencies starting from around 60% to 75%³².

³² One must notice that these frequencies for GSSCP are relatively high. STRÖMBERG *et al.* (2018, p. 241) mentions that grasses tend to be overrepresented as their phytoliths are ubiquitous and dominant in assemblages.

Wet environment indicators

For US28 BULLIFORM FLABELLATE was notably present. The ICPN2.0 mentions that BULLIFORM FLABELLATE is related to a high water availability (ICPT: NEUMANN *et al.*, in press). Consequently, we can state based on the presence of these phytoliths that the transition (US28) is characterized by a wet environment. For US2_1 we also note a higher presence of phytoliths deriving from Cyperaceae often associated with wetlands or wet environments. This is supported by a marked presence of other opaline microfossils (diatoms, sponge spicules and chrysophycean cysts³³) in US2_1 that also indicate a wet environment. As a whole, these observations point towards a wet environment for the upper part of the peat (**Fig. 20**).

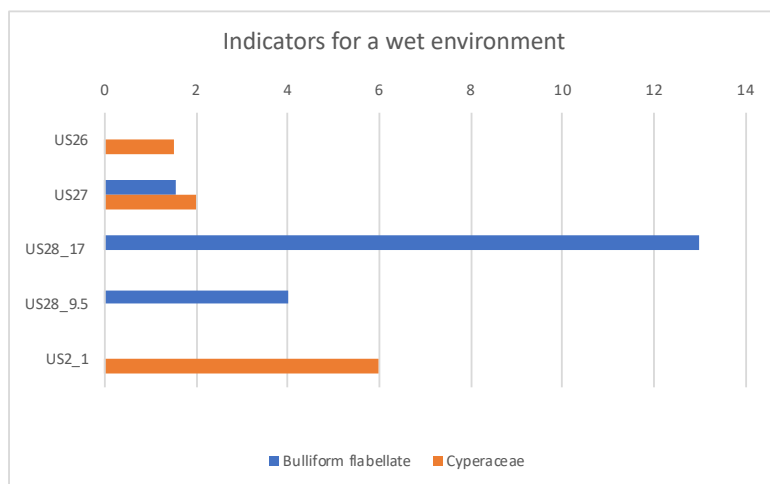


Figure 20: Indicators for a wet environment per sample

³³

Diatoms occur in freshwater, marine, brackish and hypersaline environments (black book p. 165)

Opal sponge spicules derive from fresh-water sponges (VRYDAGHS, 2017, p. 171).

*Chrysophycean cysts are mostly (marine species are rare) freshwater organisms (VERLEYEN *et al.*, 2017, p. 165).*

Presence of cereals

ELONGATE DENTATE is attributed to the epidermis of the leaves, common in the inflorescence parts, of wild and domesticated Poaceae (grasses) (ICPT: NEUMANN *et al.*, in press). ELONGATE DENDRITIC mostly occurs in the inflorescence bracts of wild and domestic species of grasses. Within archaeological deposits, they are often used to indicate domesticated cereals³⁴. Furthermore, it is not always easy to discriminate ELONGATE DENTATE phytoliths from ELONGATE DENDRITIC phytoliths. According to the ICPN2.0, ELONGATE DENTATE and ELONGATE DENDRITIC form a morphological continuum in the inflorescences parts of Poaceae (ICPT: NEUMANN *et al.*, in press).

Figure 21 shows the ELONGATE DENTATE and ELONGATE DENDRITIC phytoliths in absolute numbers out of 300 counted phytoliths per sample. One notes that while ELONGATE DENTATE are present in the peat units, the amounts are low. Their amounts gradually increase from the upper part of the peat sequence starting from US2_1 to the Dark Earth units US27 and US26. Furthermore, we note the first presence of ELONGATE DENDRITIC at the top of the peat (US2_1). The amount of ELONGATE DENDRITIC increases rapidly for the Dark Earth units. The grey line visualizes the summation of ELONGATE DENTATE and ELONGATE DENDRITIC phytoliths for each sample. One notes that this results in a gradual, almost linear increase and that there is a positive correlation between the presence of ELONGATE DENTATE and ELONGATE DENDRITIC. This could suggest a more marked presence of cultivated crops starting with the top of the peat (US2_1).

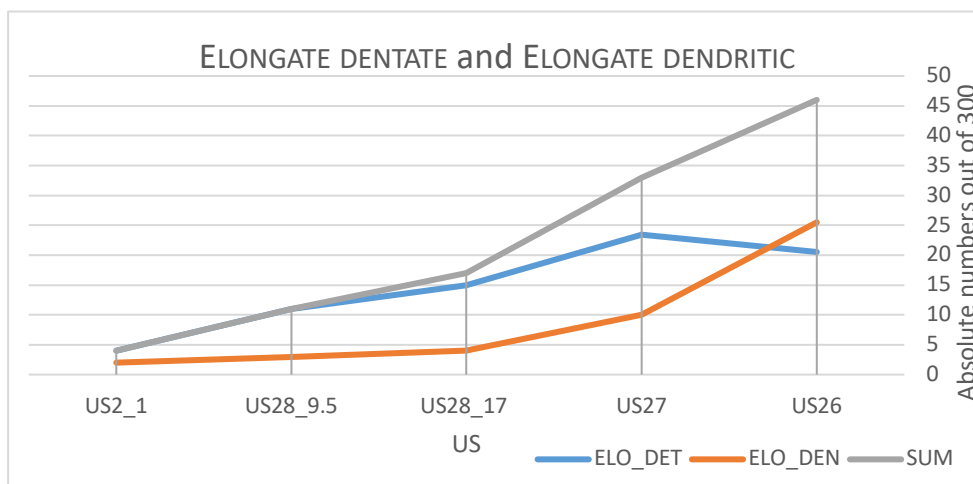


Figure 21: Presences of ELONGATE DENTATE and ELONGATE DENDRITIC per sample

Abbreviations: ELO_DET = ELONGATE DENDRITIC, ELO_DEN = ELONGATE DENTATE, SUM = sum of ELO_DET and ELO_DEN

³⁴ The presence of ELONGATE DENDRITIC in an archaeological deposit does not necessarily lead to the interpretation that domesticated cereals are present, as they can also occur in wild grasses. Archaeological contextual information is of vital importance in this case (ICPT: NEUMANN *et al.*, in press).

Non-identified phytoliths

Figure 22 illustrates that around 5-10% of the phytoliths in the samples are non-identified phytoliths. This means that based on current phytolith knowledge these morphotypes could not be identified. Especially for US2_1 the number of non-identified phytoliths (more than 10%) is high.

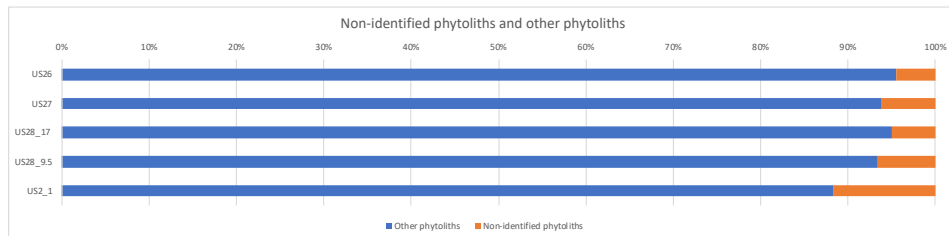


Figure 22: Non-identified and other phytoliths per sample

6.2 Results from the thin sections (US28, US27, and US26)

6.2.1 Taphonomical aspects

Overall, phytoliths are well-preserved in all three units (**Fig. 23**). Around 50% percent of the phytoliths have a perfect preservation, followed by 20-25% of the phytoliths with an almost perfect to good preservation. Only 17-20% of the phytoliths in the units have a moderate to bad preservation.

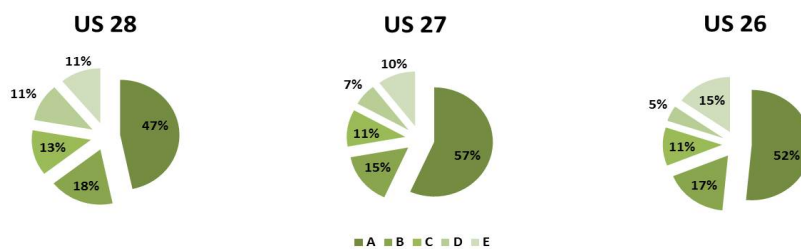


Figure 23: Relative frequencies of phytoliths preservation grades

A = perfect preservation; B = almost perfect preservation; C = good preservation; D = moderate preservation; E = bad preservation.

Furthermore, the report states that the phytoliths do not share the same taphonomic context. The phytoliths are situated in:

- *Fragments of organic tissues for US27 and US28*: these phytoliths are still located *in situ*. This group forms the minority of observations and therefore it will not be taken into further account;
- *Excrements for US26 & US27*: The phytoliths in the excrements are intrusive phytoliths;
- *Within the soil matrix for US26, US27, and US28*.

Phytoliths in excrements

Excrements were observed for US26 and US27. In total, 15 coprolites – 6 for US26 and 9 for US27 - were analyzed in order to examine the presence of phytoliths, while their distribution pattern and morphotype was registered if they were present. 13 out of 15 coprolites yielded positive phytolith results, while one could not be examined with certainty, and one did not contain phytoliths. Of the 13 coprolites that contained phytoliths, 12 contained one isolated phytolith each. Either their morphotype was ELONGATE ENTIRE or it could not be determined due to a bad visibility, orientation or if the phytolith was just a phytolith fragment. One coprolite, however, contained a group of articulated phytoliths. The group was composed of at least 10 ELONGATE DENTATE (**Fig. 24**). This distribution indicates the *in situ* decomposition of some grass plant fragments. The other phytoliths that were present in the coprolites are, taxonomically, insignificant morphotypes. These results indicate the herbivorous/omnivorous character of the excrements.

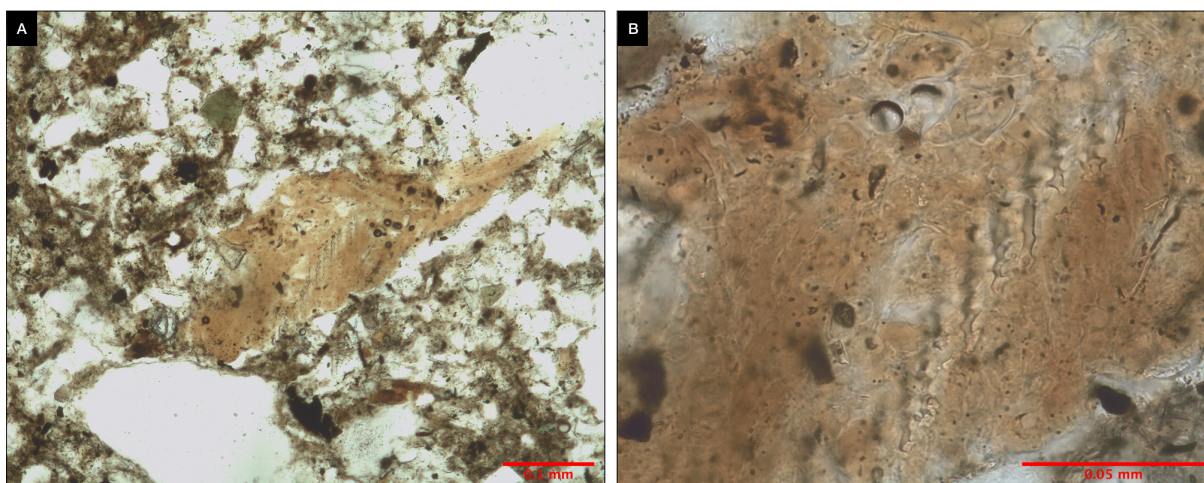


Figure 24: Group of articulated phytoliths in excrements from US27

A) image of the coprolite at x100 (PPL) B) image of the same coprolite at x500 (PPL)

Source: pictures of Rue des Boîteux taken by Luc Vrydaghs

Phytoliths within the soil matrix

The phytoliths within the soil matrix can be divided into three distribution patterns: isolated, clustered and articulated phytoliths. **Table 12** shows the results for each unit (US26, US27, and US28). The isolated phytoliths dominate in each sample in relation to the clustered and articulated phytoliths. Clustered distribution patterns are present for all three studied units. Articulated phytoliths, in contrast, were almost not observed. Only US27 contains one articulated distribution pattern containing 6 phytoliths. The high amount of isolated phytoliths forms evidence for post-depositional perturbations.

US	N (#square)	Isolated phytoliths	Clustered phytoliths	Articulated phytoliths
26	1	230	40	0
27	1	247	60	6
28	1	137	16	0

Table 12: Number of isolated, clustered and articulated phytoliths per sample.

Number of minimal observations based on the analysis of one square of 5x5 mm per unit.

6.2.2 Number of phytoliths

It is noted that the US27 contains the most phytoliths followed by US26. In comparison to the top of the peat sequence there is an increase in the number of phytoliths for the Dark Earth units (**Table 13**).

Unit	N (#square)	Phytoliths
US 26	1	270
US 27	1	313
US 28	1	153

Table 13: Absolute numbers of phytoliths per sample
per square of 5x5 mm per unit (US26, US27, and US28)

8.2.3 Inventory

The phytoliths observed within the soil matrix were classified into three categories: ELONGATE (ELO), Grass Silica Short Cell (GSSCP) and unidentified phytoliths (NI). The unidentified phytoliths do not only cover the unidentifiable and non-identified phytoliths, but also the phytoliths that are not identifiable due to a bad visibility or orientation.

Figure 25 shows that the clustered distribution patterns are dominated by unidentified phytoliths, while the isolated phytoliths are characterized by a higher frequency in ELONGATE and GSSCP.

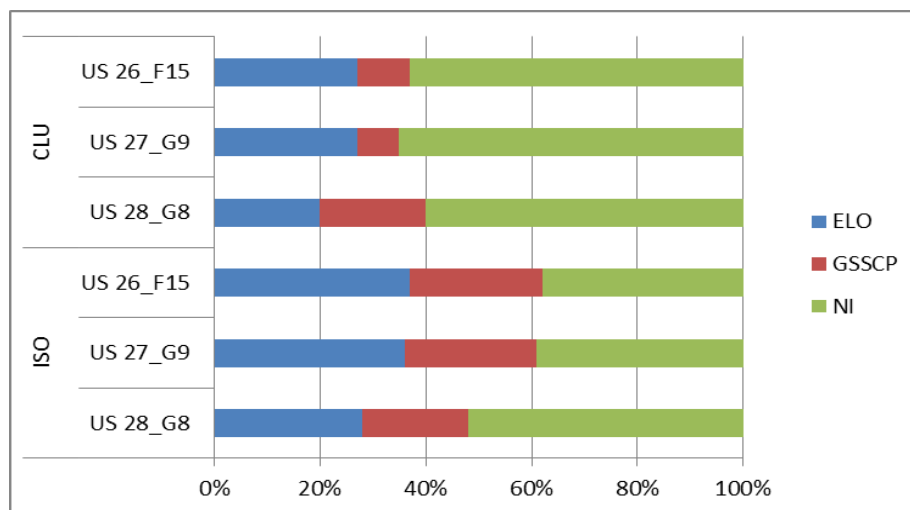


Figure 25: Relative frequencies of the ELONGATE, GSSCP and unidentified
For each distribution pattern for US28, US27, and US26.

The assemblages of the articulated and the clustered distribution patterns will not be taken into account as not enough phytoliths were observed to obtain reliable results. There was only one articulated distribution pattern in US27, consisting out of 6 ELONGATE ENTIRE, which are taxonomically insignificant. For the cluster distribution patterns respectively only 17 (US26), 27 (US27), and 8 (US28) clusters were observed containing 40 (US26), 60 (US27), and 16 (US28) phytoliths. This number of phytoliths is too low to be representative with certainty.

Hence, we will focus on the assemblages of the isolated phytoliths (**Fig. 26**). The isolated ELONGATE are classified into three subcategories: ELONGATE ENTIRE (ELO_ENT), ELONGATE DENDRITIC/DENTATE (ELO_DEN/DET), and ELONGATE SINUATE (ELO_SIN). The GSSCP consist out of RONDEL (RON), BILOBATE (BIL), TRAPEZOID (TRZ), and CRENATE (CRE)³⁵.

One notes:

- The appearance of ELONGATE SINUATE for US26 and US27;
- Relatively high frequency of RONDEL for US28;
- Relatively low frequency of TRAPEZOID for US28.

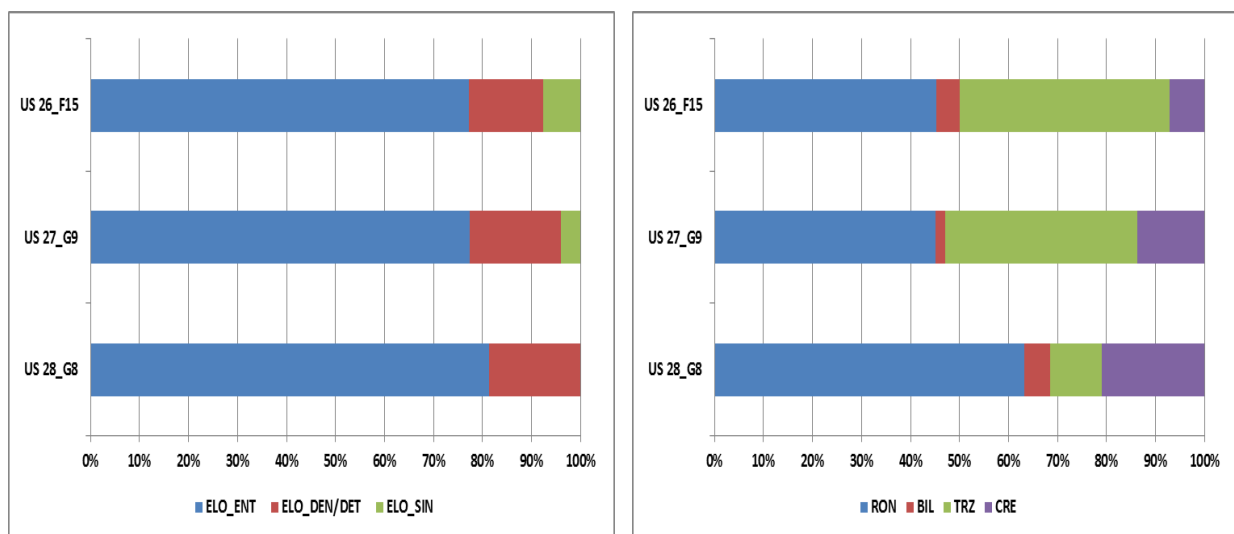


Figure 26: Inventory of Elongate and the GSSCP in the isolated distribution pattern

For US26, US27, and US28. ELONGATE ENTIRE (ELO_ENT); ELONGATE DENDRITIC/DENTATE (ELO_DEN/DET); ELONGATE SINUATE (ELO_SIN);

³⁵ Some ACUTE BULBOSUS were observed as well.

Chapter 7: Discussion and interpretation

7.1. Peat sequence (9th millennium BC – 12th/13th centuries AD)

7.1.1 Environmental changes

Currently, the environmental changes are not accurately reflected in the phytolith record for the peat, while both palynological and carpological analyses do provide a more detailed picture of the environmental changes during the Holocene (see chapter 4). The major reason why the environmental changes could not be analyzed in detail is the difference in number of phytoliths between the lower part of the peat and the upper part of the peat. One could preliminarily state that for the upper part of the peat phytoliths are present, while for the lower part few to zero phytoliths were observed. The first question that arises is why phytoliths were not observed for certain parts of the sequence. The phytoliths could either be absent or have been insufficiently preserved. **Table 14** shows a range of general explanations and evaluates their probability for Rue des Boîteux.

Explanation	Rue des Boîteux
No silicon available to form opal phytoliths (BRAADBAART <i>et al.</i> , 2017, p. 1690). In some peatlands, especially raised peatlands, silicon for the deposition of the opal in the plant cells can be unavailable as nutrient-poor rain water is the only source for feeding the plants.	The peat of Rue des Boîteux is not a raised peatland, but a peat bog (L. Speleers, pers. comm.). Peat bogs are known to have a low solubility rate of the silicon (BENNETT <i>et al.</i> , 1991). However, for the moment, too little is known about the peat and its available silicon in Brussels, because of which this hypothesis cannot be ruled out.
The peat contained plants that did not produce phytoliths (BRAADBAART <i>et al.</i> , 2017, p. 1690). In some peats there can be an absence of phytoliths as some sedge taxa and mosses do not produce opal phytoliths (OLLENDORF, MULHOLLAND and RAPP, 1987; BOZARTH, 1993).	This explanation is highly unlikely. The phytolith record can be integrated with the other archaeobotanical evidence. For the parts of the sequence that contained zero to few phytoliths, both the palynological and the carpological report indicate the presence of plants that are known to produce phytoliths.
The flow of the groundwater has removed the phytoliths in the peat (BRAADBAART <i>et al.</i> , 2017, p. 1690). This explanation is likely when the peat is situated in a wetland.	The peat was indeed situated in a marshy environment during the first phase ³⁶ . However, during the second phase ³⁷ the area evolved into a dry land. For the moment, too little is known about the soil processes to evaluate this

³⁶ Dating from ca. 10900 and 9700 cal BP (palynological report) / ca. 11100 and 9300 cal BP (carpological report)

³⁷ Dating from ca. 9700 and 7800 cal BP (palynological report) / ca. 9300 and 7800 cal BP (carpological report)

	hypothesis. Therefore, this hypothesis should be re-evaluated in the future.
Phytoliths have degraded in the soil (BRAADBAART <i>et al.</i> , 2017, p. 1690). A high soil pH (pH >9) is known to accelerate the breakdown of phytoliths in the soil. Furthermore, it cannot be excluded that phytoliths can also break down under reducing or neutral conditions (THORN, 2004-2005; WILLIAMS and CRERAR, 1985; WILLIAMS, PARKS and CRERAR, 1985). Other reason for the degradation in the soil is the deposition of aluminum within the phytoliths as this decreases their solubility (BARTOLI, 1985; CARNELLI <i>et al.</i> , 2002; WÜST and BUSTIN, 2003) and the process of silica recycling (BARTOLI, 1983; ALEXANDRE <i>et al.</i> , 1997; GÉRARD <i>et al.</i> , 2008; CORNELIS <i>et al.</i> , 2010, 2011)	Based on the current evidence this explanation cannot be ruled out. The pH (measured in H ₂ O) from the samples ranges around 7 (neutral conditions). Currently, there is no information available about the deposition of aluminum. This hypothesis is supported by the absence of other opaline microfossils (diatoms, chrysophycean cysts and sponge spicules). As the lower part of the sequence is identified as a marshy area, we should expect the presence of these other opal microfossils as they are indicators of a wet environment.
Phytoliths have dissolved or disintegrated during the laboratory processing. Some phytoliths can be altered during laboratory processing (JENKINS, 2009; SHILLITO, 2011a).	Four series of processing took place. Method (1) had been executed twice (2X 16 samples), Method (2) (16 samples) and (3) (16 samples) once. In all four series the number of phytoliths for the lower part of the peat sequence was low to zero. As these four series gave similar results we can state that the results are reliable. However, it could be that the peat needed a different laboratory treatment, making current results invalid. The acid step during the processing, for example, could cause a breakdown of phytoliths.

Table 14: Hypotheses for not observing phytoliths in the lower part of the peat

Based on these hypotheses we can state that observing few to zero phytoliths for the lower part may be unrelated to a change in environment between the lower and the upper part. We can conclude that following hypotheses are most likely for observing few to zero phytoliths in some samples: 1) dissolution or disintegration of the phytoliths in the laboratory; 2) degradation of the phytoliths in the soil; 3) lack of silicon in the soil to form phytoliths; 4) removal of the phytoliths from the soil due to the flow of groundwater.

For the upper part of the sequence, one notices that the phytolith record holds a wide variety of types of phytoliths. The record marks the presence of Poaceae (grasses) and Cyperaceae (sedges) for the

last phase³⁸ which corresponds to the carpological and palynological results. Another aspect that is marked in the record is the presence of opal microfossils such as sponge spicules and diatoms and their good preservation indicating a wet, non-disturbed environment which corresponds well with the context of the archaeological site, characterized by the presence of peat in marshland.

7.1.2 Anthropogenic signals

The first anthropogenic signals

As mentioned in chapter 4 both the palynological as the carpological report³⁹ mention anthropogenic signals for the last phase⁴⁰. The carpological study mentions the presence of manyseed goosefoot (*Chenopodium polyspermum*) and henbane (*Hyoscyamus niger*). These can occur in a natural environment, but they tend to grow on places impacted by anthropogenic activities. Both species were observed for the top of the peat, US28 (1615-1225 BP).

The palynological study notes the presence of anthropogenic indicators during the last phase including *Plantago lanceolata* type, *Polygonum aviculare*, *Cirsium*-type, and Cichorioideae. These are indicators for activities such as trampling, pasture and opening of the forest. **Figure 27** presents the records of these indicators for the last phase. It is pointed out that all the samples of this phase are characterized by the presence of these indicators., while for the third phase⁴¹ the pollen of these indicators were only sporadically observed.

³⁸ dating from ca. 3400 and 2700 cal BP (palynological report) / ca. 3400 and 1050 cal BP (carpological report)

³⁹ Note: Besides the archaeobotanical records, the paleo-fire study for Rue des Boîteux also provides evidence for human activity. The peak in fire frequency in the Late Holocene is most likely caused by human activity since there is a positive correlation between the CHAR peaks and *Plantago lanceolata* type, Cichorioideae. There is, however, a negative relation between tree pollen and charcoal suggesting the contribution of fire to forest disruption (MARINOVA, 2017, p. 6).

⁴⁰ dating from ca. 3400 and 2700 cal BP (palynological report) / ca. 3400 and 1050 cal BP (carpological report)

⁴¹ ca. 7800 and 3400 cal BP (palynological report) / ca. 7800 and 3400 cal BP (carpological report)

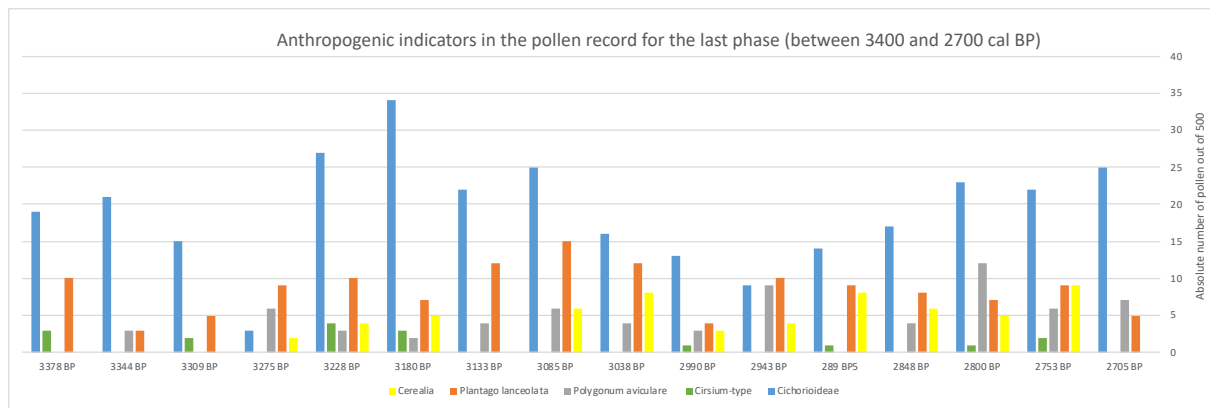


Figure 27: Anthropogenic indicators in the pollen record for the last phase
(between 3400 and 2700 cal BP)

Source: Figure was made based on the raw data of MARINOVA (2017).

Figure 27 also presents the presence of pollen from *Cerealia*. The appearance of cereals is likely linked to human activity, more specifically the cultivation of the soil. Therefore, analyzing when the cereals start to appear in the soil, is interesting for understanding the human impact on the environment. In the pollen record these *Cerealia* first start to appear in the sample that is dated to 3275 BP. In the phytolith record ELONGATE DENDRITIC and DENTATE, the types that are often linked to the presence of cereals, were first observed for US2_1 which is dated to 3085 BP. These observations demonstrate that both the phytolith record and the palynological record indicate an early presence of cereals in the soil. While making statements based solely on these observations is premature, they are promising for future research as the early presence of cereals could provide new insights on the early development of Brussels.

The urbanization process (10th – 13th centuries AD)

The urbanization process should correspond to the samples from US28 that yielded positive phytolith results. However, there is not that much of a difference between the phytolith record from the Dark Earth units and the top of the peat (US28). It is likely that this is also the result of the dynamic post-depositional processes being the horticulture. Currently, I am unable to discuss this topic as the middle and lower parts of peat did not yield enough results to compare with the results from US28. An increase in absolute number of phytoliths is linked to anthropogenic activities (MADELLA, 2007). One notes that for the upper part of the peat (US20 and US28) the number of phytoliths increases followed by an even higher number for the Dark Earth units (US27 and US26). However, as there are currently complications with the reliability of the results from the middle and the lower part of the peat, it is impossible to make clear statements about the change in the number of phytoliths and if this is an indicator for more intensive land use by humans.

7.1.3 Identification issues

The number of unknown phytoliths (non-classical and non-identified phytoliths) for the upper part of the peat is relatively high compared to the number in the Dark Earth units. It should be noted that for US2_1 more than 50 out of 300 phytoliths⁴² could not be determined with certainty. **Figure 28** details the absolute number of non-classical phytoliths and the non-identified phytoliths per sample. Both groups correlate, except for US28_17, and as such, they give a similar view on the site's history. This high number of unknown phytoliths in the upper part of the peat indicates that a large part of the phytolith record bears potential for identifying environmental changes, but that in the present study the record in the peat remains enigmatic. The identification issues of both groups could be tackled with the development of a modern phytolith reference collection for Northern Europe. Here, I focus on two groups of phytoliths occurring at the top of the peat facing identification issues. Both groups were matched with phytoliths from worldwide modern phytolith reference collections or phytoliths from archaeological sites.

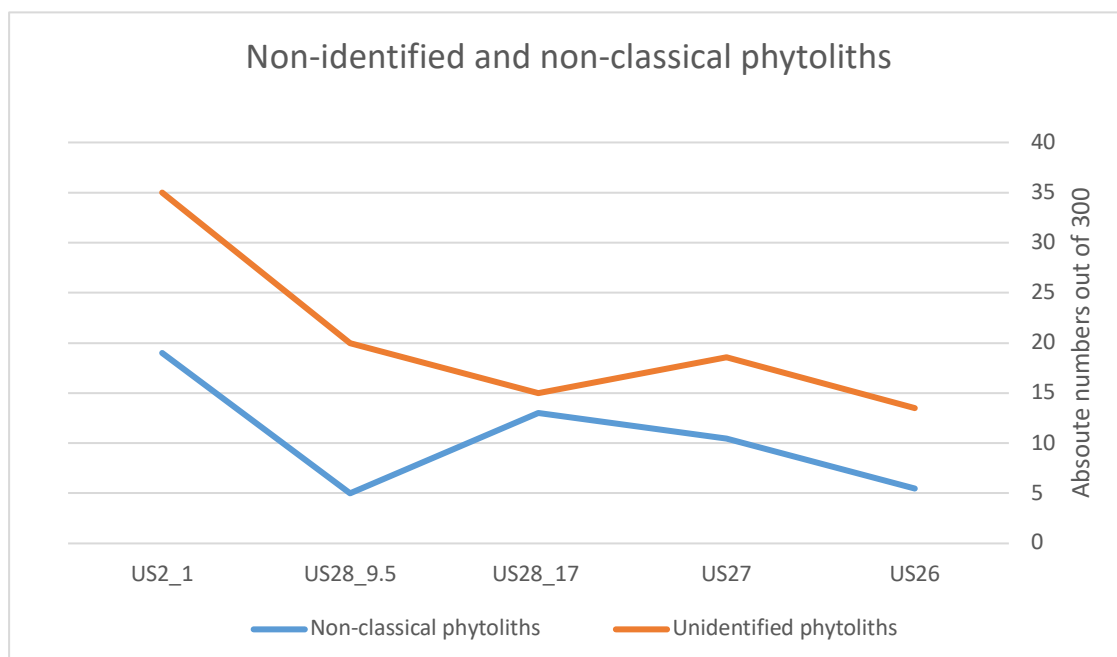


Figure 28: Non-identified and non-classical phytoliths per sample

(1) Non-classical phytoliths with lobes and / or wavy outline: The non-classical phytoliths with lobes (all non-classical phytoliths except for non-classical RONDEL type 1) raise questions as well. Although they are similar to classical GSSCP, there are subtle differences based on the presence of lobes and / or a wavy outline. Similar phytoliths were observed in a study on modern plant material from

⁴² Sum of the non-identified and non-classical phytoliths

Minnesota, USA. One notes that the modern GSSCP from Minnesota, USA have similar lobes and / or wavy outlines (**Fig. 29**). However, plants grow under local circumstances and therefore considering the non-classical phytoliths from Brussels to be wetland grasses, based solely on material from the USA, would be a premature conclusion. That being said, it does form a starting point for further investigation.

(2) Sedge phytoliths: Mostly, plants of the Sedge family are identified through typical cone shaped phytoliths. However, in the samples of Rue des Boîteux the presence of sedge is marked by a different type of sedge phytoliths: achene phytolith (plate: G-L) (**Fig. 30**). Image A-F show that phytoliths with comparable outlines were observed which in turn suggest they could derive from sedges. However, the main problem with a more detailed identification is that we cannot compare these phytoliths to each other as they derive from sedges from Patagonia, New Mexico, French Guiana, Ecuador, and Panama. Furthermore, images M-O show non-identified phytoliths from Rue des Boîteux that are somewhat similar in morphotype to the sedge phytoliths, but differ as they have an 'echinate'⁴³ surface (**Fig. 30**).

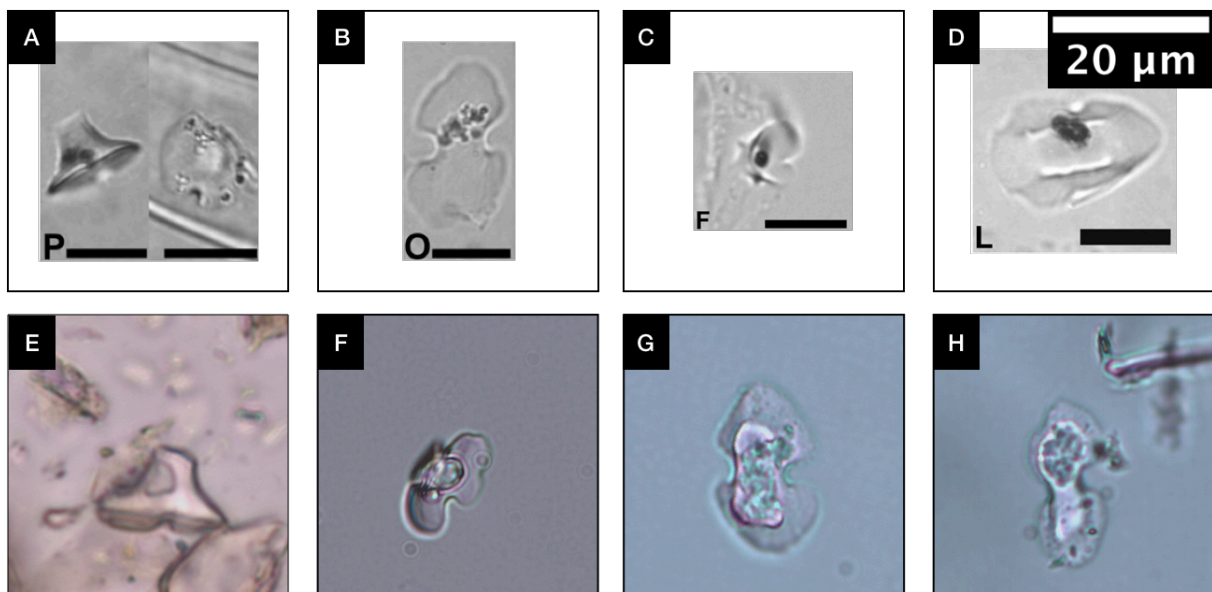


Figure 29: Examples of non-classical GSSCP

A-D) non-classical GSSCP from wetland grasses from Minnesota, USA (Yost and BLINNIKOV, 2011, p. 1981): A-B) *Glyceria canadensis*: A) PAPILLATE in side view and top view in situ; B) inflorescence BILOBATE in top view. C) *Phragmites australis*: inflorescence RONDEL, base/oblique view. D) *Phalaris arundinacea*:

⁴³ having spiny, conical, more or less sharply acute projections (ICPT: NEUMANN et al., in press).

leaf/culm *TRAPEZIFORM*, top view. **E-H) non classical GSSCP from Rue des Boîteux:** E) non-classical *RONDEL* in side view; F) undetermined GSSCP base/oblique view; G-H) non-classical *BILOBATE* in top view.

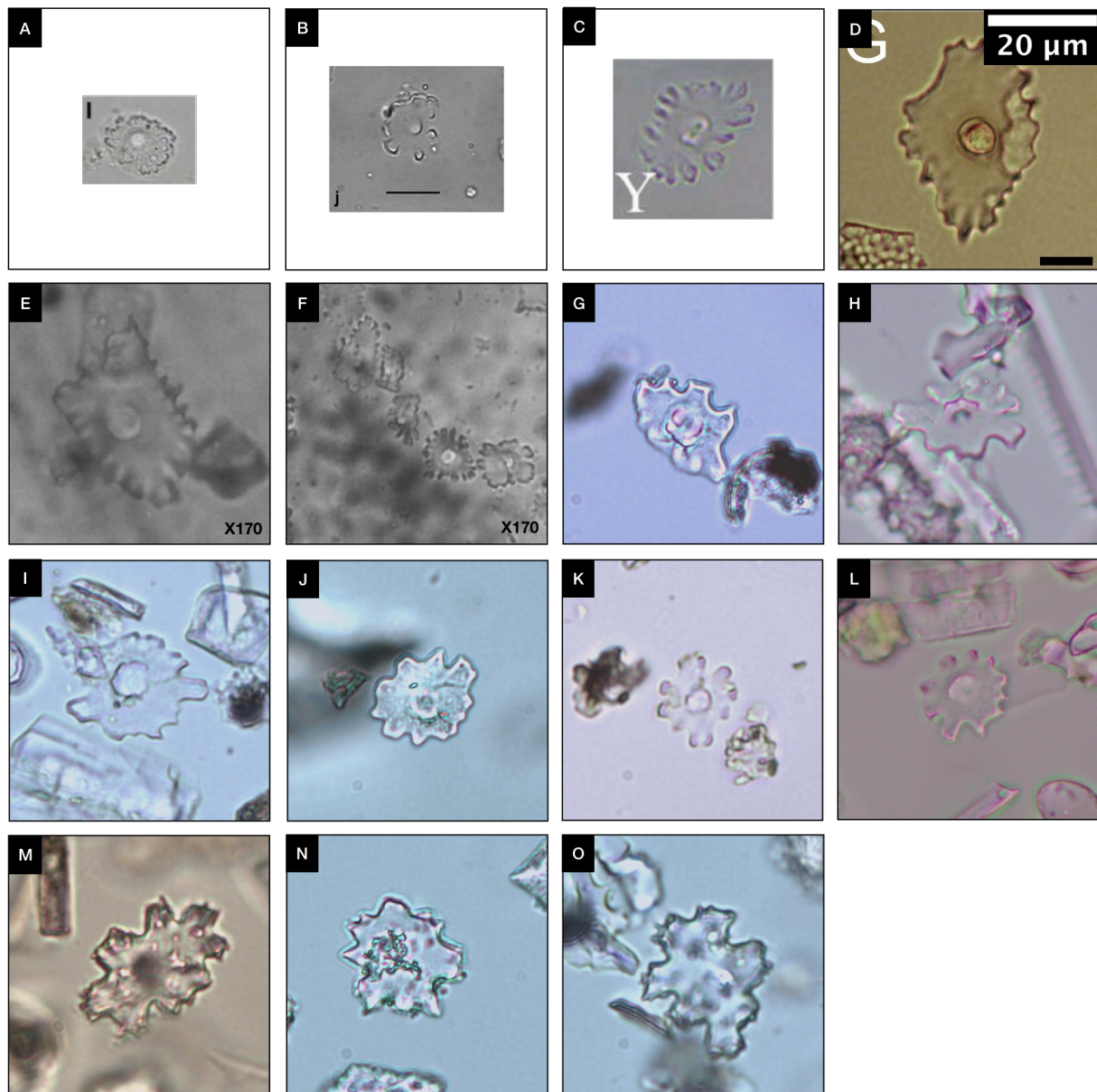


Figure 30: Examples of sedge phytoliths

A-F) sedge phytoliths from various archaeological sites: A) Conical sedge plate from Patagonia (STRÖMBERG *et al.*, 2018, p. 237); B) Polygonal cone from *Scirpus asper* achene⁴⁴ from the coastal savannas of French Guiana (WATLING and IRIARTE, 2013, p. 172); C) Cone cell phytolith derived from sedge achenes, possibly a species of *Scirpus* from New Mexico (Yost, 2016, p. 22); D) Achene phytolith from a member of the Cyperaceae (cf. *Scirpus*) from Ecuador (YOST, 2008, p. 15); E) A *Cyperus* sp. (?) phytolith from central Pacific Panama, magnification 170 x (PIPERNO, 1989, p. 170); F) Achene phytoliths

⁴⁴ small, one-seeded fruit

from *Scirpus cyperinus*, magnification 170x (PIPERNO, 1989, p. 152). **G-0) phytoliths from Rue des Boîteux:** G-L) phytoliths that were classified as ‘Cyperaceae’; M-O) phytoliths that were classified as non-identified that could derive from ‘Cyperaceae’.

7.2 Dark Earth units (13th – 15th centuries AD)

7.2.1 The marks of horticulture in the Dark Earth units

The Dark Earth units, situated directly on top of the peat, are likely linked to a heavily cultivated environment. The taphonomic context of the phytoliths does not oppose the hypothesis of horticulture. First, the phytoliths showed traces of physical breakage (erosion). Secondly, almost all phytoliths had an isolated or clustered distribution pattern. Both observations can be ascribed to dynamic post-depositional perturbation.

Another aspect that can be discussed in the presence of in the *in situ* cultivation. The cultivation of cereals can probably be excluded, seeing as more articulated ELONGATE DENDRITIC would have been present in the soil matrix if cereals had been cultivated.

Lastly, phytoliths in excrements were observed. This observation shows us that the phytoliths a) derive from different contexts due to this horticulture; b) are part of the manure i.e. a cultivation practice. One part of the phytoliths derives from plant fragments that decompose *in situ* and as such from local vegetation. Another part of the phytoliths derives from the addition and decomposition of manure. However, most of the phytoliths in the excrements were unidentifiable or taxonomically insignificant. Therefore, making any clear further statements on the phytoliths from the manure is impossible.

7.2.2 Difference in the phytolith record from the peat and the Dark Earth units

The first difference between the phytolith record from the peat and the Dark Earth is the number of phytoliths. The lower part of the peat contained few to zero phytoliths, the upper part of the peat (US20 and US28) faced an increase in the numbers of phytoliths, and the Dark Earth units contained a lot of phytoliths compared to the peat. These results evoke two comments. First, a ‘few’ or a ‘lot’ is relative to the context. For Brussels the phytoliths of some other sites have been quantified as well (**table 15**) (ESTEBAN and ALBERT, 2017). Compared to the number of phytoliths from other anthropogenic units from several archaeological sites in Brussels the numbers of Rue des Boîteux are rather ‘low’. How we should interpret these numbers is currently unclear. Second, the lack of phytoliths in the peat raises questions. The second difference between the peat and the Dark Earth units is the difference in the phytolith records. **Table 16** synthesizes the similarities and the differences in phytolith assemblages for the upper part of the peat (US2_1), the transition (US28) and the Dark Earth units.

Site	Description	Sample code	Estimated number of phytoliths per gram of sediment
Rue des Boîteux	Peat	BR295 (US20)	100.000
	Peat	BR295 (US2)	50.000
	Peat (transition)	BR295 (US28)	550.000
	Horticulture	BR295 (US27)	1.300.000
	Horticulture	BR295 (US26)	350.000
Rue des Pierres		BR223 (US119)	7.150.000
		BR226 (US120)	8.450.000
Rue de Dinant		BR170 (US631b)	2.950.000
		BR170 (US431b)	3.000.000
Poor Clarens	Midden	BR100 (US412)	2.100.000
	Plough layer	BR100 (US415)	4.200.000
Court of Hoogstraeten	Garden	BR061 (US2331)	2.150.000
		BR061 (US2337)	1.200.000
	Plough layer	BR061 (US7321)	2.600.000
Treurenberg	Plough layer	BR059 (US173)	2.450.000

Table 15: Absolute number of phytoliths for several archaeological sites in Brussels

Source: (ESTEBAN and ALBERT, 2017).

Peat (US2_1)	Transition (US28)	Dark Earth (US27 and US26)
Presence of Poaceae	Presence of Poaceae	Presence of Poaceae
Presence of non-classical GSSCP (except for non-classical RONDEL type 1)	Presence of non-classical GSSCP	Presence of non-classical GSSCP
Non-classical RONDEL type 1 not observed	Non-classical RONDEL type 1 only observed at the top of US28	High numbers of non-classical RONDEL type 1
	Presence of cereals	Presence of cereals
Wet environment (Cyperaceae phytoliths + opaline microfossils)	Wet environment (BULLIFORM FLABELLATE)	
High presence of non-identified phytoliths		

Table 16: Similarities and differences in the phytolith assemblages

There are two similarities in the phytolith assemblages, which are the presence of Poaceae and non-classical GSSCP. Non-classical RONDEL type 1 only occurs at the top of the transition and in the Dark Earth units. Therefore, a preliminary interpretation is to link this type to the anthropogenic units. However, this type of Rondel does face identification issues. The morphologies of the RONDELS from Rue des Boîteux (F-K) slightly differ (**Fig. 31**). This raises the question whether the category non-classical type 1 should be split into different subcategories. The ‘carinate’ aspect of the RONDELS should be taken into account in future studies. Does the RONDEL have a keel shaped ridge or a keel shape form, or neither, and what does this imply for their classification and taxonomic identification? Currently, a preliminary position is that some of the RONDELS from Rue des Boîteux have similar aspects as the RONDELS from *Avena* (A, D, E). *Avena* sp. (oats) is a genus of the Poaceae (Grass family). This position could be supported by the fact the non-classical type 1 RONDEL only seems to appear at the transition (US28)⁴⁵ and the Dark Earth units (US26 and US27) (**Table 17**). The carpological report mentions the presence of charred cereals which can be linked to the use of manure. One of the identified species is oat (*Avena* sp.). Of course, future research is needed to confirm this preliminary position.

US2_1	US28_9.5	US28_17	US27	US26
0	0	18	17	10

Table 17: Absolute number of non-classical type 1 RONDEL for each sample

⁴⁵ The micromorphological study indicates that US28 contains material from US27 due to the intensive horticulture. Therefore, it is likely the non-classical type 1 RONDEL in US28 was originally to be found in the Dark Earth units instead of the peat.

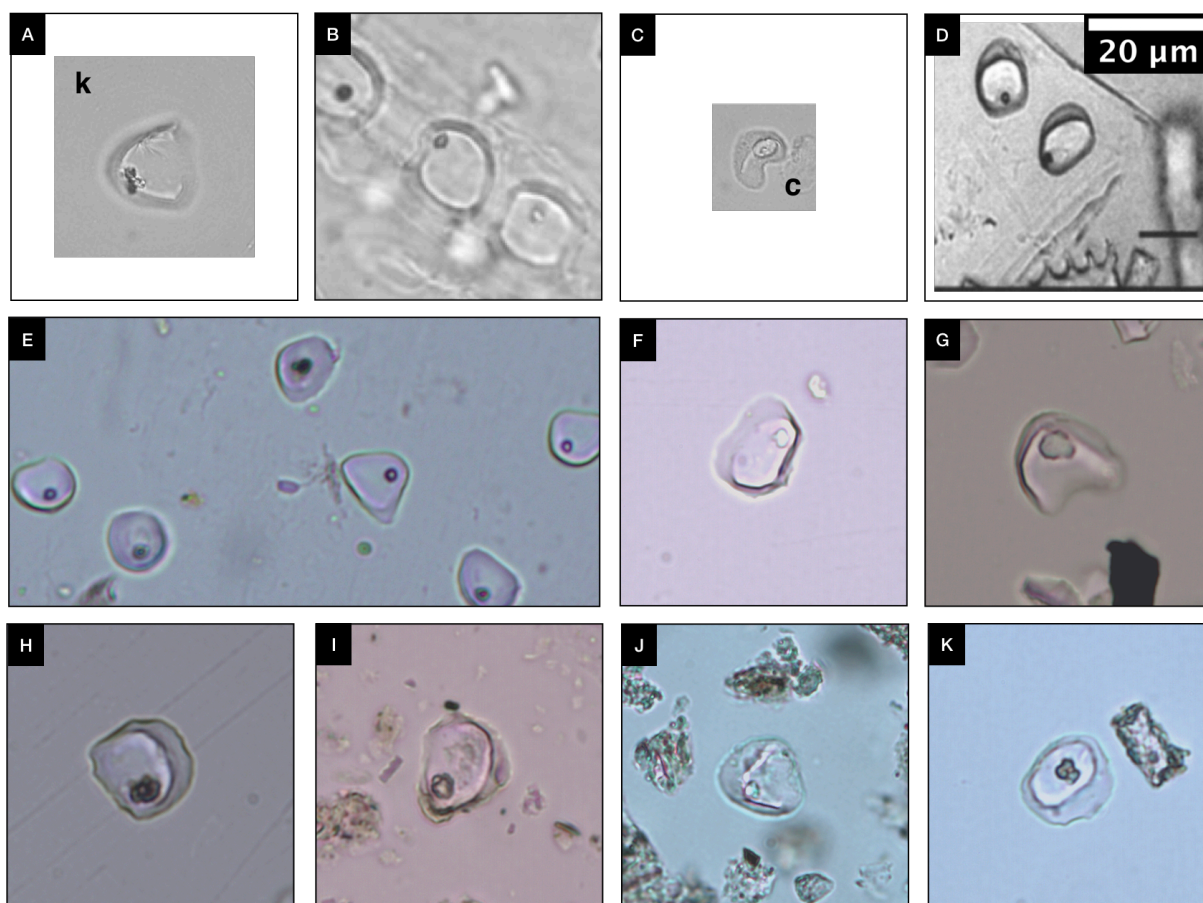


Figure 31: Examples of non-classical RONDEL type 1

A-E) Non-classical Rondel type 1 from various sources: A) RONDEL with curved keel (KR-2) from *Avena* reproductive material in top view (STRÖMBERG, 2003, p. 324); B) *Phragmites australis*: sequence of leaf concave RONDEL in situ in top view from Minnesota, USA (YOST and BLINNIKOV, 2011, p. 198); C) RONDEL with curved keel found in Tertiary samples (STRÖMBERG, 2003, p. 543); D) phytoliths produced in the inflorescence of *Avena sativa* (PORTILLO, BALL and MANWARING, 2006, p. 124); E) Rondels from *Avena sativa*, plants samples at a modern day cultivated field in Poland (material from Vrydaghs and Y. Devos). **F-K) Non-classical Rondel from Rue des Boîteux.**

A second difference in the phytolith record between the peat and the Dark Earth units is that for both Dark Earth (13th- 15th centuries AD) units cereal phytoliths were markedly present. The palynological and carpological study also mention the presence of remains of cereals. The palynological study, however, could not distinguish whether these cereals were processed *in situ* or whether they derived from the manure. The carpological study stated that as some cereals were charred, they would probably derive from household waste or waste from hearths. The phytoliths, observed in the coprolites, could confirm whether part of the phytoliths derive from locally cultivated cereals or if they were added in the form of manure. However, the observation of the phytoliths in the coprolites did

not yield significant information on this topic. Only morphologically insignificant or undetermined phytoliths were observed in the coprolites, except for one coprolite containing Poaceae phytoliths.

Another difference in assemblages is the frequency of phytoliths and other opal microfossils, mainly diatoms, clearly indicating a wetter environment for the top of the peat sequence than for the Dark Earth units. As stated above, these observations can be linked with the micromorphological report stating that the peat was drained and subsequently transformed into horticulture layers. Finally, an interesting observation is that the upper part of the peat contains a number of non-identified phytoliths.

7.2.3 Comparative analysis between Rue des Boîteux and the Hopmarkt (Aalst, Belgium)

There is future interest into more systematical investigation of medieval urban horticulture in Belgium. For the moment, only one other case in Belgium can be compared to Rue des Boîteux, the archaeological study of the Hopmarkt in Aalst, situated in East-Flanders. Here, the results for the Hopmarkt are briefly presented. For a more comprehensive overview the reader is referred to DE GROOTE and MOENS (2018).

During early medieval times the Hopmarkt was used as an arable field and was linked with the 'Villa Alost' that emerged during the early Merovingian period. After the area was included within the second city wall that was built ca. 1200, all records point towards a continuation of using the area as arable land for at least 100 years with the exception of some loam extractions starting from the mid-13th century AD onwards. It takes up until the 14th century AD until the first traces of habitation can be observed in the archaeological records. By 1350 all plots in the area were occupied, although the records do show that about half of the area of the plots were used as arable fields. After 1360, when a fire affected the town, including the Hopmarkt, a change in land use took place. From this point on, the accumulation of organic material indicates the transformation from an open arable area into closed gardens. Although there is a transformation to more closed horticultural units, the character of the area remains semi-rural up until 1497, when the Carmelite Convent emerges. The archaeobotanical records points towards both the presence of arable fields as gardens and the observation of some burials of cadavers from ox, horse, and pig together with archaeobotanical evidence for fodder indicate the presence of these animals in medieval times (DE GROOTE, MOENS and ERVYNCK, 2018, p. 370).

There are similarities and some differences between Rue des Boîteux and the Hopmarkt. Firstly, both sites are medieval urban horticulture units. Both units also have a similar dating. The horticulture units from Rue des Boîteux go back to the 13th – 15th centuries AD, while the Hopmarkt units are ascribed to

the 15th century AD. Secondly, both sites are located within the perimeter of the first and the second city wall of Aalst and Brussels. They both indicate the need for expansion within the medieval city and the urban food demand. Both sites demonstrate the importance of urban cultivation and the use of space. Furthermore, both sites indicate the presence of rural elements within the medieval city. Especially for the Hopmarkt, the observation that even after the second city wall was built, little changes in use of space occurred, is significant for our view on medieval cities. Both sites help re-evaluate the traditional vision of the densely built-up cities. However, there are some differences between the sites as well. One should note a difference in cultivation between the two sites. Rue des Boîteux contained strictly horticultural activity, while the results of the Hopmarkt indicate the presence of both horticulture units and arable fields. Tightly embedded with this observation is the preceding history of both places. In the case of Rue des Boîteux the marshland was drained and afterwards horticulture activities were installed, while the Hopmarkt was already familiar with arable fields before 1200. Furthermore, for the Hopmarkt records of fodder and animal cadavers indicate the semi-rural character of this place. For Rue des Boîteux no such observations were made.

A final remark should be made about the research conducted for the Hopmarkt. Palynological, carpological, anthracological, and archaeozoological research was conducted on several present structures such as a cattle pond and a cesspit, but not on the horticulture unit. One can compare the archaeobotanical results of the cattle pond and the cesspit with the results of the horticulture units from Rue des Boîteux. However, in the light of horticultural activities, a comparison of results from horticulture on both sides would have been more valuable.

One can conclude that based on the similarities of both sites, the future of horticulture research in the context of medieval urbanism is promising. These two cases also show that the urban medieval horticulture study would benefit from a systematic approach in Belgium and Europe rather than single case studies with different methodologies. HEIMDAHL (2014, p. 15) addresses the topic of handling ancient gardens during fieldwork and stresses the development of a methodology including a multidisciplinary approach. Ideally, a geological stratigraphic interpretation in the field should combine both a macro- and microanalysis of the soil.

7.3 Used methods

7.3.1 Phytoliths in peat

This section elaborates the protocols used for the samples from Rue des Boîteux. Based on the laboratory processing and the microscopic observations, following aspects will be discussed for the different extraction techniques: processing time, quantification, permanency, and clearness.

1) Processing time: Method (1) is time-consuming to execute. It can take up to two weeks to process the samples. Method (2) and (3), in contrast, are rapid methods with a maximum execution time of 1 day, which is their major advantage. These methods can be used during excavations to evaluate the samples within a day. Consequently, areas with potential for phytolith analysis can be sampled more thoroughly with other procedures.

2) Quantification: Quantification is very important for archaeological contexts as anthropogenic units can be characterized by a high number of phytoliths (MADELLA, 2007). Method (1) does not work with quantification of the phytoliths. This makes it impossible to compare the number of phytoliths per sample systematically. Method (2), like method (3), can be used for quantification.

3) Permanency: The disadvantage of method (2) is that it is a non-permanent method. Slides cannot be reconsidered after 24 hours. This could be restricting as sometimes re-observing slides is a key element for gaining insight. As method (3) is an adaptation of method (2) to make method 2 permanent, this limitation of method (2) is resolved.

4) Clearness: Method (1) is a profound method that removes all particles except for biogenic silica. This results in microscopic slides with phytoliths with a high visibility. As the clearness was high, it was also easy to recognize morphotypes and estimate whether the phytoliths were intact or altered. For method (2) and method (3) some other soil particles were still present, which sometimes impaired the visibility, especially for the peat samples that contained high amounts of organic material.

	Limitations	Advantages
Method (1): KBIN	- No quantification - Time-consuming	- Clean method - Permanent
Method (2): KATZ et al. (2010)	- Non-permanent method - Sometimes low visibility	- Quantification - Fast method
Method (3): R. M. Albert	- Sometimes low visibility	- Quantification - Permanent method

Table 18: Limitations and advantages per method

All three methods have their limitations and advantages (**Table 18**) which results in methods that work complementary. In the present study the results were obtained through a combination of all three methods. As the clearness was the highest for the slides from method (1), this method was chosen to build up the inventory of the phytoliths and evaluate the state of preservation. However, for the quantification method (2) was used. Without the quantification it would not have been possible to state with certainty that in relation to the peat there is an enormous increase in phytoliths for the Dark Earth units. Method (3) and method (2) were used together to see whether choosing between a permanent or non-permanent method affects the presence of the microscopic aggregates. Method (3) confirmed that these aggregates (all kinds of soil particles) are indeed the results of drying the phytolith sediment at the end of the processing. Section '7.4.1 Phytoliths in the peat' explains a protocol for phytoliths in peat that can resolve the aggregate issue as it tries to eliminate all soil particles as thoroughly as possible. A recommendation for future research would be to improve method (1) by adding quantification.

Relevance of combining several methods in future studies

1) Different protocols cater to different stages of a research design. Method (2), the protocol of KATZ *et al.* (2010), is extremely useful when one needs to evaluate whether conducting a thorough phytolith analysis would be interesting or not. Sometimes, archaeologists have time restrictions on excavations, for example in case of rescue archaeology. In such cases it is recommended to take some samples in different areas and to process them immediately. Afterwards, the results of these processed samples can indicate which areas should be sampled more thoroughly and which areas do not need further investigation. However, a more profound way of processing like method (1), the protocol from the KBIN, seems recommendable for executing detailed phytolith analyses.

2) Other protocols serve as control. While each protocol has advantages and limitations, using different protocols allows for easy evaluation and comparison between different protocols to see whether they yield the same results.

7.3.2 Combination of the phytolith extraction method with phytoliths in thin section

In the present study some results have shown to be complementary for the extraction method and thin section method, while other results are exclusive to one method. For the taphonomical aspects both methods indicated that overall the preservation of the phytoliths was good. However, the thin section was able to yield more information concerning the taphonomical aspects than the extraction method. The thin section analysis showed that the phytoliths in the Dark Earth units derived from different taphonomical contexts, being the *in situ* vegetation and phytoliths that were situated in

manure. Furthermore, the different distribution patterns of the phytoliths indicated that the post-depositional context was dynamic. Regarding the taphonomical aspects one can conclude that the thin section method adds exclusive information on this matter. Secondly, both the extraction technique and the thin section one mark an absolute increase in number of phytoliths. Although an increase in phytoliths is marked by both methods, it is preferable to work with the extraction method for the quantification of the phytoliths. The extraction method allows for a clear view of the phytoliths while counting them, as opposed to the thin section method. In addition, the extraction method allows an assessment of the absolute number of phytoliths per gram of sediment, while the thin section method does not. Finally, the inventory of phytolith differs according to each method. The phytolith analysis from bulk sediments presents a higher variety of phytolith morphotypes when compared to phytolith analysis from thin section. In conclusion, both methods have been shown to work complementarily for the present study. **Table 19** summarizes both the complementary strengths and limitations of both methods.

	Extraction method	Soil and sediment thin section
Taphonomical aspects	Limitation: Destruction of the soil particles and high disturbance of phytoliths prohibit studying the relationship between phytoliths and the surrounding particles such as the distribution pattern of the phytoliths within the soil matrix.	Strength: Preservation of the soil particles and low disturbance of the phytoliths facilitate studying the relationship between phytoliths and the surrounding soil particles such as the distribution pattern of the phytoliths within the soil matrix.
Morphotypes	Strength: The orientation and clearness of phytoliths can be manipulated with bulk samples. The laboratory processing removes surrounding soil particles to obtain a good visibility of the phytoliths under the microscope. The phytoliths are mounted on the slides in a sort of glue. As a result they can be studied within different orientations.	Limitation: The orientation and clearness cannot be manipulated within thin section. The surrounding soil particles are not removed which results in microscopic slides containing phytoliths that can be (partially) obscured and which can have an unfortunate orientation, possibly prohibiting the identification of the phytoliths' morphotypes.

Table 19: Major complementary strength and limitation for both methods

Table 19 does show why it is interesting to combine both methods for future research. Although working with only one method is not incorrect, working with both methods together does provide more complementary information. An important aspect that influences the choice of the methods is the archaeological context. In the present context studying the Dark Earth units only through the extraction method would have been limiting as the Dark Earth units demonstrated that the phytoliths derived from different contexts (local vegetation and adding of manure).

7.4 Recommendations for future research

7.4.1 Phytoliths in the peat

There are two recommendations for future research concerning the observation of few to zero phytoliths in some parts of the peat: 1) trying a more suited processing protocol for phytoliths in peat and; 2) processing the peat of other sites in Brussels for an intersite comparison.

1) A more suited processing protocol for phytoliths in peat

HUBER (1987) has developed a procedure to extract phytoliths from peat (**Table 20**). The aim of the protocol is to obtain clean residues for microscopic slides. It differs from the methods used in the present study as it uses a high temperate oven to burn the organic material and treats the samples several times with KOH (10%). This protocol could eliminate the presence of aggregates under the microscope. If this protocol yields positive results, it could also result in rejecting the hypothesis that phytoliths dissolved or disintegrated during the processing.

2) Processing the peat of other sites in Brussels for an intersite comparison

Over the last 15 years several peat deposits have been uncovered and sampled in Brussels (DEVOS and DEGRAEVE, 2018, p. 82). **Figure 32** presents a map showing the different locations where peat has been discovered: Rue Boîteux, Rue du Midi, Rue aux Choux, Pauvres Claires, Rue Léopold, Rue des Pierres, Rue Notre Dame du Sommeil en Quai aux Barques. In order to test the following hypotheses:

- 1) the phytoliths disintegrate in the soil
- 2) there was no silicon available in the soil to form phytoliths

The peat from these sites could be investigated as well. By studying the peat from different archaeological sites with a suited processing method a detailed, general evaluation of the peat in Brussels could be made.

Step 1	2 ml of peat together with 7 ml of water is placed in a high temperature oven (350°C) for 24 hours. Afterwards the samples are rehydrated and transferred to a 15 ml tube.
Step 2	KOH (10%) treatment for 10 minutes in a hot water bath. Afterwards the samples need centrifuging until the water is fairly clear (no brown supernatant).
Step 3	The samples are rinsed twice with 10 ml of concentrated glacial acetic acid, and centrifuged.
Step 4	5 ml of acetolysis solution ⁴⁶ is added to each sample. The samples are heated in a water bath at 75-85°C for 2 minutes. Consequently, each tube is filled with cold glacial acetic acid, and centrifuged.
Step 5	3 ml of KOH (10%) and 7 ml water is added to each tube. Afterwards, the samples need centrifuging.
Step 6	10 ml of KOH (10%) is added, while the samples are placed in a hot water bath. Thereafter, the samples are centrifuged until the water is fairly clear.
Step 7	10 ml of ethanol (95%) is added. Then, samples are centrifuged twice. Consequently, ethanol (95%) is added to be able to transfer the samples to glass vials. If several transfers are needed, centrifuge the samples and remove the supernatant with a pipette each time.
Step 8	The vials are covered with parafilm to prevent the ethanol from evaporating.

Table 20: Extraction method for phytoliths in peat

Source: HUBER (1987)

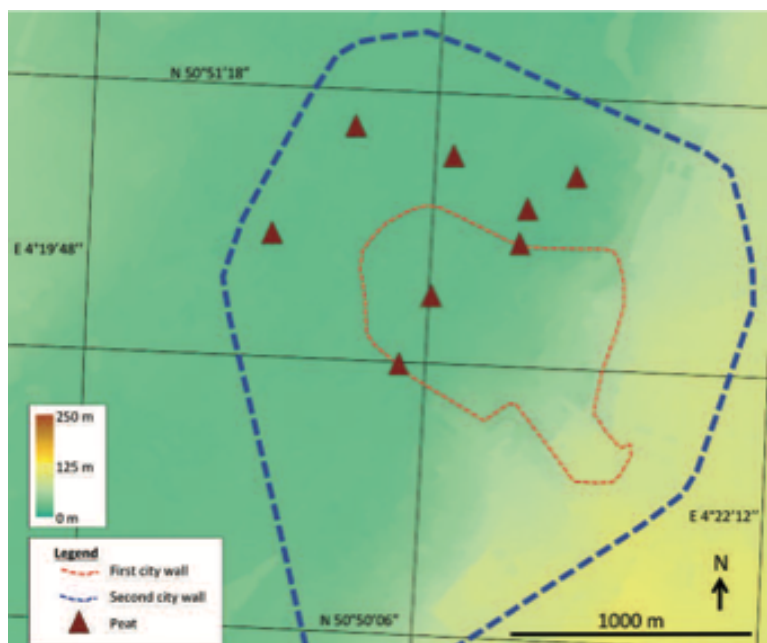


Figure 32: Map with the sites in Brussels where peat has been uncovered

Source: DEVOS and DEGRAEVE (2018, p. 83).

⁴⁶ Acetolysis solution consist of 1 part concentrated sulfuric acid (H_2SO_4) and 9 parts acetic anhydride.

7.4.2 Identification issues

A second issue that merits further examination is that of the identification of a high number of phytoliths. The present chapter explained that all samples, especially the upper part of the peat (US2_1), contained high numbers of unknown (non-identified and non-classical) phytoliths. Another example that was highlighted in the present chapter was the non-classical RONDEL type 1 only occurring at the top of the peat and in the Dark Earth units. As mentioned it is highly likely that this type of RONDEL can be linked to anthropogenic activities. In the present study comparable worldwide phytolith material was linked with the phytoliths from Rue des Boîteux which faced identification issues. The main comparison problem is that plants and their phytoliths develop under local climatological circumstances. Therefore, the phytolith morphologies differ locally. This implies that the comparison is not the most appropriate procedure. However, it is the only procedure for the moment, as modern phytolith reference collections for Northern Europe are lacking. Future phytolith research would benefit from the development of a modern phytolith reference collection for Northern Europe. Modern plants will need to be collected and subsequently different parts⁴⁷ of the plant should be extracted. For the present study it would be interesting to look further into wetland grasses as some of the non-classical phytoliths with lobes and / or wavy outline turned out to have similar shapes as wetland grasses from the USA. There are two methods to extract phytoliths from modern plants: 1) wet oxidation; and 2) dry ashing. **Table 21** presents the wet oxidation processing procedure of PIPERNO (2006, p. 97) and the dry ashing procedure of the Environmental Archaeology Laboratory at Boston University (WADE, 2018) which is an adaptation from PIPERNO (2006, p. 97) and PEARSALL (2015, p. 294).

⁴⁷ *The morphotypes of phytoliths vary based on inter- and intra-plant (the stem, the leaves, the roots and the inflorescence part) taxonomic differences. Therefore, not only phytoliths from different taxa, but also from different parts of each taxon should be collected.*

	Wet oxidation (Piperno)	Dry ashing (Environmental Archaeology Laboratory at Boston University)
Step 1	Pretreatment: The samples are cut and weighted (at least 0.1 gram per sample) and placed in tubes under 50 ml.	Pretreatment: The samples are cut and weighted (at least 0.1 gram per sample) and placed in tubes under 50 ml.
Step 2	Cleaning: Samples are soaked in a 1% solution of Alcanox for a couple of hours and washed several times afterwards. Next, the samples are put in tubes.	Cleaning: A 2% solution detergent is added and the samples are left overnight. The next day the samples need a 15 minute sonication. Afterwards they are rinsed with H ₂ O by centrifuging. Hereafter, the samples are dried overnight at 30°C.
Step 3	Wet oxidation and chemical processing: Concentrated nitric acid is added and the tubes are put in a hot-water bath. Afterwards solid potassium chlorate (KClO₃) is added as a catalyst. <i>Optional: 1:1 mixture of ethyl alcohol and benzene is added if waxy residues are present.</i> The phytolith suspension is rinsed with a 10% solution of hydrochloric acid to remove the calcium by centrifuging, whereupon twice rinsed with H₂O by centrifuging and lastly, twice rinsed with acetone by centrifuging.	Dry ashing and chemical processing: The samples are cut or ground into small pieces (0.5 cm X 0.5 cm), placed in a ceramic crucible and dried for 6 hours at 450°C. Afterwards, the ash is transferred to 1.5 ml tubes. After 1N HCL is added, the samples are centrifuged for 5 minutes at 6000 rpm. Next, the samples are rinsed with H₂O by centrifuging them three times. Lastly, the samples are dried overnight at 30°.
Step 4	Mounting: The dried phytolith fraction is mounted onto the slides.	Mounting: The dried phytolith fraction is mounted onto the slides.

Table 21: Wet oxidation and dry ashing processing method

After modern specimen are processed and their phytoliths are mounted onto slides, the phytoliths should be registered and one should look for ways to share this collection with other scholars who do not have direct access to the reference collection. Currently, an inclusive and workable platform for scholars is the Phytcore database (ALBERT *et al.*, 2016). However, one limiting aspect about the platform, and this applies to all databases, is that they only include two-dimensional images of phytoliths. As the three-dimensional character of the phytoliths is crucial for their identification, the two-dimensional aspect of the images is limiting. To tackle this problem, one should look for ways to register these phytoliths while taking into account their three-dimensional character. Though still in its infancy for phytolith research, 'Whole Slide Imaging' (WSI) could be interesting for future image registering of phytoliths. Whole Slide Imaging is a mode, applied worldwide in pathology departments. It scans microscopic glass slides and digitally renders them into three-dimensional images. As with the microscope, one is able to see the slide at different depths of focus (PANTANOWITZ *et al.*, 2012; GHAZNAVI *et al.*, 2013; FARAHANI *et al.*, 2015). As an experiment, the method was applied in 2019 for some of the microscopic slides of Rue des Boîteux by The Center for Microscopy and Molecular Imaging and yielded positive and promising results. This offers future opportunities for the three-dimensional registration of phytoliths.

Chapter 8: Conclusions

8.1 Peat sequence

A full evaluation of the environmental changes could not be achieved for the moment through the phytoliths record since issues, including the presence of phytoliths and a high number of non-identified phytoliths, occurred for the peat. Further research on peat from other sites in Brussels and the development of a phytolith modern plant reference collection can resolve both issues.

The anthropogenic signal is clearly marked in the phytolith record by the presence of cereal phytolith for US2_1 (3085 BP). These observations correlate with the pollen records first observing *Cerealia*-pollen at 3275 BP. Although it would be premature to draw conclusions on this matter, these observations make for an interesting working hypothesis.

The urbanization process (10th – 13th centuries AD) was not clearly visible in the phytolith record as it was hard to compare the results from the transition, which correspond to the urbanization process, with the phytolith record from the peat. However, the absolute number of phytoliths does increase for the transition and the Dark Earth units, which is linked to anthropogenic impact.

8.2 Dark Earth units

The phytolith study has contributed to our understanding of horticultural practices. First, the phytolith study was able to demonstrate a difference in preservation state between the phytoliths from the peat and the Dark Earth units. Secondly, the phytolith record has shown the presence of Poaceae (grasses), including cereal and a non-identified type of RONDEL probably linked to *Avena* sp. (oats), and Cyperaceae (sedges). The taphonomical study of the phytoliths in the thin sections demonstrated that the phytoliths derived from both *in situ* vegetation and excrements as part of manure.

The two archaeological contexts, the peat and the Dark Earth units, are clearly reflected in the phytolith record. The peat has shown to be a non-disturbed, wet environment, while the Dark Earth units were characterized by a dynamic environment with phytoliths from different depositions. Furthermore, both the peat and the Dark Earth units contained exclusive, unknown phytolith material (the high number of non-identified phytoliths and the non-classical RONDEL type 1 for the Dark Earth units).

8.3 Methodology

The choice of extraction method(s) depends on the context and the research design. In the present study all three methods have proven valuable. Each method has advantages and limitations. The main

limitation of method 1 is that it does not have a quantification and that it is very time-consuming. The advantages are that it is a clean and permanent method. Method 2 and 3 sometimes had a low visibility, but they could quantify and were fast. Lastly, it is a disadvantage that method 2 is a non-permanent one. In the present study two valid reasons were presented to keep combining different methods in the future: 1) different protocols can be used at different phases of the research design: for example, sampling using protocol 2 and thorough analyses using protocol 1; 2) the different methods can serve as control.

The extraction methods and the thin section did not yield the same results. The thin section was able to yield more information concerning the taphonomic processes including the presence of phytoliths from different depositions and a high-disturbance of the soil suggesting perturbation. On the other hand, the extraction methods are better to quantify the phytoliths and presented a higher variety of morphotypes. These observations indicate that the combination of methods has shown to be complementary. The main strengths of the extraction methods, a good orientation and clearness, complement the limitation of the thin sections that the orientation and clearness cannot be manipulated which can hinder identification of morphotypes of phytoliths. The main strength of the thin sections, the preservation of the soil particles and low disturbance of the phytoliths, complement the limitation of the extraction methods, the high disturbance of phytoliths and absence of surrounding archaeological context. As both methods are clearly complementary, it surely is interesting to combine both methods in future research.

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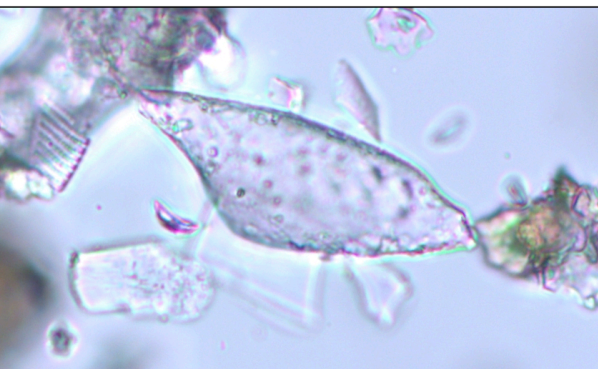
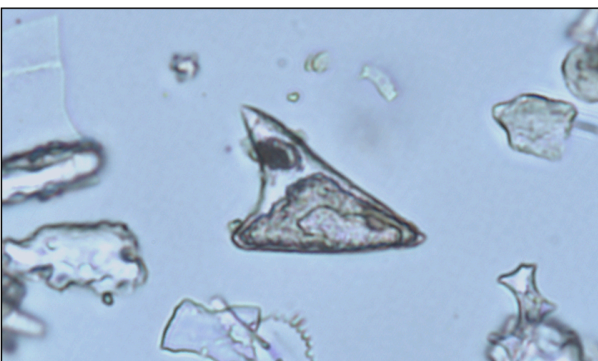
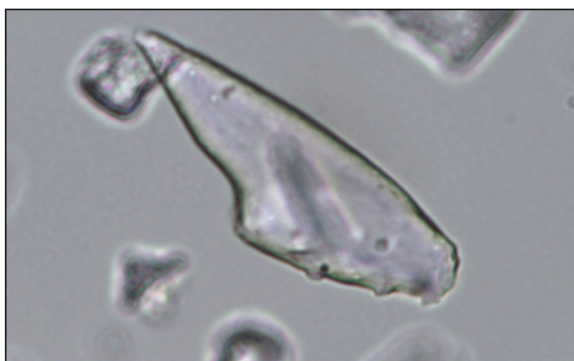
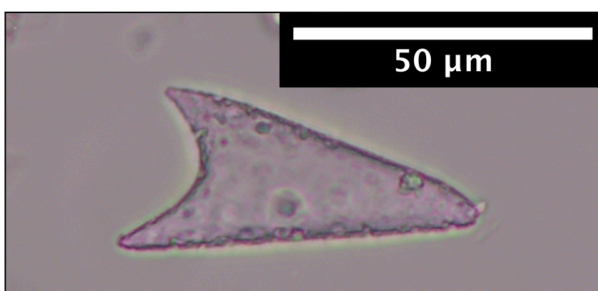
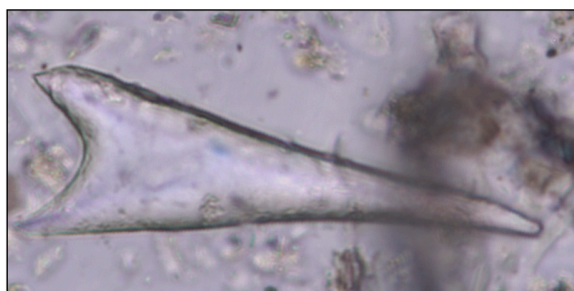
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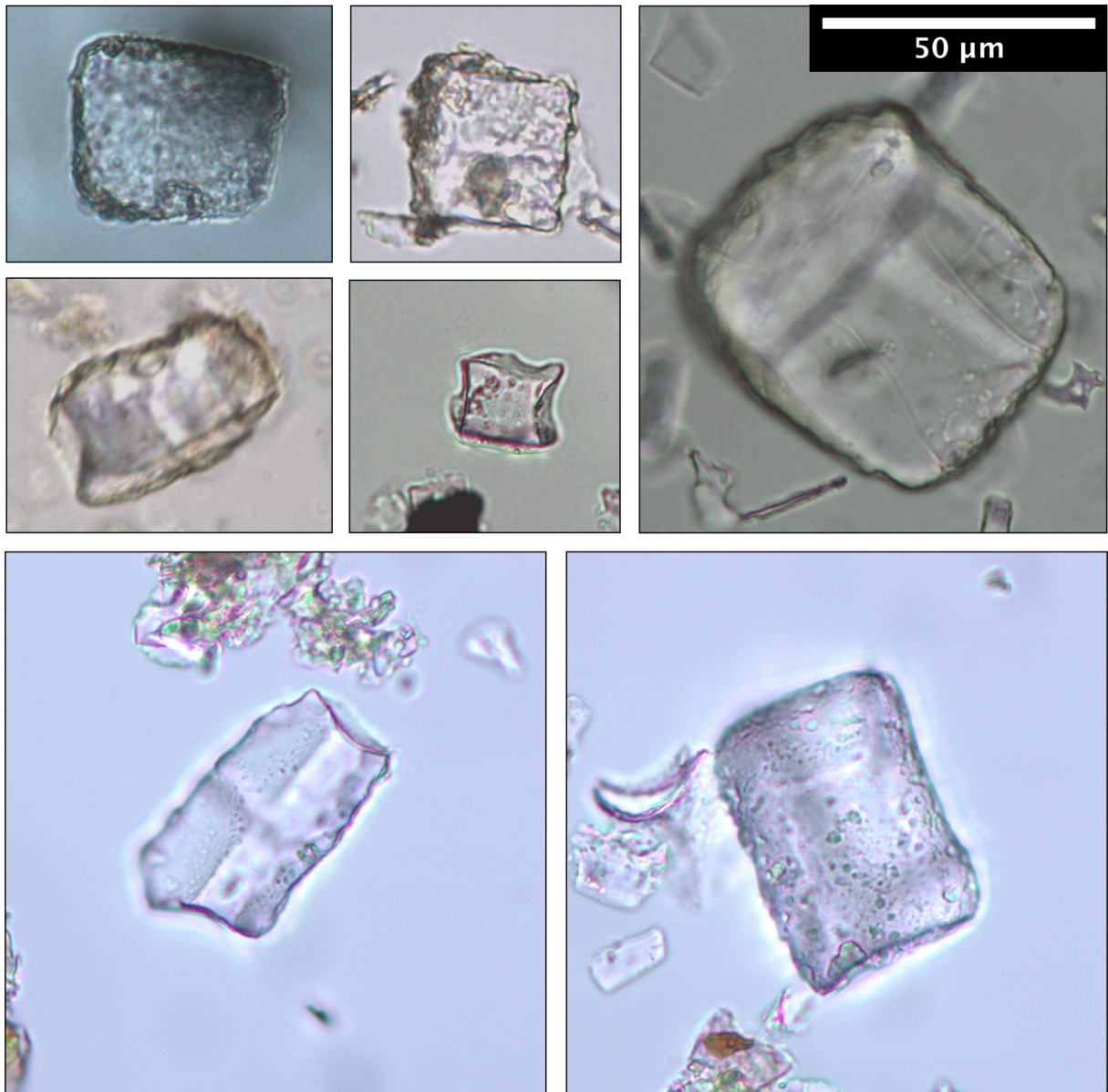
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Appendices

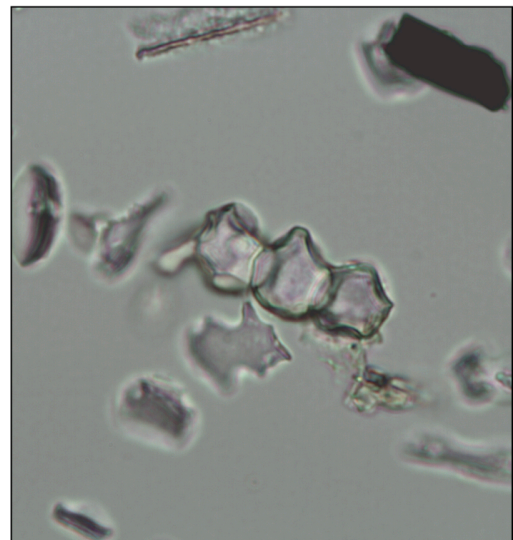
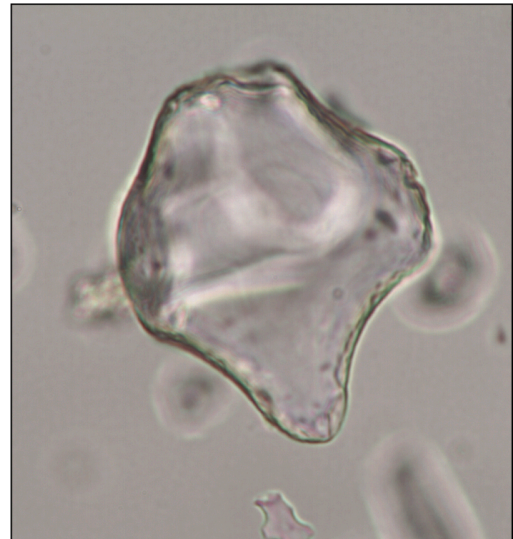
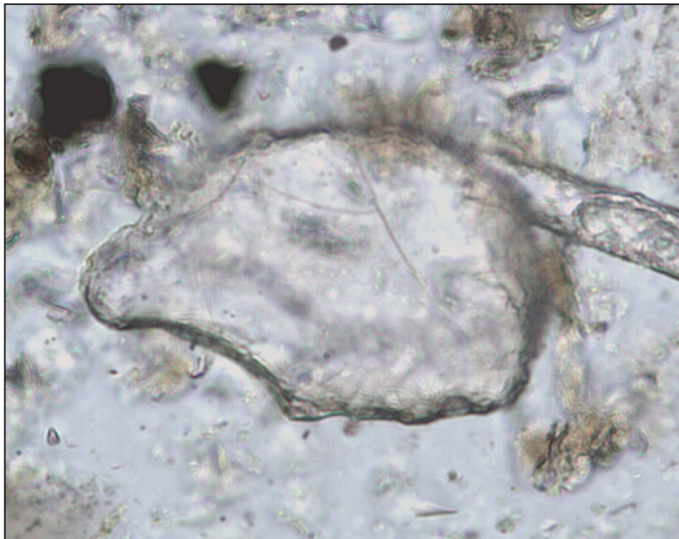
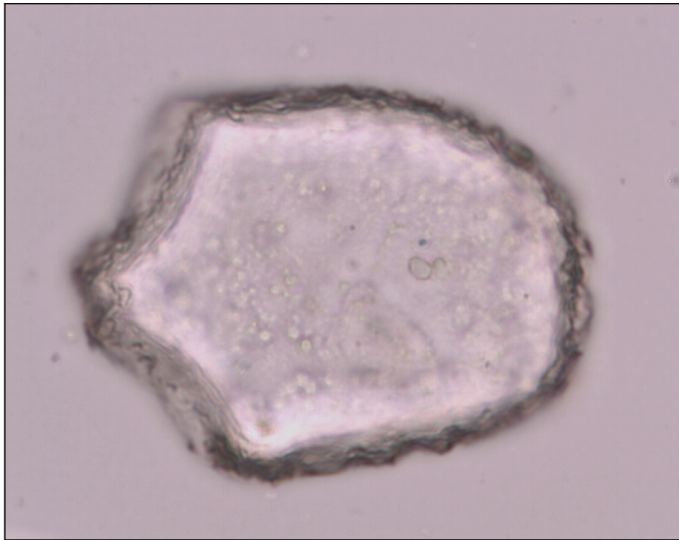
Appendix A: phytolith images



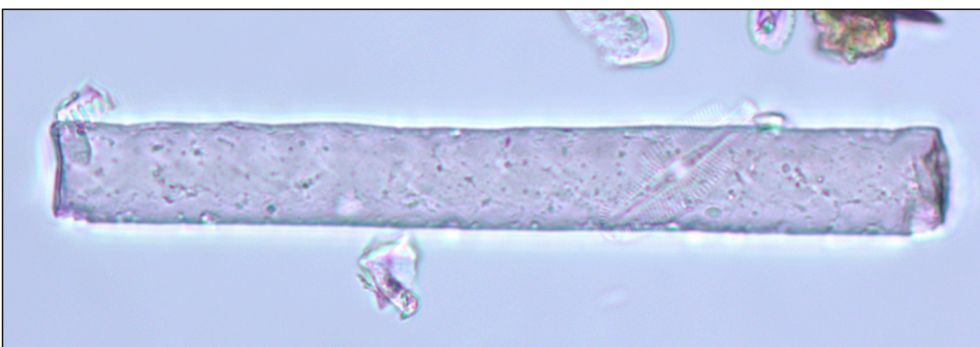
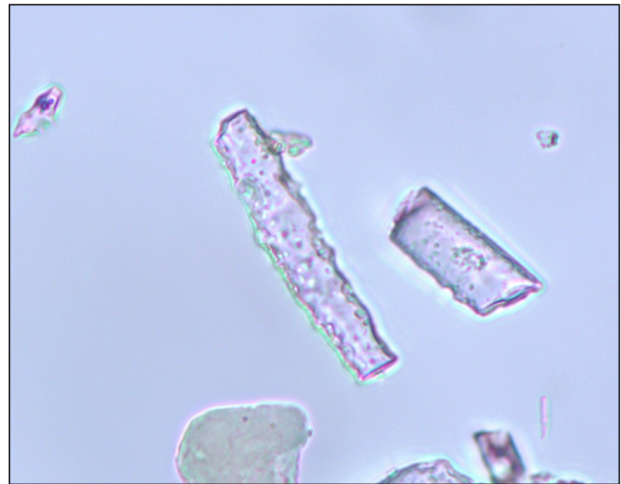
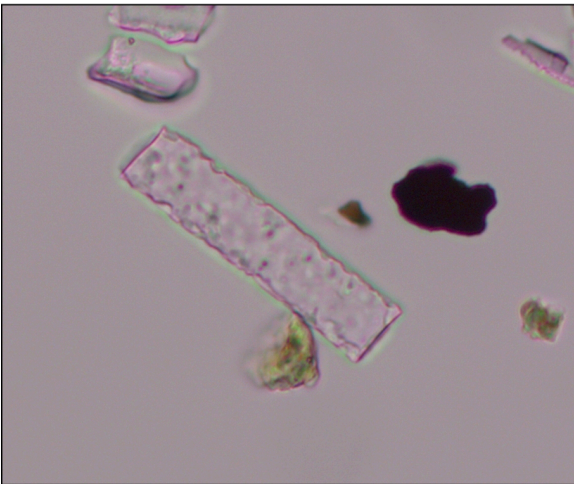
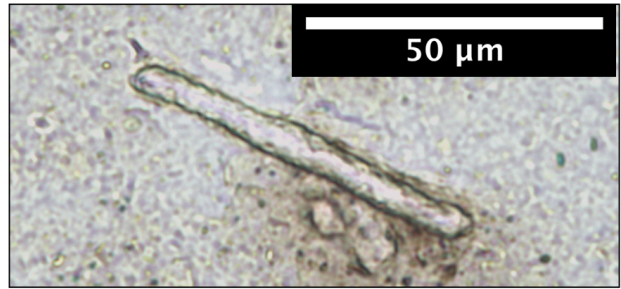
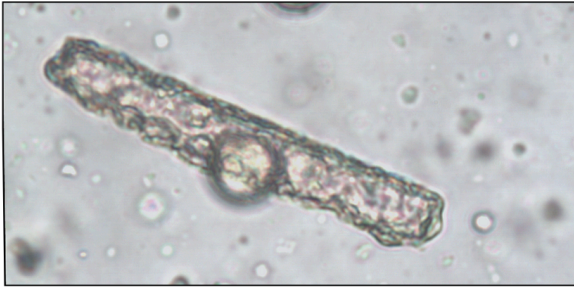
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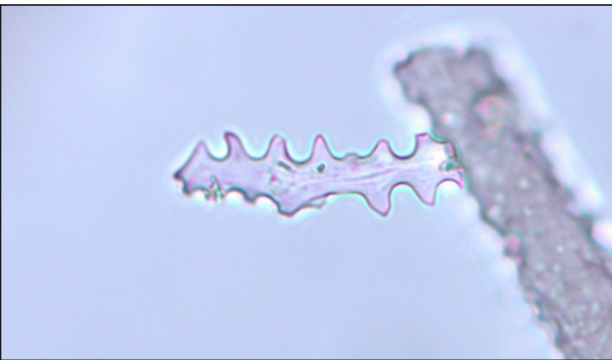
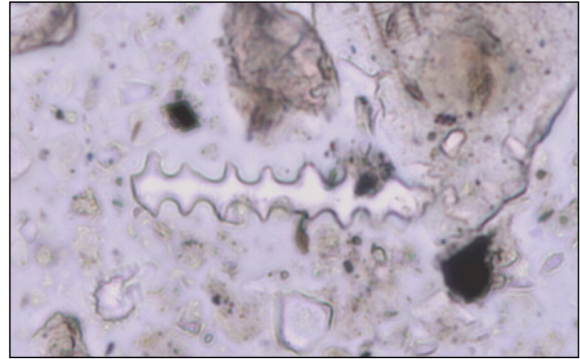
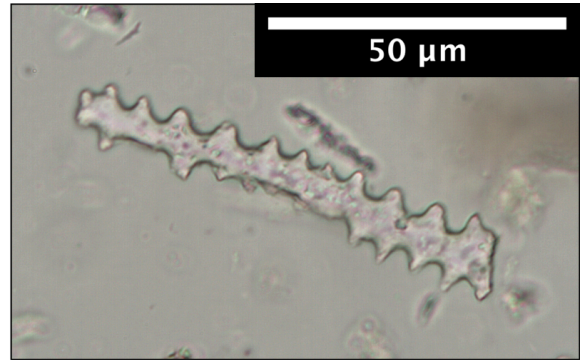
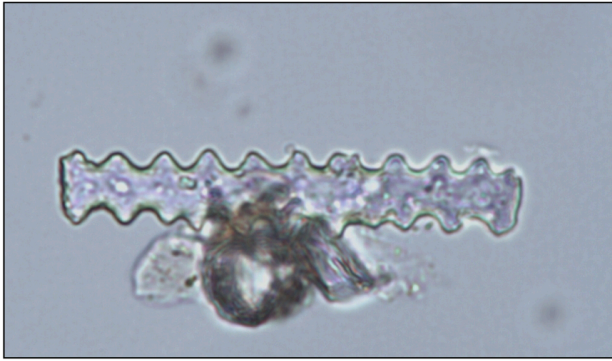
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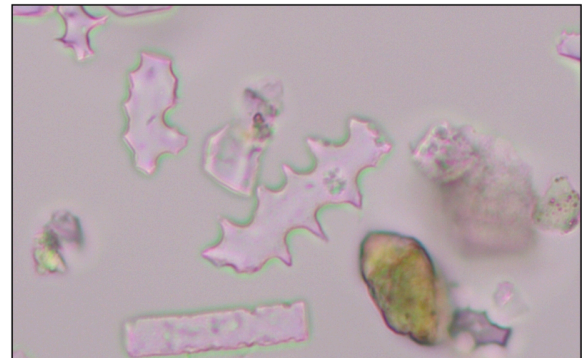
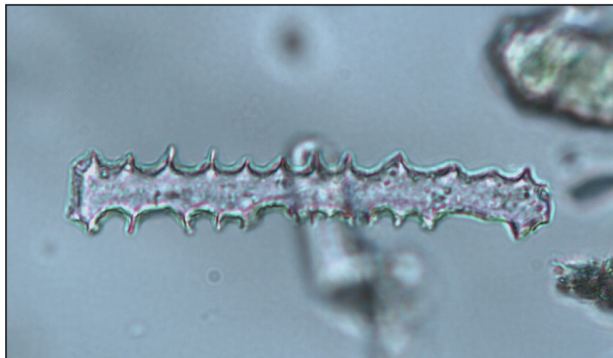
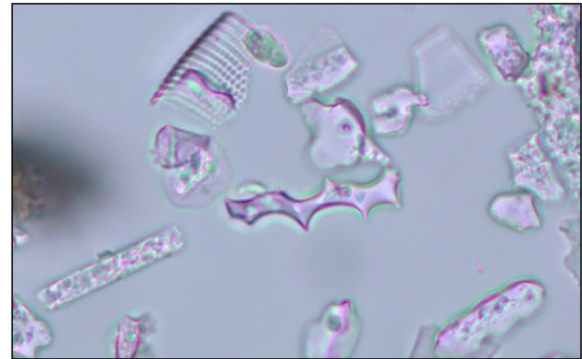
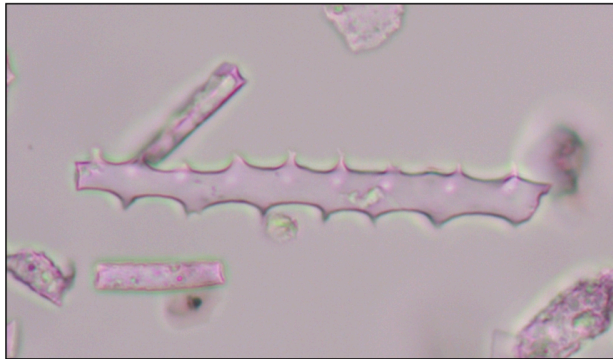
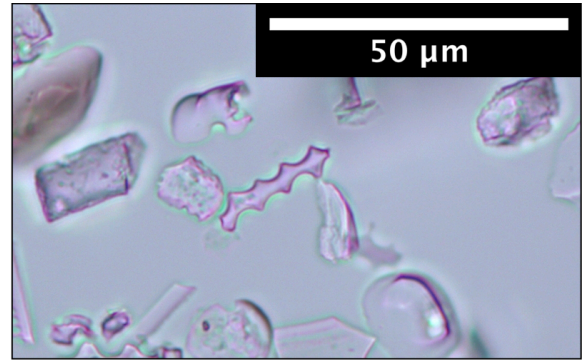
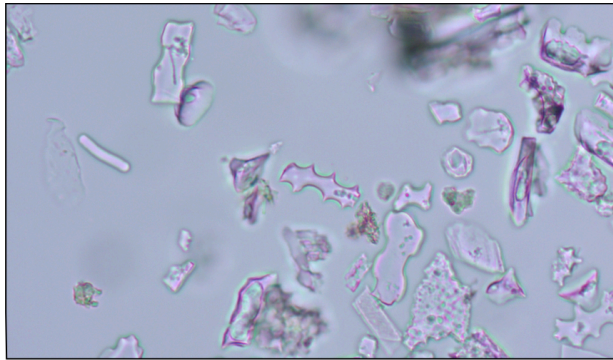
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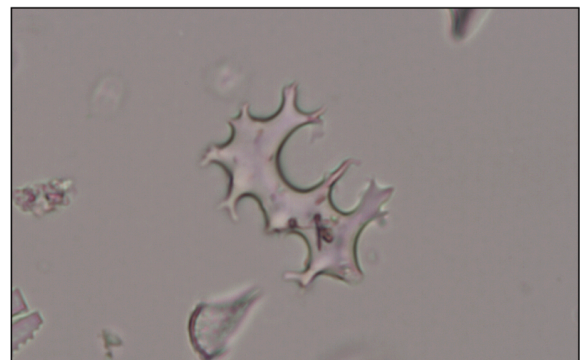
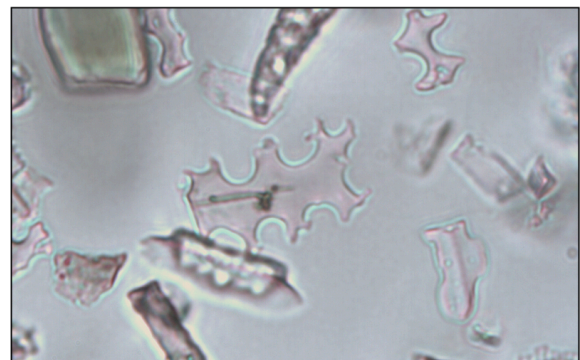
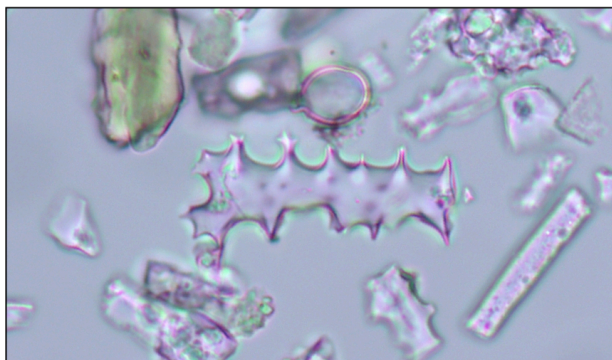
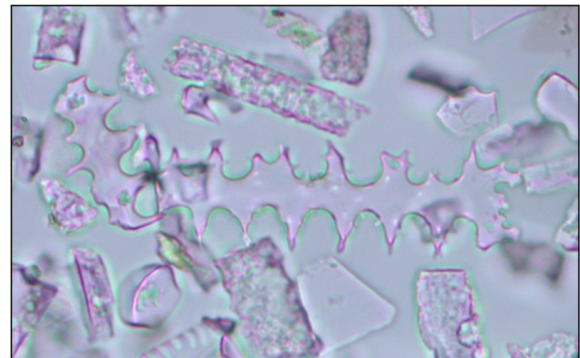
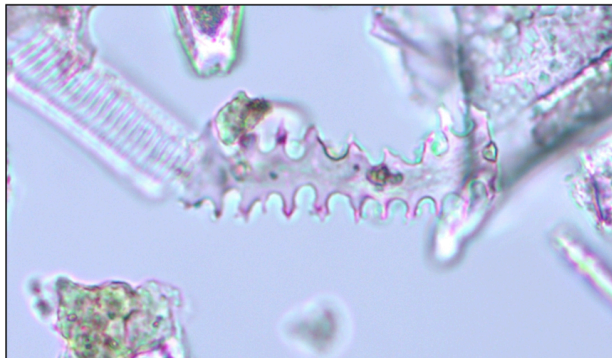
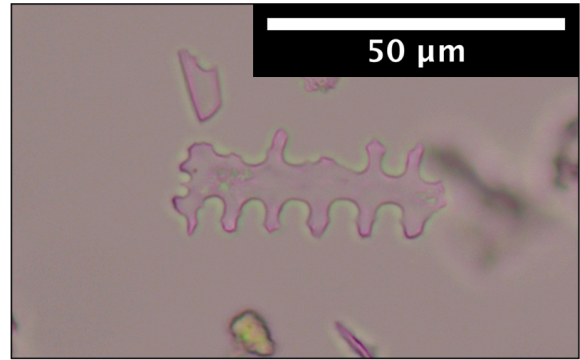
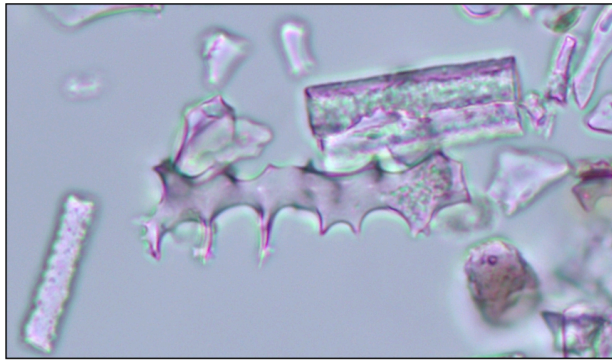
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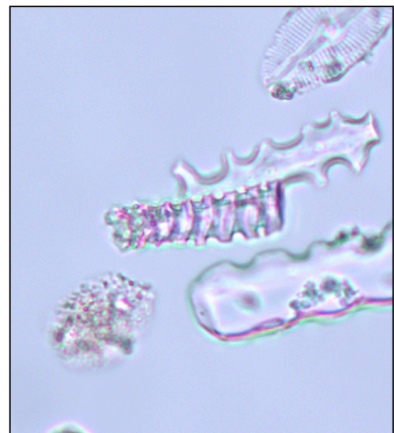
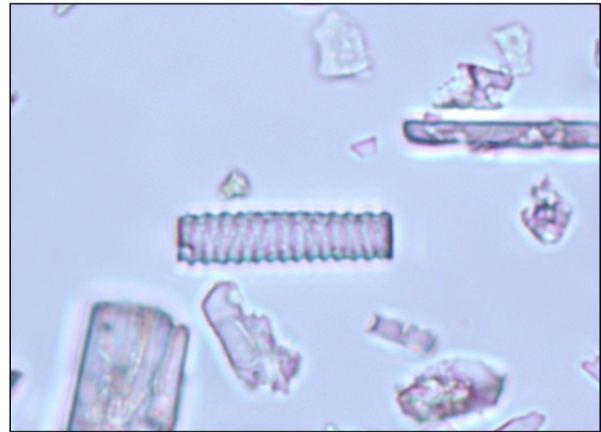
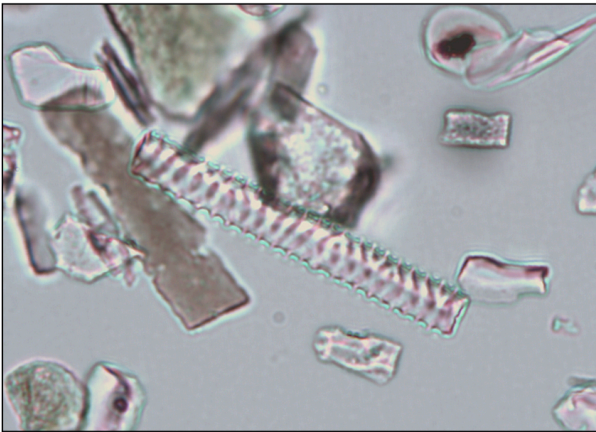
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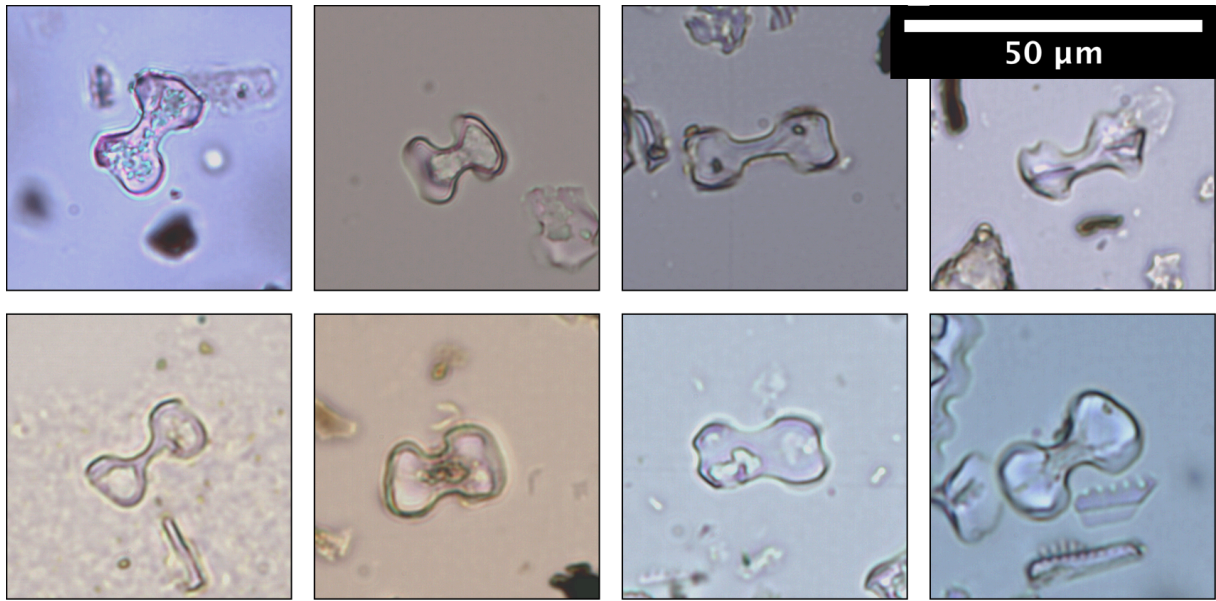
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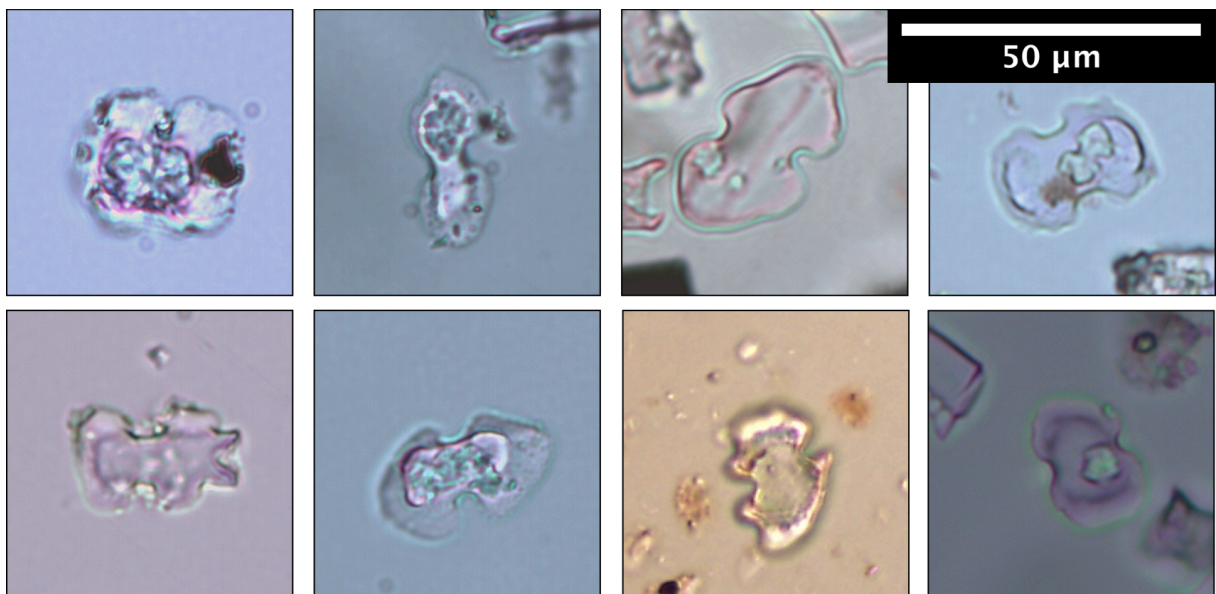
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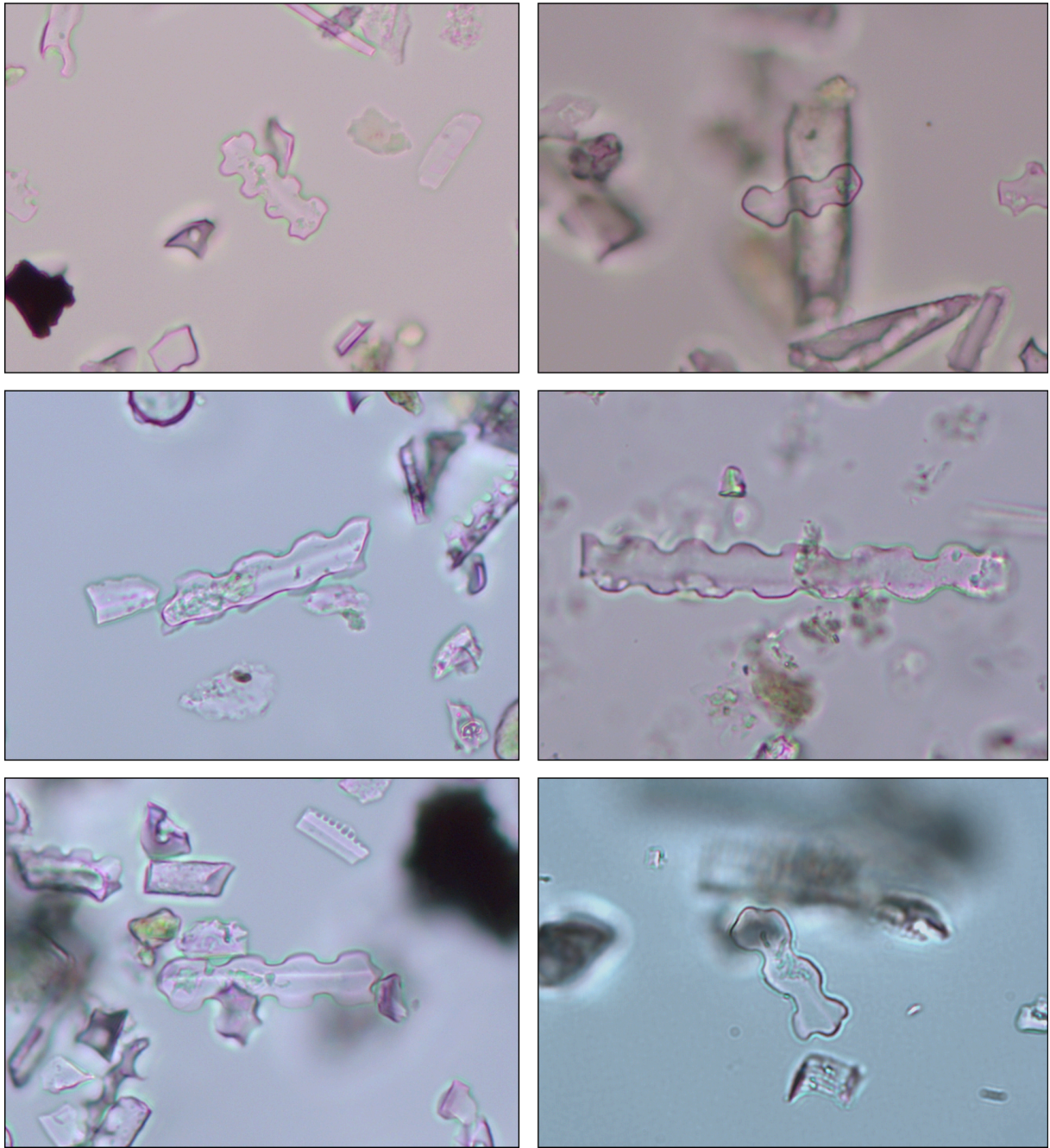
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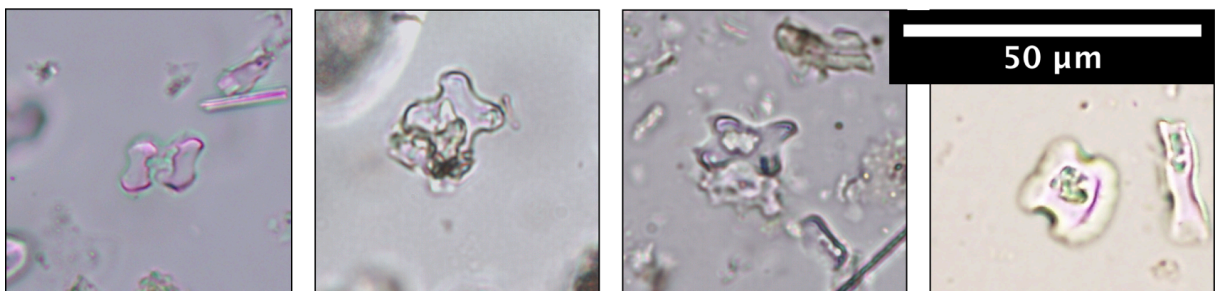
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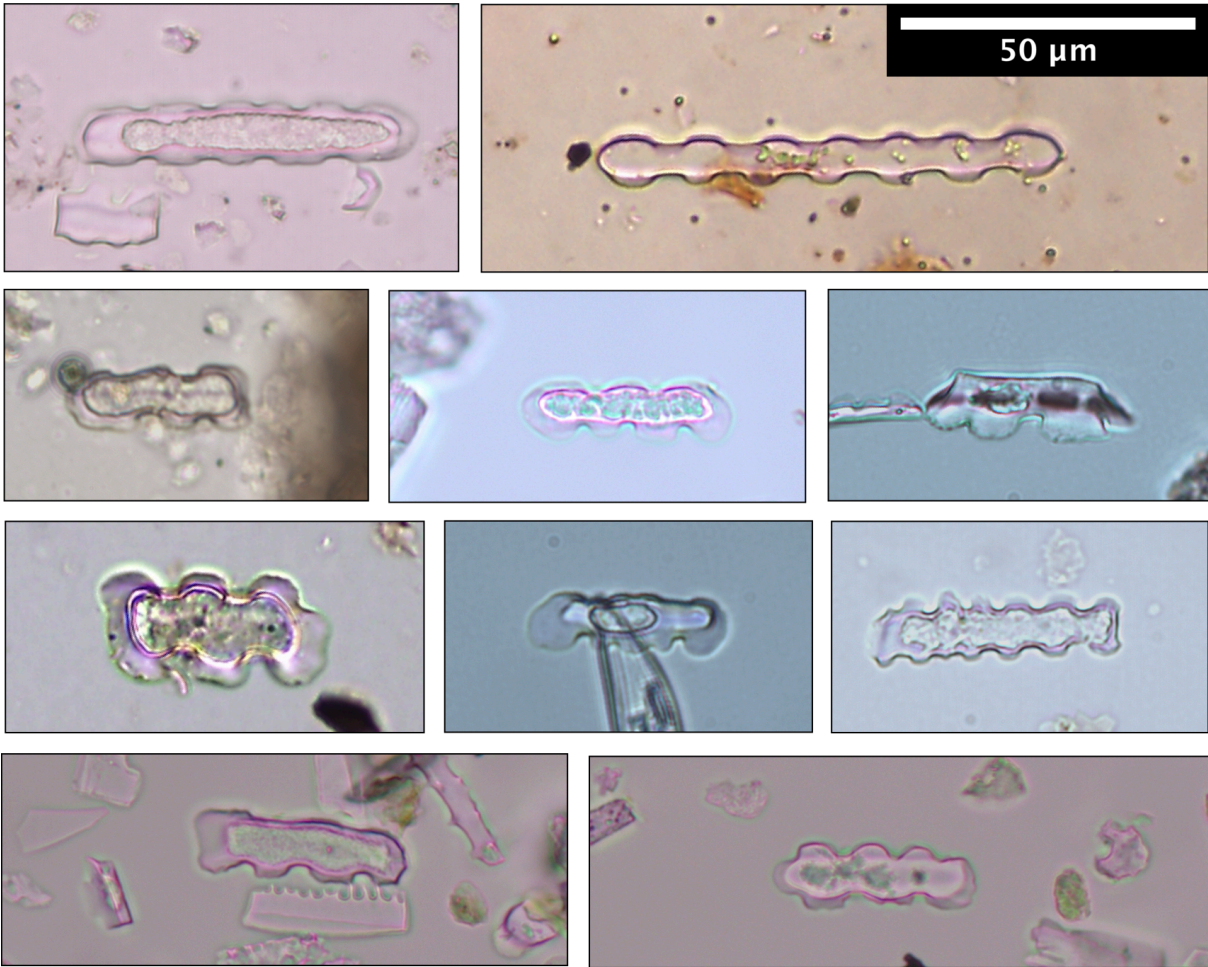
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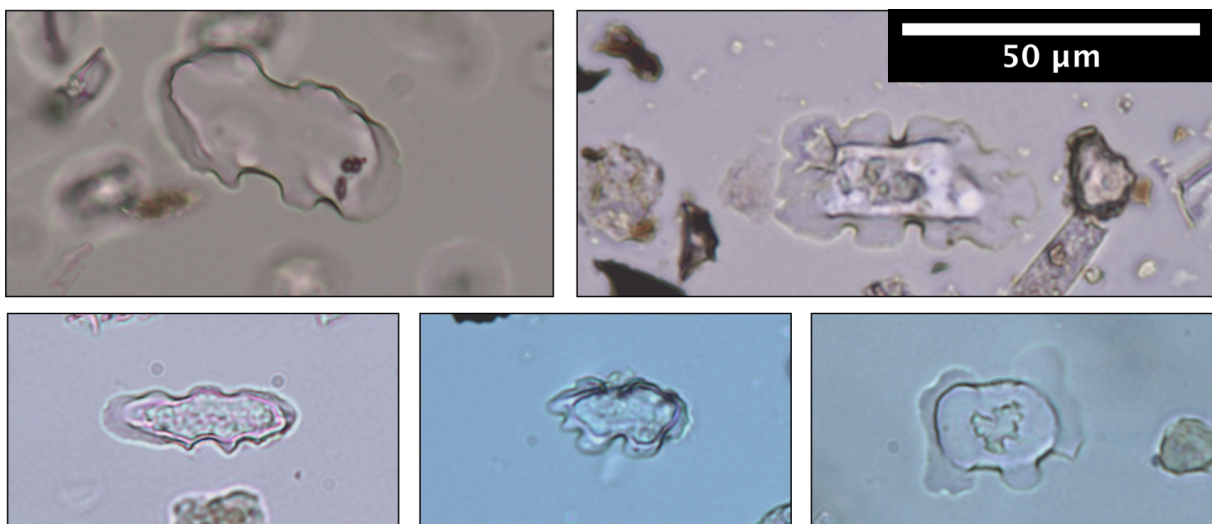
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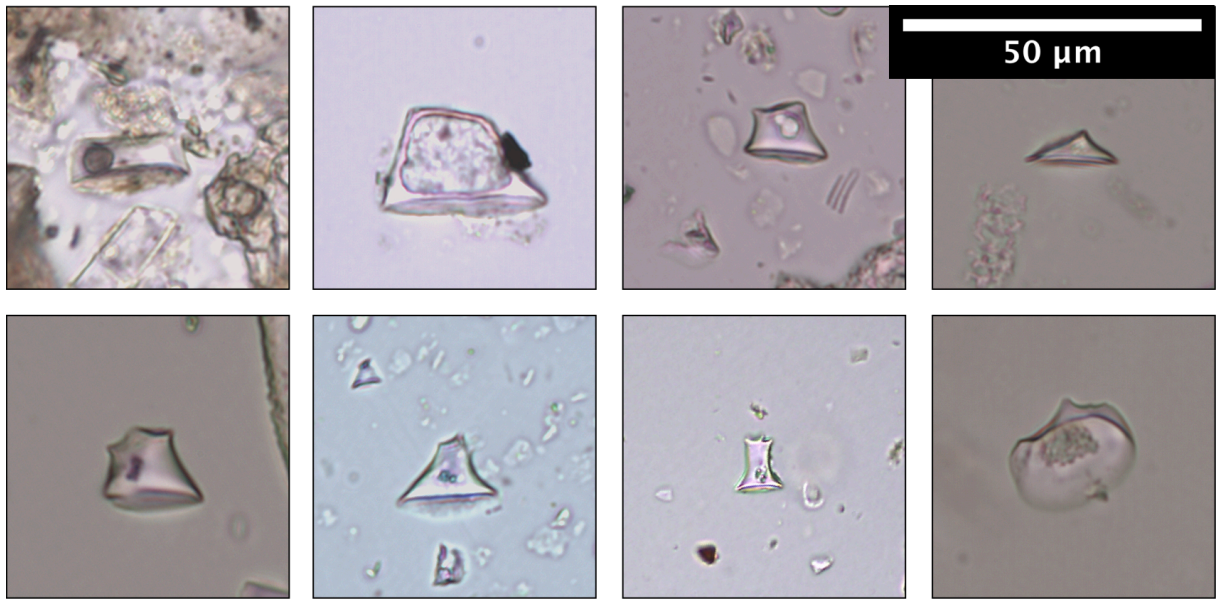
CROSS (the most right image is a non-classical CROSS as it has only three lobes)



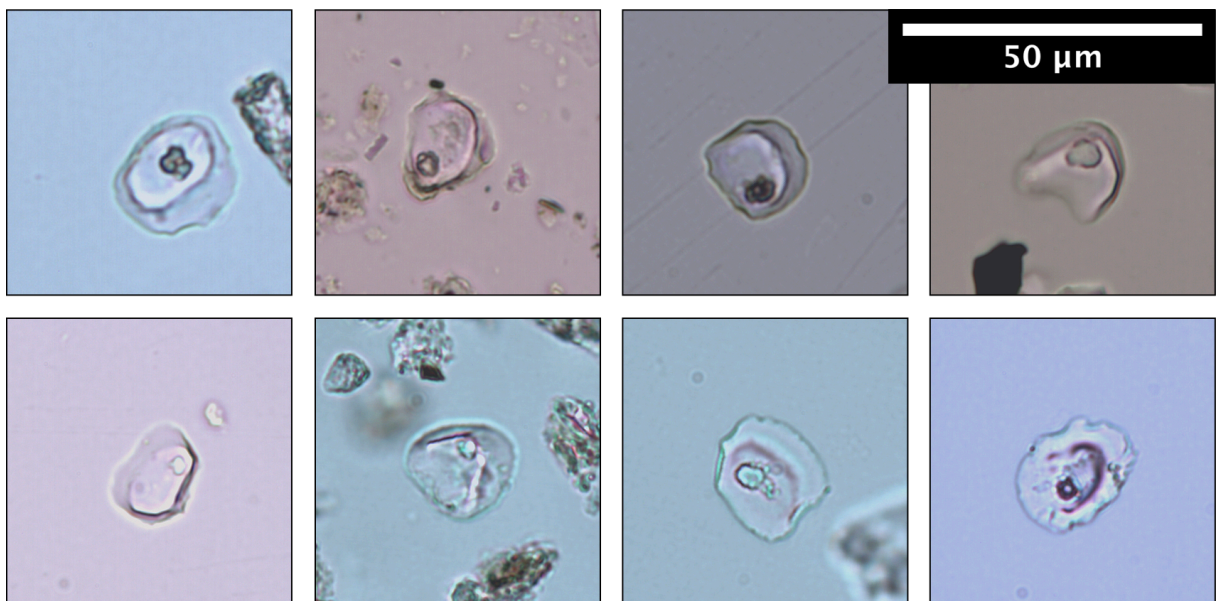
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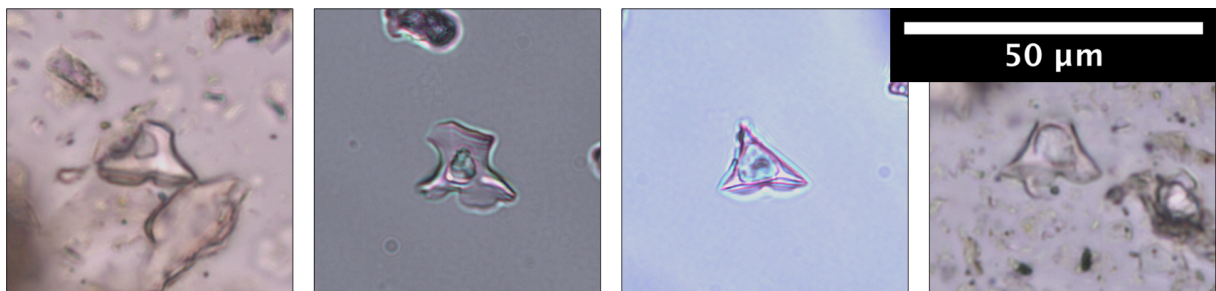
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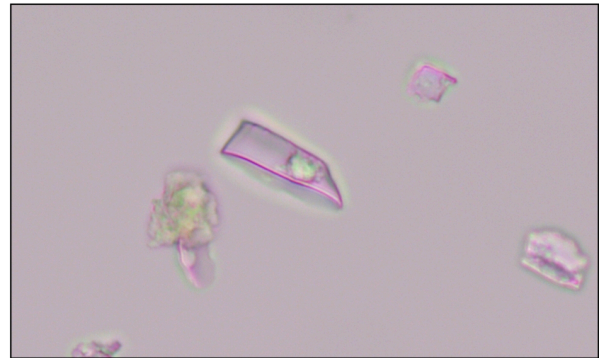
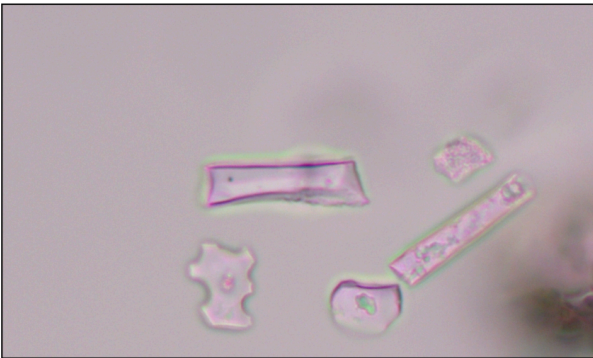
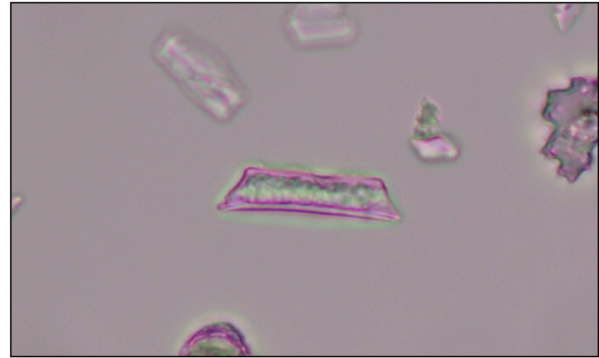
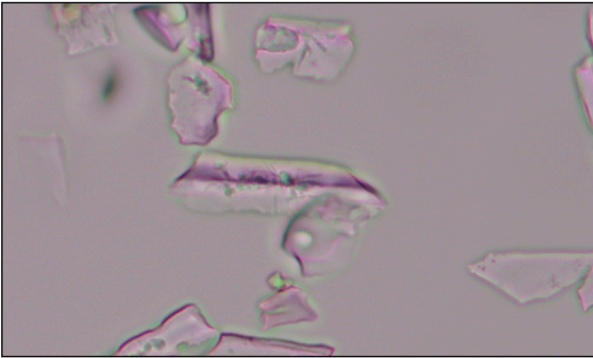
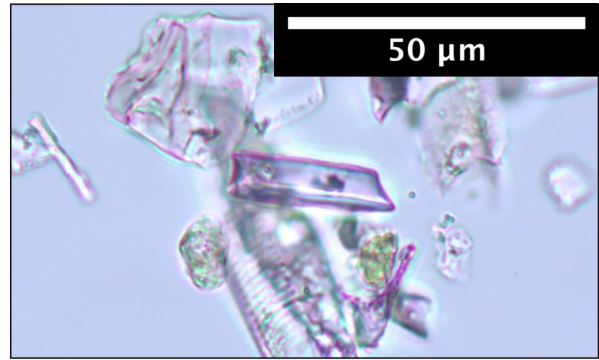
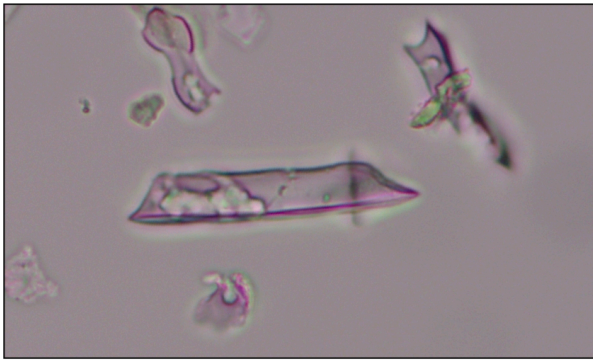
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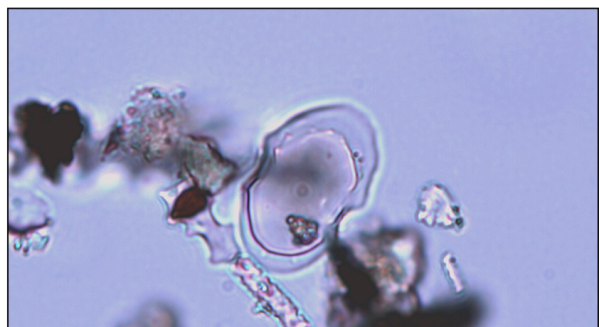
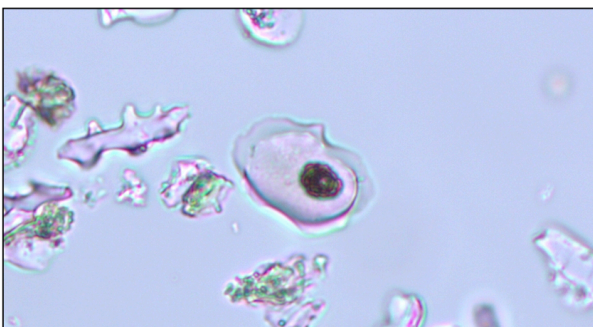
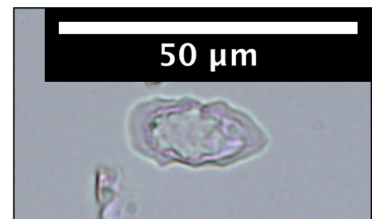
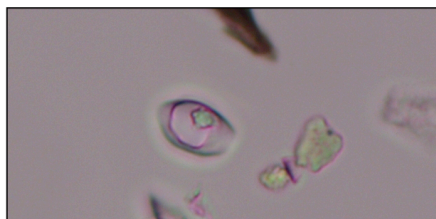
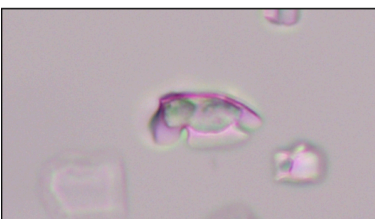
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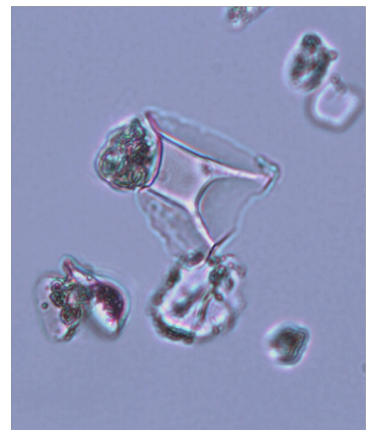
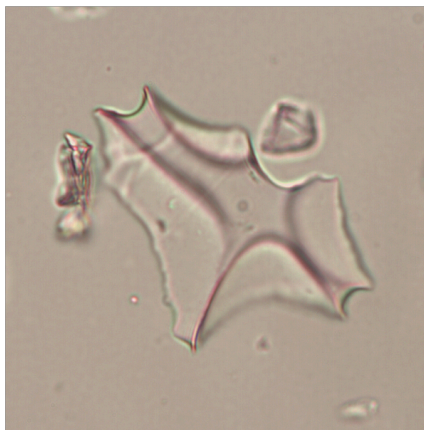
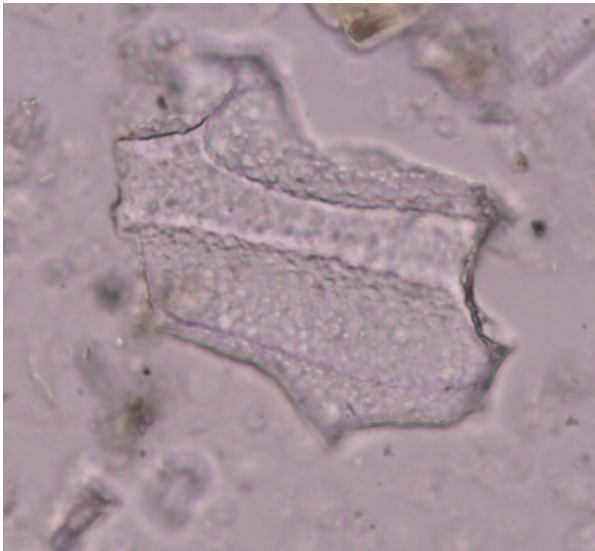
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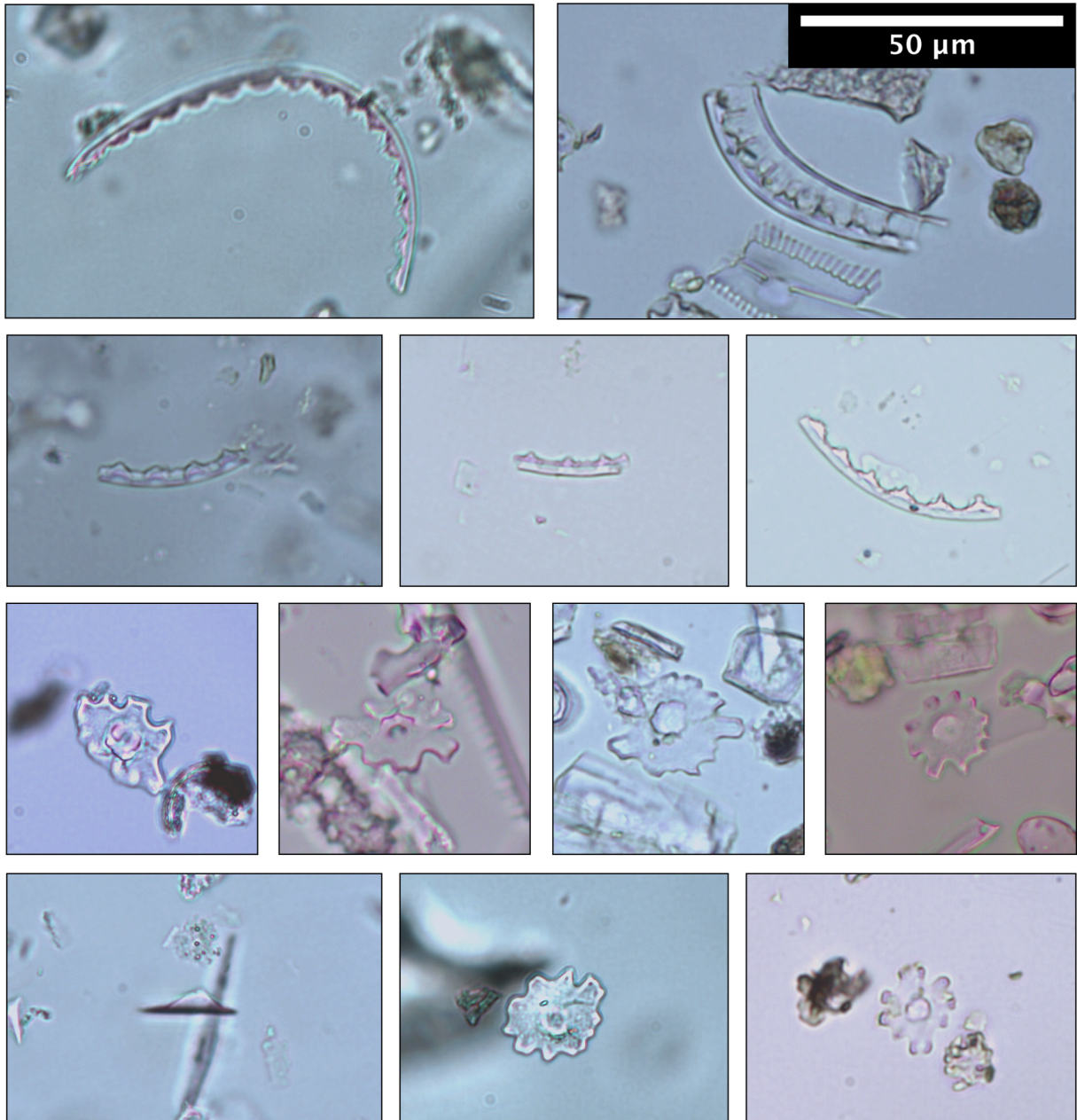
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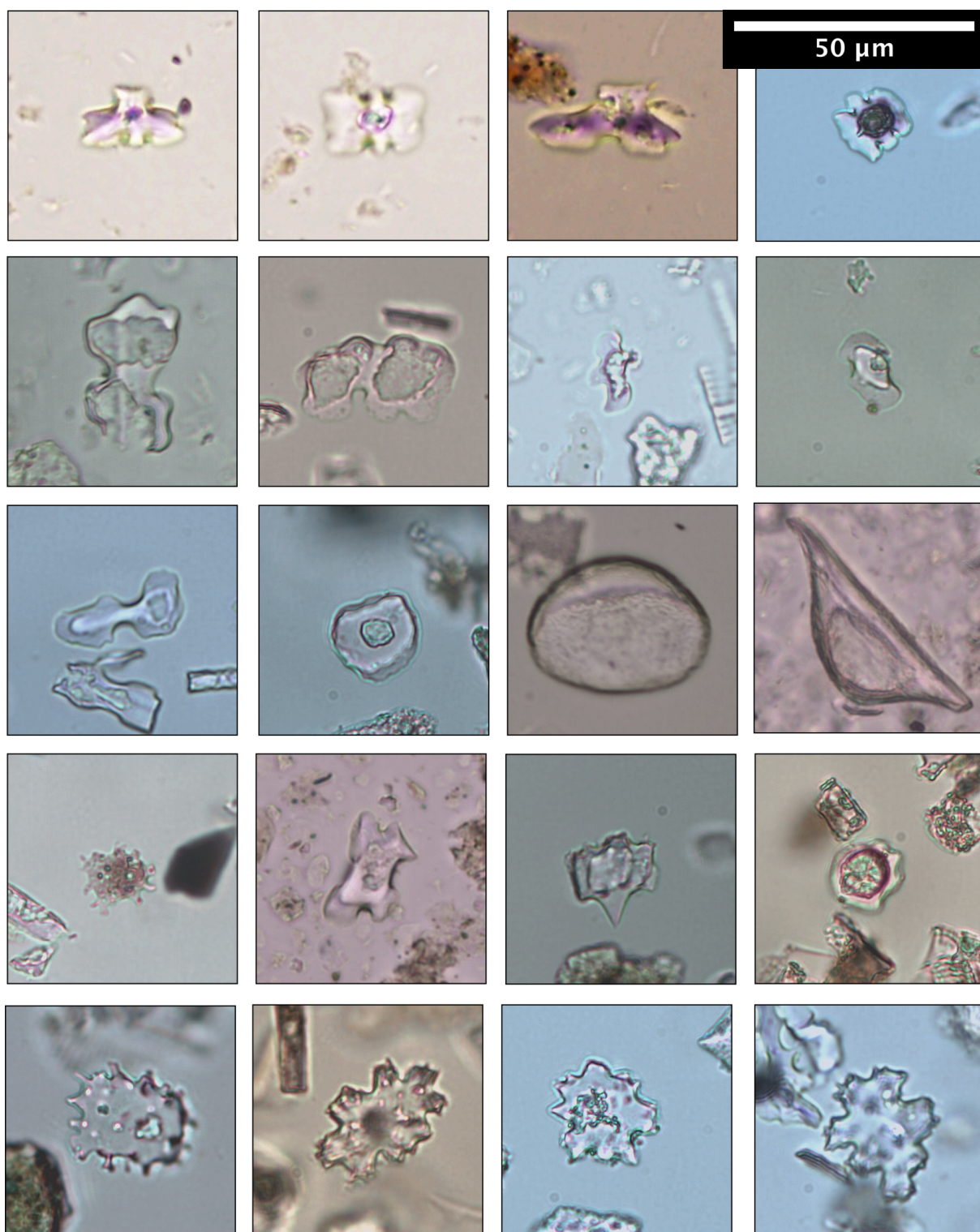
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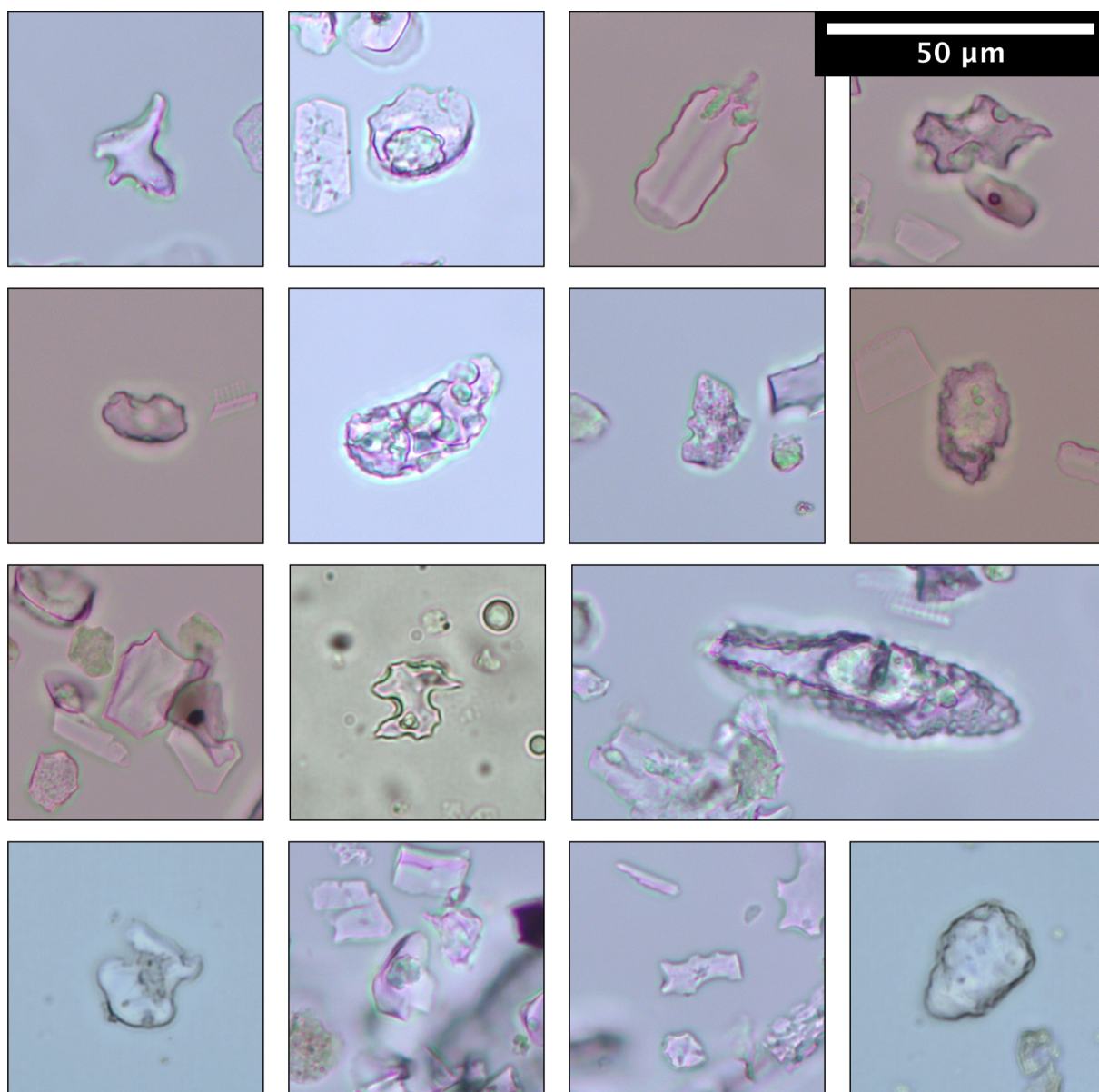
CELL WALL phytoliths



Cyperaceae phytoliths



Non-identified phytoliths



Unidentifiable phytoliths

Appendix B: laboratory methods

Laboratory method 1 (Royal Belgian Institute of Natural Sciences)

Preparation Between 1-5 gram of sediment is taken for each sample and put in 50 ml tubes.

Step 1: Disaggregation and elimination of soil particles

Removal of carbonates Initially a 10% solution of hydrochloric acid (HCl) was added. As no reaction could be observed, a 37% HCl solution was added and the samples were stirred in a hot-water bath to accelerate the gas reaction. No reaction could be observed which implies that the share of carbonates in the processed soil sediments was very low to zero. The samples were rinsed twice by centrifuging for 10 minutes at 2500 revolutions per minute (rpm) (Piperno, 2006, p. 92).

Removal of organic matter by adding a 65% concentration of nitric acid (HNO₃) which is a powerful oxidizing acid that reacts violently with many organic materials. The tubes were put in a hot-water bath to accelerate the reaction.

Breaking metallic bonds Next, a 1:1 mixture of a 65% solution of HNO₃ and a 37% solution of HCl was added. Hereafter the samples were put in a hot-water bath until the reaction was completely over. After this process each sample was rinsed twice by centrifuging for 10 minutes at 2500 rpm.

Eliminating organic and humic colloids After a 10% solution of potassium hydroxide (KOH) was added the samples were stirred in a hot-water bath for five minutes and rinsed twice by centrifuging for 10 minutes at 2500 rpm. The liquid in the tubes after centrifuging, also called the supernatant, had a orangish or orangish-brown color which is an indicator of humic colloids (Chevalier A., pers. com.).

Deflocculation and elimination of silts Deflocculation was accomplished through a combination of mechanical agitation and the addition of a chemical deflocculant. Each sediment was put in an Erlenmeyer together with 2,5-5 ml Sodium bicarbonate NaHCO₃ and H₂O. They were left in a mechanical shaker for 12 hours. In order to remove the clay the samples were transferred to 1000 ml beakers and H₂O was added to the top. As the lighter clay particles remain in suspension they can be siphoned off, while the rest of the material rests at the bottom of the beaker. The siphon process (add H₂O and siphon off) was repeated until most clay particles had been eliminated (Piperno, 2006, p. 91).

Step 2: Floatation and recovery of the phytoliths

Sodium polytungstate solution (Na₆[H₂W₁₂O₄₀]) with a gravity of 2.32 sg was used as a heavy liquid. The samples were diluted and centrifuged for 10 minutes at 2500 rpm.

Step 3: Mounting of the slides

All slides were mounted with the permanent technique using Canada Balsam.

Laboratory method 2: Rapid phytolith extraction from Katz *et al.* (2010).

Preparation Firstly, the sediments were pre-dried. Thereafter, sediments containing fraction larger than 0.5 mm were crushed using a mortar. Between 24-40 µg of sediment is taken for each sample and put in 1.5 ml tubes.

Step 1: Disaggregation and elimination of soil particles

Removal of carbonates 50 µl 6 N HCl was added using an adjustable pipette. Next, the tubes were vortexed for about 3 seconds. and the tubes were put in a hot-water bath. When the bubbling ceases, this means that the carbonates are completely dissolved.

Optional: Removal of organic matter 50 µl of fresh hydrogen peroxide (H₂O₂) were added for the samples that contained a lot organic matter, in this case the peat samples.

Step 2: Floatation and recovery of the phytoliths

Sodium polytungstate solution (SPT) with a gravity of 2.26 sg was used as a heavy liquid. Afterwards the tubes were vortexed for about 3 seconds and sonicated for 15 minutes. Next, the tubes were centrifuged for 10 min at 5000 rpm. This results in minerals (quartz, clay et cetera) to sink to the bottom, while phytoliths and charred organic material (if not removed with the additional step) remain in suspension. Hereafter, all the supernatant is pipetted off and transferred to a new tube.

Step 3: Mounting of the slides

An aliquot of 50 µl of the supernatant is placed on a microscopic slide. Slides are mounted with Entellan.

Laboratory method 3: from R. M. Albert

Preparation Firstly, the sediments were pre-dried. Subsequently, sediments containing fraction larger than 0.5 mm were crushed using a mortar. Between 24-40 µg of sediment is taken for each sample and put in 1.5 ml tubes.

Step 1: Disaggregation and elimination of soil particles

Removal of carbonates 50 µl 6 N HCl were added using an adjustable pipette. Next, the tubes were vortexed for about 3 seconds. and the tubes were put in a hot-water bath. When the bubbling ceases, this means that the carbonates are completely dissolved.

Breaking metallic bonds 50 µl of 3N HCl + 3N HNO₃ were added. Afterwards, the samples were centrifuged three times.

Optional: Removal of organic matter 50 µl of fresh hydrogen peroxide (H₂O₂) were added for the samples that contained a lot organic matter, in this case the peat samples.

Step 2: Floatation and recovery of the phytoliths

Sodium polytungstate solution (SPT) with a gravity of 2.26 sg was used as a heavy liquid. Afterwards the tubes were vortexed for about 3 seconds and sonicated for 15 minutes. Hereafter, the tubes were centrifuged for 10 min at 5000 rpm. This results in minerals (quartz, clay et cetera) to sink to the bottom, while phytoliths and charred organic material (if not removed with the additional step) remain in suspension. Lastly, the samples were transferred to other 1,5 ml tubes, vortexed and rinsed four times by centrifuging. Afterwards the samples were put in the oven at 70 degrees Celsius in order to dry.

Step 3: Mounting of the slides

An aliquot of 0,00080 g of the supernatant is placed on a microscopic slide. Slides are mounted with Entellan.

Sample	Laboratory method (1)	Laboratory method (2)	Laboratory method (3)
US26-27_19.5 (US26)	X		
US26-27_17 (US26)	X	X	X
US26-27_7 (US27)	X	X	X
US26-27_4.5 (US27)	X	X	X
US26-27_2 (US27)	X	X	X
US27-28_17 (US27)	X	X	X
US27-28_14 (US27)	X		
US27-28_12 (US27)	X	X	X
US27-28_9.5 (US27)	X	X	X
US27-28_7 (US27)	X	X	X
US28_17	X		
US28_9.5	X	X	X
US28_2	X		
US20_8.5	X	X	X
US2_13.5	X		
US2_11	X	X	X

US2_1	X		
US3_13.5	X		
US3_1	X		
US4_13.5	X		
US4_3.5	X		
US5_16	X		
US5_6	X	X	X
US6_18.5	X		
US6_6	X	X	X
US7_21	X		
US7_8.5	X	X	X
US7_3.5	X		
US8_18.5	X	X	X
US8_3.5	X		
US12_18	X	X	X
US12_8.5	X		

Processed samples by each protocol. Note that not all samples have been processed with all three methods. This can be explained as there was no more material left to process for some samples for method (2) and (3).



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Convention DMS-ARC/CREA-Pat/C-2017-250 entre la Région et le Centre de recherches en archéologie et patrimoine de l'ULB relative aux études paléoenvironnementale

Site de la Rue des Boiteux/Rue d'Argent (BR 295). Résultats préliminaires d'analyses phytolitariennes de lame mince de sol des US 26, 27 et 28.

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Table des matières

Table des matières 2

Résumé	3
1. Introduction	4
2. Matériel et méthode	5
3. Résultats et discussion	7
3.1 L'opale d'origine biologique	7
3.2 L'analyse des phytolithes	7
3.2.1 Faisabilité des analyses et Nombre Minimal d'Observations (MNO)	7
3.2.2 Visibilité	9
3.2.3 Aspect	10
3.3 Approche intégrée	12
3.3.1 Modèles de distribution	12
3.3.2 Les assemblages	13
3.3.3 Distribution isolée	16
4 Conclusions et perspectives	17
5 Références	19
6 Annexe	21

Résumé

Trois Unités stratigraphiques (US 26, 27 et 28) du site de la Rue des Boiteux/Rue d'Argent (BR 295) ont fait l'objet d'analyse phytolithes en lames mince de sol.

En l'état, les analyses établissent que tous les phytolithes observés ne partagent pas la même taphonomie. L'étude de faisabilité quant à elle suggère que pour les 3 US soumises à analyse :

- seule l'US 28 n'apporte pas actuellement un volume d'observations statistiquement fiable ;
- visibilité et préservation ne composent pas des obstacles à l'analyse des phytolithes en lames minces de sol.

L'approche intégrée suggère :

- de fortes perturbations post-depositionnelles ;
- les phytolithes isolés attestent d'une signature graminéennes avec une présence de graminée cultivées. Cependant, selon l'US, l'inventaire des phytolithes attestant de cette présence varie.

A ce jour, aucune interprétation de ces variations concomitantes ne peut être avancée.

Site de la Rue des Boiteux/Rue d'Argent (BR 295). Résultats préliminaires d'analyses phytolithariennes de lame mince de sol des US 26, 27 et 28.

Luc Vrydaghs

1. Introduction

Le présent rapport vise l'analyse des phytolithes observés en lames mince de sol pour le site de la Rue des Boiteux/Rue d'Argent (BR 295). Elles portent sur 3 Unités Stratigraphique (US), les US 26, 27 et 28. D'entrée, il sera signalé que l'étude des phytolithes par extraction du sol double ces analyses. Ce volet du suivi est assuré par R Hermans (VUB) dans le cadre de son mémoire de Master en Archéologie (Promoteur : Prof. D. Tys). L'auteur du présent rapport participe à l'encadrement de ce mémoire de Master.

Le développement de cette stratégie d'étude (une combinaison de l'étude de lames minces de sol et d'échantillons en vrac) s'explique par la stratigraphie du site de la Rue des Boiteux/Rue d'Argent soit, une séquence de tourbe couvrant l'Holocène et un horizon de transition coiffé par 2 unités de terres noires (voir section 2 : Matériel et méthode). Cette stratigraphie autorise le traitement de diverses questions liées à la discrimination de la signature phytolithique de l'anthropomorphisation du paysage. Plusieurs déclinaisons de la question peuvent se formuler :

- une étude détaillée de la taphonomie des phytolithes ;
- l'existence de différences significatives dans la composition des assemblages phytolithariens (tourbe *versus* terres noires);
- une évaluation du nombre absolu de phytolithes comme signature de l'activité anthropique. En effet, la littérature spécialisée propose que les dépôts anthropiques se caractérisent par un contenu en phytolithes plus conséquent que les dépôts naturels (Madella 2007) ;
- la signature phytolitharienne des céréales et donc, celle de l'impact des activités agricoles sur le paysage bruxellois. La profondeur historique de cette question pourrait s'avérer importante. L'étude palynologique de la séquence de tourbe de la Rue des Boiteux/Rue d'Argent (BR 295) est typique du nord de l'Europe tempérée. La partie supérieure de cette séquence (LAPZ 4, datée de 3400/2790 cal BP) détecte la présence de marqueurs directs de l'anthropomorphisation du paysage couplée à des pollens de céréalia (Marinova 2015, 2016 & 2017, Marinova et al. 2018). De précédentes analyses phytolithes des mêmes échantillons enregistrent la présence de phytolithes de céréales (Hermans 2018). Il serait donc possible de documenter les activités agricoles et leurs impacts sur une séquence de temps longue.

Ce rapport se limite aux données phytolithes relatives aux lames minces de sol. Il esquissera des tendances en relation aux différentes thématiques évoquées sans pour autant présenter des conclusions définitives. La poursuite des travaux se devra de les confirmer ou infirmer.

2. Matériel et Méthode

Le matériel soumis à analyse en lames minces de sol porte sur trois US, les US 26, 27 et 28. Les US 26 et 27 composent les 2 unités de terres noires. L'US 28, l'horizon de transition entre la séquence de tourbe et les unités de terres noires (Fig. 1. Devos 2014).

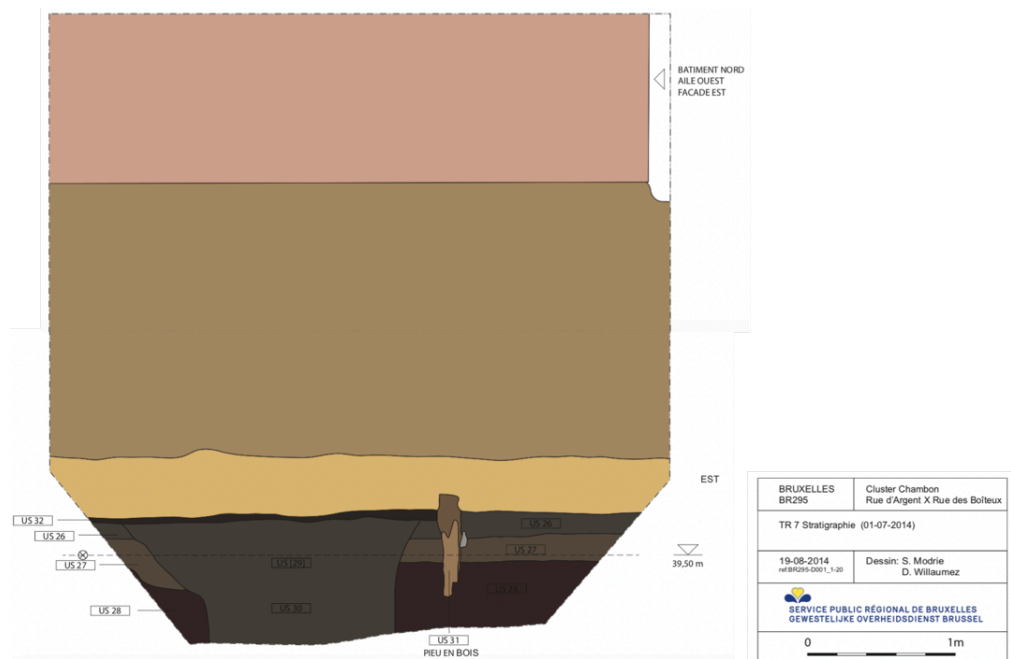


Fig. 1 : Séquence de la Rue des Boiteux/Rue d'Argent étudiée. Tranchée7, Profil nord.

Les analyses phytolithariennes en lames minces de sol se développent dans le suivi des analyses micromorphologiques (Devos 2018). Sur base des résultats de ces analyses, pour les US 26 et 27, une sélection de 3 carrés de 5x5 mm a été menée par Y. Devos aux fins d'analyses phytolithariennes. Ce protocole n'a pas été suivi pour l'US 28, les 3 carrés ayant été sélectionnés par l'auteur du présent rapport. Pour l'heure, seul un carré par US a été étudié. Les résultats présentés sont donc provisoires. La méthode d'analyse phytolitharienne des lames minces de sol suit Vrydaghs et al. (2016), Devos et al. (2017), Kaczorek et al. (2018) et Vrydaghs and Devos (2018, in press)⁴⁸. Elle vise un inventaire systématique :

- de l'opale d'origine biologique (phytolithes, diatomées, chrysophycées, spicules d'éponge) (Kaczorek et al 2018) ;
- des modèles de distribution des phytolithes (isolés, clusters et articulés) (Vrydaghs et al. 2016 ; Vrydaghs et Devos 2018 ; Devos et Vrydaghs 2017) ;
- des phytolithes composant chaque modèle de distribution (Vrydaghs et Devos 2018 ; Devos and Vrydaghs 2017). La nomenclature adoptée pour cet inventaire suit l'ICPN 2.0 (ICPT (Neumann et al.) in press). Elle induit une révision complète de l'inventaire des phytolithes adopté depuis 2012.
- de la visibilité et aspect des phytolithes composant chaque modèle de distribution (Vrydaghs and Devos in press). Dans le cadre de cette étude, les notions de Visibilité et Aspect sont pour la première fois appliquées à l'analyse de l'ensemble de l'opale d'origine biologique (diatomée, cystes de chrysophycée, spicules d'éponge). Cette adaptation compose

⁴⁸ Une présentation plus détaillée de la méthode d'analyse des phytolithes en lame mince de sol est reprise en Annexe au présent rapport.

l'innovation méthodologique dans l'analyse en lames minces de sol apportée par l'étude de la Rue des Boiteux. Le Tableau 1 illustre quelques cas de ce système de description.

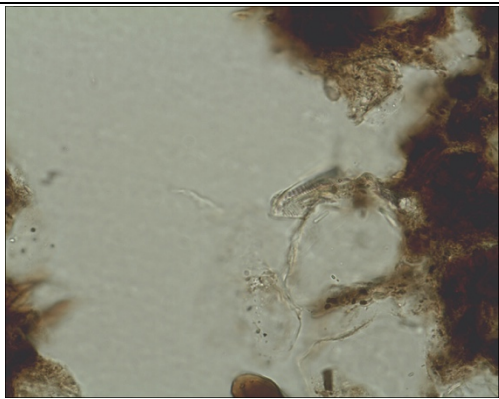
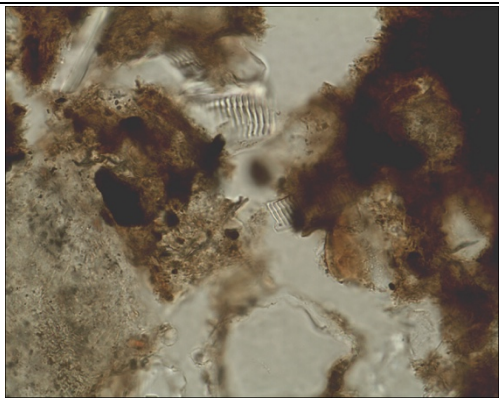
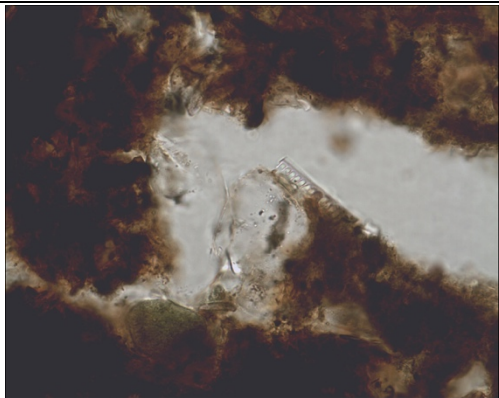
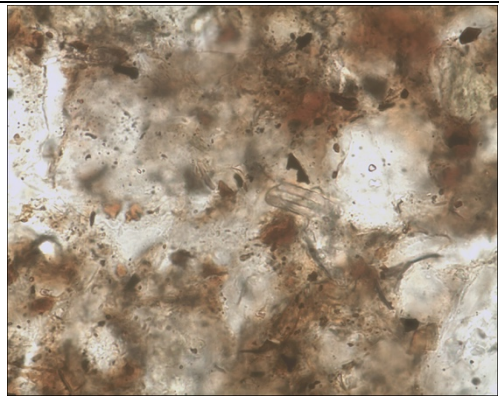
	
Visibilité: A; Aspect: B	Visibilité: B; Aspect : ?
	
Visibilité B ; Aspect :	Visibilité: C; Aspect: C

Tableau 1 : Exemple de la description de la Visibilité et de l'Aspect de l'opale d'origine biologique, et plus spécifiquement, des diatomées inspiré de Vrydaghs et Devos (in press).

3. Résultats et discussion

3.1 L'opale d'origine biologique

Le cortège d'opale d'origine biologique classiquement enregistré pour les dépôts archéologiques bruxellois s'observe : phytolithes, diatomées, cystes de chrysophycées et spicules d'éponge (Tableau 2).

	Phy	Dia	Chr	Spi
US 26	270	63	7	6
US 27	313	133	1	1
US 28	227	123	6	1

Table 2 : Nombre absolu d'observations pour la fabrique d'opale d'origine biologique après l'étude d'un carré de 5x5 mm. Phy : Phytolithe ; Dia : Diatomée ; Chr : Chrysophycée ; Spi : Spicule d'éponge.

Les phytolithes dominent l'opale d'origine biologique suivis des diatomées (Table 1). La présence des cystes de chrysophycées et de spicules d'éponge s'avère négligeable. L'ensemble de ces observations donnent à penser que des questions liées à une corrosion des phytolithes (et plus généralement de l'opale d'origine biologique) ne se poseraient pas.

3.2 L'analyse des phytolithes

La première phase des analyses observe des phytolithes :

- dans des fragments d'organe et de tissus (*sensu* Stoops 2003) pour les US 27 et 28 (Fig. 2);
- dans des excréments pour l'US 27 (Fig. 3) ;
- dans la matrice du sol pour les US 26, 27.

Il en est conclu que l'ensemble des phytolithes ne partagent pas la même taphonomie. L'observation de phytolithes au sein de fragments d'organes et de tissus végétaux tend à établir que à tout le moins une partie du matériel phytolitharien observés dans la matrice du sol trouverait son origine dans une décomposition *in situ* de matière organique.

La suite de ce rapport portera exclusivement sur les phytolithes de la matrice du sol.

3.2.1 Faisabilité des analyses et Nombre Minimal d'Observations

L'étude de la faisabilité des analyses phytolithariennes porte sur le Nombre Minimal d'Observations des modèles de distribution (isolés, clusters et articulés) (MNPa) et de phytolithes par modèle de distribution (MNPh), la visibilité et l'aspect de chaque phytolithe isolés.

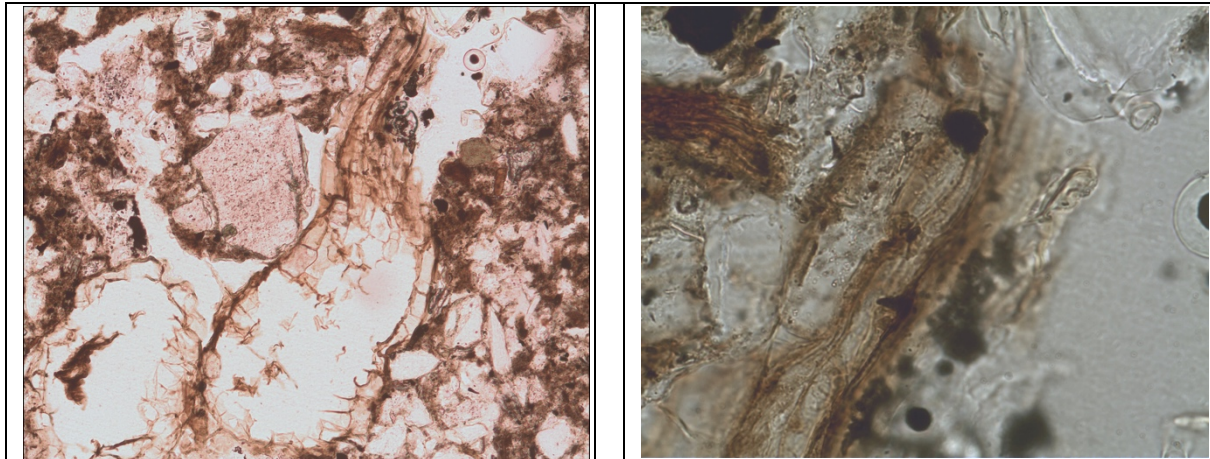


Fig. 2 : Phytolithe observé dans un fragment de tissu. L'image de gauche présente une vue d'ensemble du fragment d'organe, celle de droite, le phytolithe *in situ* (BR 295_US 28_x400 PPL).

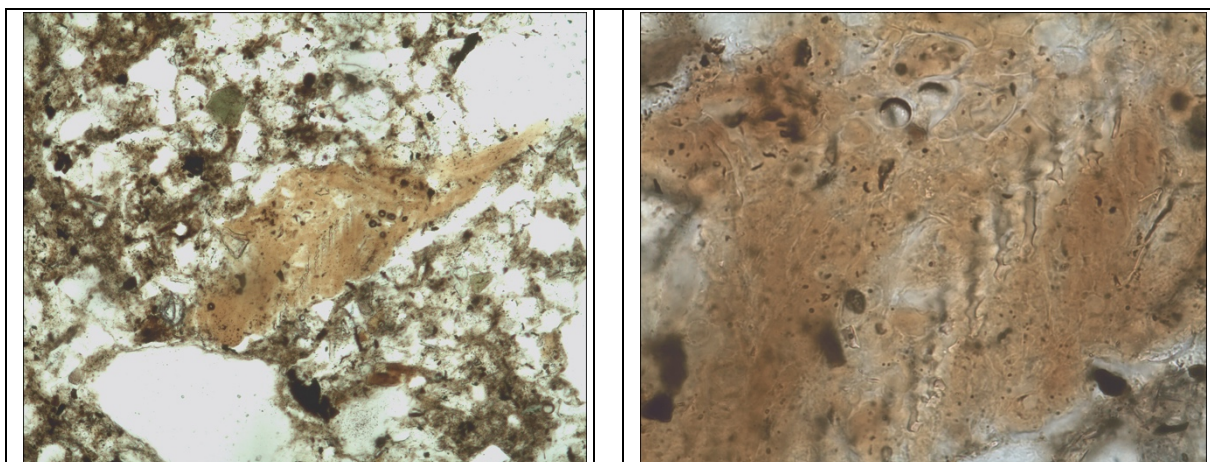


Fig. 3 : ELONGATE DENDRITIC/DENTATE articulé observé dans un excrément de l'US 27. Cette observation suggère qu'il s'agit d'un fragment d'excrément d'herbivore non ruminant (Image de gauche : x100 ; image de droite : x400 ; PPL).

US	n	Isolé	Cluster		Articulé		Total MNPh
			MNPa	MNPh	MNPa	MNPh	
26	1	230	17	40			270
27	1	247	27	60	1	6	313
28	1	137	8	16			153

Tableau 3 : Nombre Minimal d'Observations réalisé par modèle de distribution sur base de l'analyse d'un carré de 5x5 mm. MNPa : Nombre Minimal de modèle de distribution. MNPh : Nombre Minimal de phytolithes par type de modèle de distribution.

Les MNPh globaux actuellement enregistrés sont respectivement de 270 (US 26), 313 (US 27) et 153 (US 28). Le Tableau 3 et la Fig. 4 détaillent par modèle de distribution les MNPa et MNPh.

Selon Zuro (2018), un volume d'observations statistiquement fiable requière l'observation de 250 à 300 phytolithes. Si nous déclinons les observations selon le MNPh des modèles de distribution (Tableau 3), aucun ne paraît apporter des populations de phytolithes suffisantes. Cette constatation appelle certains commentaires :

- Il sera d'abord rappelé qu'en l'état, seul un carré de 5x5 mm par lame mince de sol a été scanné. Au vu des observations déjà conduites, il est plus que probable que la poursuite des analyses atteindra le seuil requis pour la distribution isolée;
- à la suite du mode de formation de la distribution en cluster, il serait permis de sommer les MNPh des distributions isolées et en clusters, toutes 2 résultants de perturbations (colonne Tic Table 2). Dans ce cas, avec un total de 153 phytolithes isolés, seule l'US 28 n'apporte pas actuellement un volume d'observations statistiquement fiable. Là aussi, il devrait être atteint avec la poursuite des analyses. Par contre, cette option confère une certaine assise statistique aux résultats présentés pour les US 27 et 28 ;
- une précédente comparaison statistique par table de contingence 2 à 2 suggère que l'observation de 80 phytolithes apporterait un nombre statistiquement significatif d'observations à même de détecter des différences larges et moyennes dans les proportions de phytolithes avec un intervalle de confiance de 95% (Slachmuylder 2015; Vrydaghs et al. 2015). Les MNPh des distributions isolées sont tous supérieurs à ce seuil de données et il ne peut être exclu que ce quota de 80 phytolithes sera également atteint par la suite pour la distribution en cluster des US 26 et 27. Cette situation autorise d'avancer dans le traitement des données recueillies.

3.2.2 Visibilité

Pour des raisons pratiques, l'analyse de la Visibilité des phytolithes ne prend en compte que les phytolithes isolés. Trois niveaux de Visibilité des phytolithes se discriminent : parfaitement visible (A), partiellement masqué et/ou entouré (C) et fortement masqué et/ou entouré par la fraction fine du sédiment (D). La situation intermédiaire entre A et C (légèrement masqué) est labellisée par B (Vrydaghs and Devos in press). Une échelle de visibilité analogue a été adoptée pour la description des diatomées, cystes de chrysophycée et spicule d'éponge.

Les phytolithes parfaitement visibles (A) représentent 5% des observations pour l'US 28 contre 8% pour l'US 27 et 18% pour l'US 26. Quant à la marge de visibilité de parfaitement visible à partiellement masqué elle représente 70% pour l'US 28, 73% pour l'US 27 et 85% pour l'US 26 (Fig. 5). Il en est conclu que :

- La Visibilité ne compose pas un obstacle à l'étude des phytolithes en lame mince de sol ;
- la Visibilité des phytolithes de l'US 26 se démarque de celle des US 27 et 28 (Fig. 5) ;
- la marge de visibilité semble aller en croissant de l'US 28 à 26. Cette croissance s'imputerait à l'oxydation de la matière organique (Y. Devos com. pers.).

Les diatomées parfaitement visibles (A) représentent 3% des observations pour l'US 28, 6% pour l'US 27 et 19% pour l'US 26. Quant à la marge de visibilité de parfaitement visible à partiellement masqué elle représente 63% pour l'US 28, 69% pour l'US 27 et 71% pour l'US 26 (Fig. 6). Comme pour les phytolithes,

- la Visibilité des diatomées ne compose pas un obstacle à leur étude en lames minces de sol ;
- la Visibilité de l'US 26 se démarque de celle des US 27 et 28. Comparé aux phytolithes, ce phénomène est plus marqué avec les diatomées;

- par contre, les marges de visibilité de parfaitement visible à partiellement masqué de ces 3 US n'attestent pas d'une croissance aussi importante que celle des phytolithes.

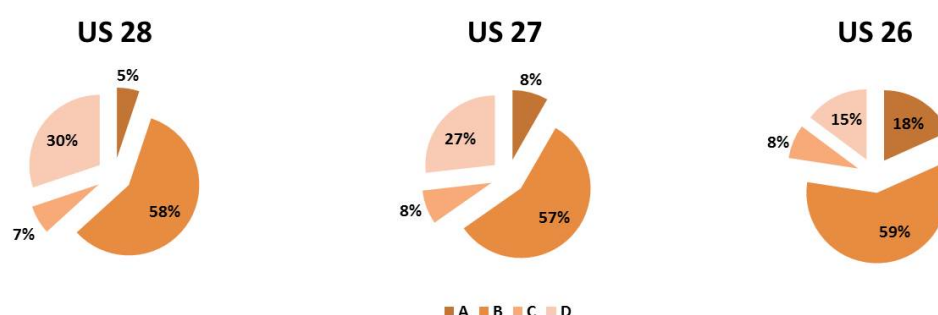


Fig. 5 : Visibilité des phytolithes pour les US 28, 27 et 26 d'après Vrydaghs et al. (in press).

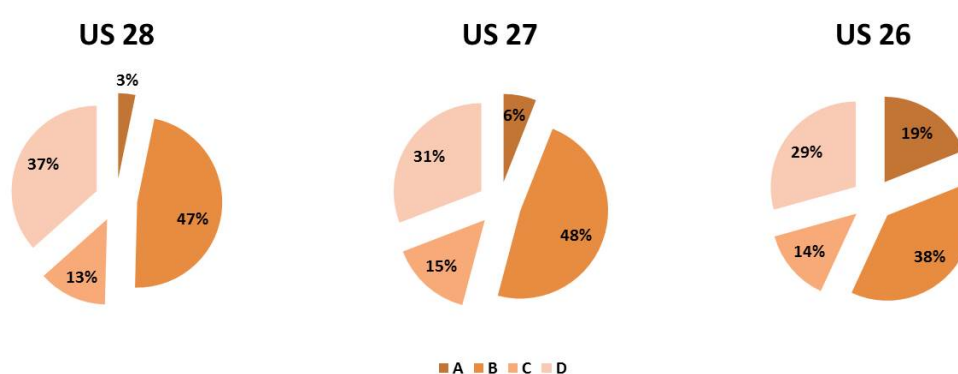


Fig. 6 : Visibilité des diatomées pour les US 28, 27 et 26 selon l'extension du système de description de Vrydaghs et Devos (in press)

3.2.3 Aspect

Pour des raisons pratiques, l'analyse de l'Aspect des phytolithes ne prend en compte que les phytolithes isolés. Trois niveaux d'aspect des phytolithes se discriminent : parfaitement préservés (A), partiellement préservés (C) et fortement altérés (E). Des situations intermédiaires entre d'une part, A et C et d'autre part, entre C et E s'observent également. Elles se labellisent respectivement B et D (Vrydaghs and Devos in press).

Les phytolithes parfaitement préservés (A) représentent 47% des observations pour l'US 28 contre 57% pour l'US 27 et 52% pour l'US 26. Quant à la marge de préservation de parfaitement préservé à partiellement préservé, elle représente 78% pour l'US 28, 83% pour l'US 27 et 80% pour l'US 26 (Fig. 7). La préservation des phytolithes varie donc peu d'une US à l'autre et ne compose pas un obstacle à leur étude en lame mince de sol.

L'échelle d'aspect mise en place pour l'observation des diatomées ne discerne que 3 niveaux de préservation : parfaitement préservé (A), fragmenté (B) et fortement fragmenté (C). A l'exception de la valeur A, cette description d'aspect n'est donc pas équivalente à celle des phytolithes, ce qui limite la comparaison des tendances. Par contre, les fractions parfaitement préservées le sont.

D'après l'échelle adoptée, les diatomées parfaitement préservés (A) représentent 8% des observations pour l'US 28 contre 12% pour l'US 27 et 20% pour l'US 26 (Fig. 8). De l'horizon de transition (US 28) à l'unité de terre noire supérieure (US 26), la proportion de diatomées parfaitement préservées paraît donc croître significativement. Une tendance similaire n'est pas suggérée pour les phytolithes.

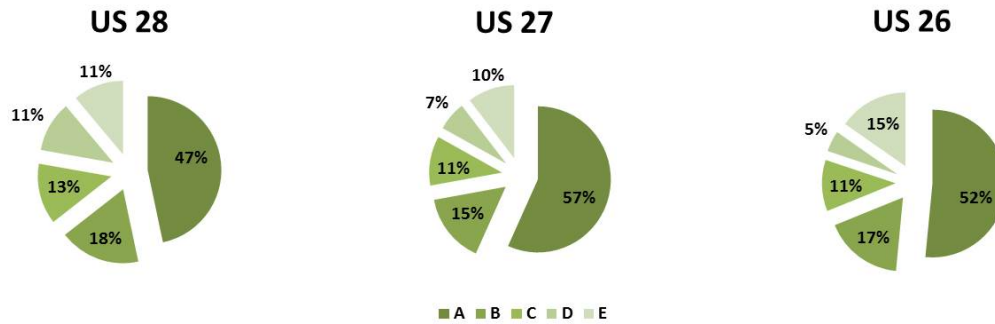


Fig. 7 : Aspect des phytolithes pour les US 28, 27 et 26 d'après Vrydaghs et Devos (in press).

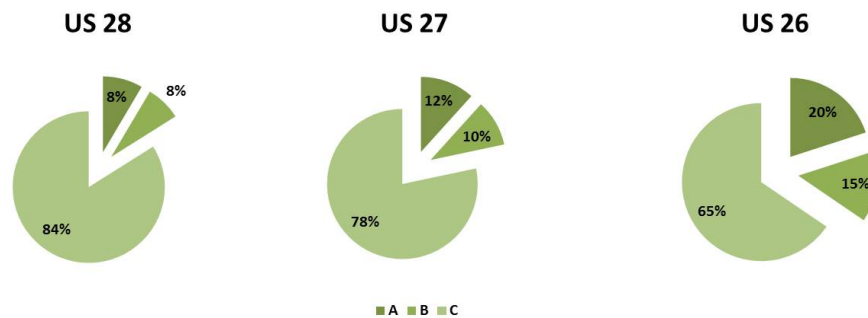


Fig. 8 : Aspect des diatomées pour les US 28,27 et 26.

Outre le fait que le support d'étude (lames mince de sols) n'est pas un obstacle à l'étude des phytolithes, l'étude de faisabilité suggère :

- Les conditions de préservation chimique des phytolithes et, plus largement de l'opale d'origine biologique, sont favorables ;
- la Visibilité des phytolithes et des diatomées de l'US 26 se démarque de celle des US 27 et 28
- une tendance vers une plus grande visibilité (phytolithes et diatomées) paraît se marquer de l'US 28 à l'US 26 ;
- si l'aspect des phytolithes ne varierait pas significativement pour les 3 US, celle des diatomées irait en s'améliorant, l'US 26 attestant de la meilleure préservation physique des diatomées.

3.3 Approche intégrée

3.3.1 Les modèles de distribution

Des données actuellement récoltées, il apparaît que pour chaque US la distribution isolée est la plus fréquente et capture la plus grande part des phytolithes observés pour chaque US (Fig. 4).

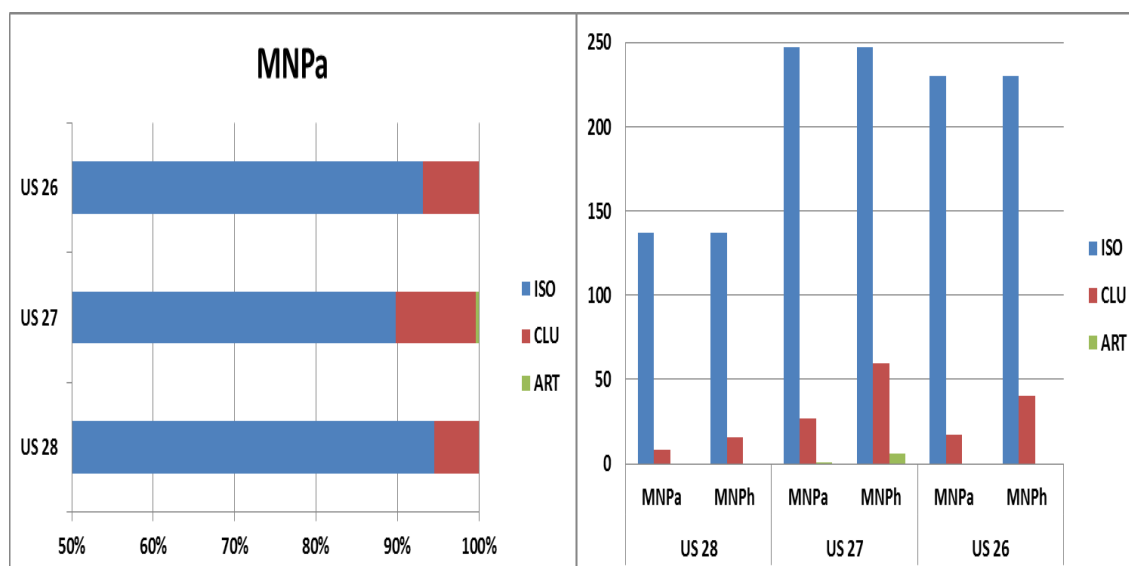


Fig. 4 : Fréquences relatives des modèle de distribution pour chaque US étudiée et MNPh par modèle de distribution pour chaque US étudiée. La figure de droite détaille les valeurs absolues des observations.

L'observation de phytolithes isolés résulte soit :

- de la désarticulation d'un matériel précédemment articulé suite à des perturbations post-dépôtionnelles. Dans ce cas, l'origine de ce matériel est locale;
- de l'incorporation d'un matériel intrusif en relation à des phénomènes tels que dépôts éoliens, érosion-sédimentation, décomposition d'un matériel coprolithique, etc. (Vrydaghs et al. 2016).

Les observations conduites suggèrent que le matériel phytolitharien des US 26 et 27 a été affecté par de fortes perturbations post-dépôtionnelles. L'observation de phytolithes isolés et en clusters (Fig. 4) (Vrydaghs et al. 2016) ainsi que l'aspect des phytolithes au sein de ces mêmes clusters (voir point 3.3.1 et Fig. 13) tendent à l'établir.

Il est également relevé que les populations de phytolithes observées pour les 2 unités de terres noires (US 27 et 28) sont plus importantes que celle relevées pour l'horizon de transition.

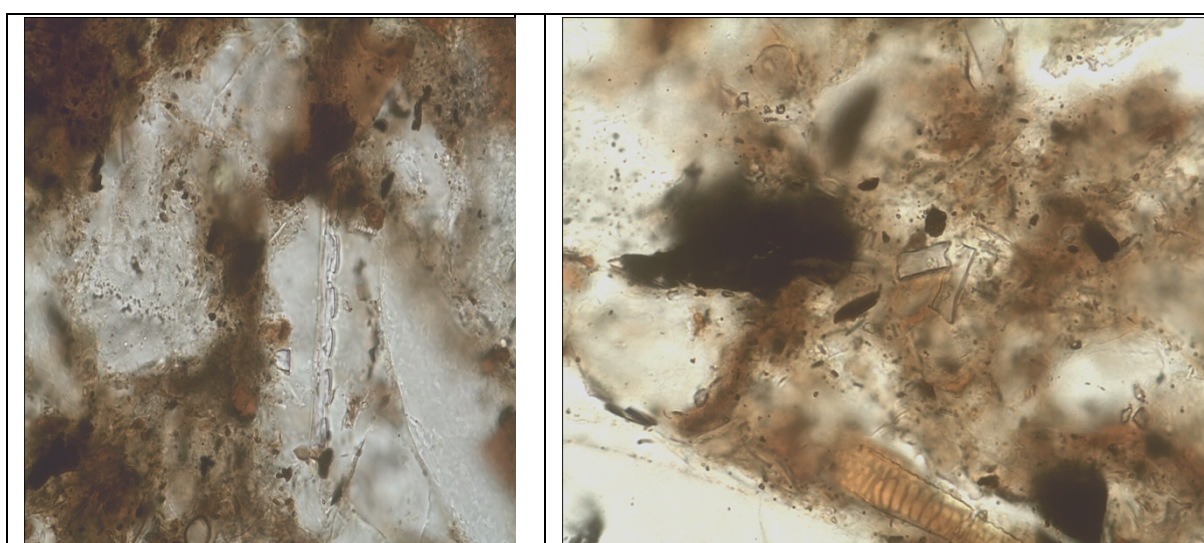


Fig. 9 : Distribution isolée d'un CRENATE (image de gauche. US 28) et en cluster de deux phytolithes non identifiés (image de droite. US 27) (x400, PPL).

L'unique système articulé observé à ce jour l'a été pour l'US 27. Il se compose de 6 ELONGATE ENTIRE, phytolithes à valeur taxonomique faible. Néanmoins, elle documente la décomposition *in situ* d'un fragment de feuille, en l'occurrence de graminée. Cette observation paraît répondre à la suggestion d'un processus de décomposition *in situ* à la suite de l'observation de fragments d'organe et tissus chargés en phytolithes.

3.3.2

Les assemblages

Un premier niveau d'analyse intégrée range les phytolithes sous 3 grandes catégories : ELONGATE (ELO) (Fig. 10), Grass Silica Short Cell (GSSCP) (Fig. 11) et NON IDENTIFIÉ (NI) (Figure 9). Cette dernière catégorie caractérise plus nettement la distribution en cluster (US 28 : 60% ; US 27 : 65% ; US 26 : 63%) tout en demeurant conséquente pour la distribution isolée (US 28 : 52% ; US 27 : 39% ; US 26 : 38%). Cependant, comparée aux clusters, la distribution isolée se caractérise par une plus grande fréquence des ELONGATE (US 28 : 52% ; US 27 : 36% ; US 26 : 37%) et des GSSCP (US 28 : 20% ; US 27 : 25% ; US 26 : 25%) (Figure 12).

Classiquement, les analyses des phytolithes discernent les phytolithes inconnus (« unknown ») de ceux mal préservés (« unidentifiable ») (Zuro et al. 2016). En lame mince de sol, le volet « unidentifiable » recouvre une plus large palette de cas. Outre l'aspect (qui est relatif à la préservation selon Zuro et al. (*ibid.*)), visibilité et/ou orientation des phytolithes rendent également compte du défaut d'identification morphologique des phytolithes. Il sera également précisé que notre notion de non identifié ne reprend pas les phytolithes reconnus comme « non classical » par le mémoire de Master de R. Hermans⁴⁹

Pour l'heure, en lame mince de sol, seule une occurrence de « unknown » phytolithe est à rapporter. Elle concerne l'US 26.

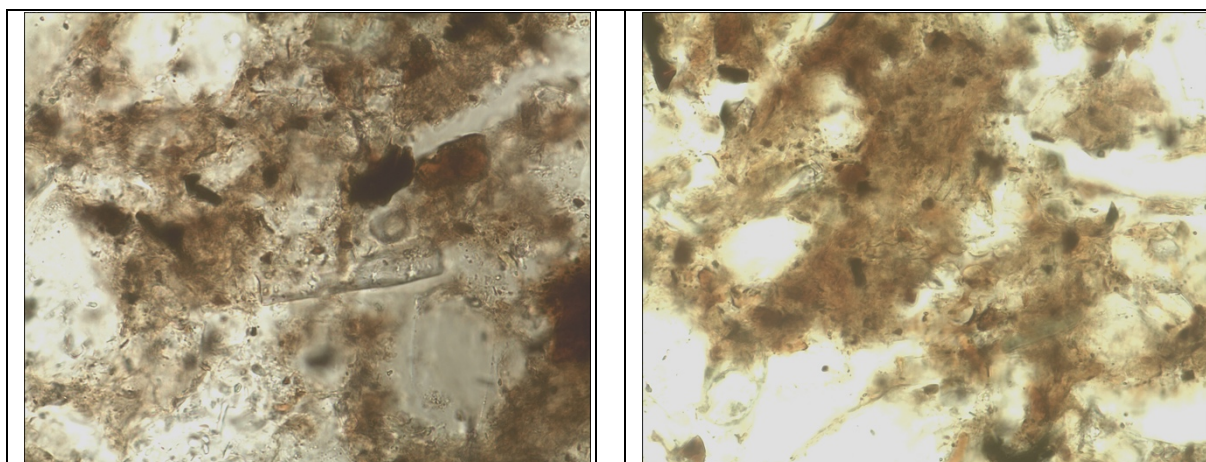


Fig. 10 : ELONGATE ENTIRE (image de gauche) et ELONGATE DENTATE (image de droite). (US 27_x400_PPL).

⁴⁹ Il sera ajouté que ces « non classical phytoliths » s'observent bien en lames minces des US 26 et 28 mais dans des proportions réduites

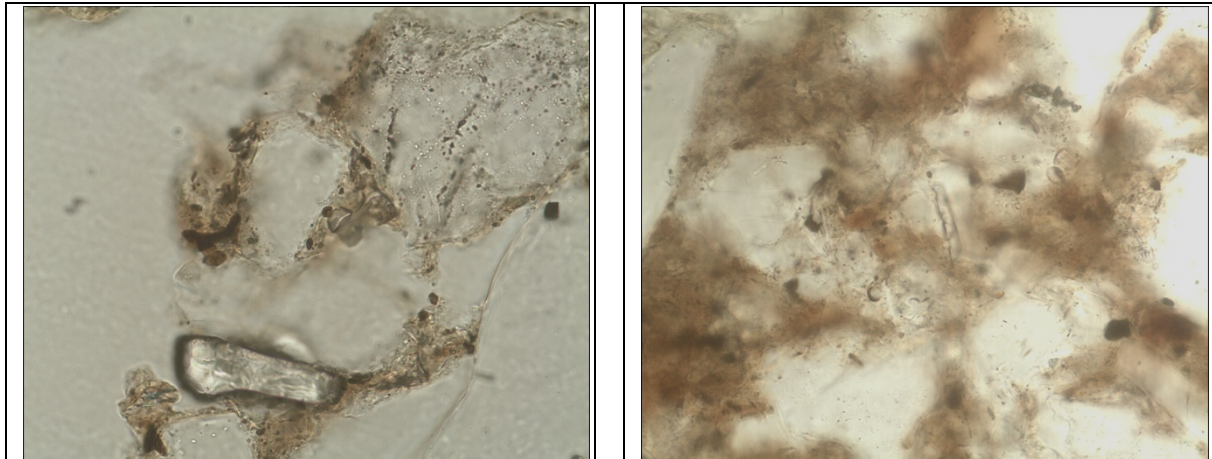


Fig. 11 : BILOBATE (image de gauche) et CRENATE (image de droite). (US 27_x400_PPL).

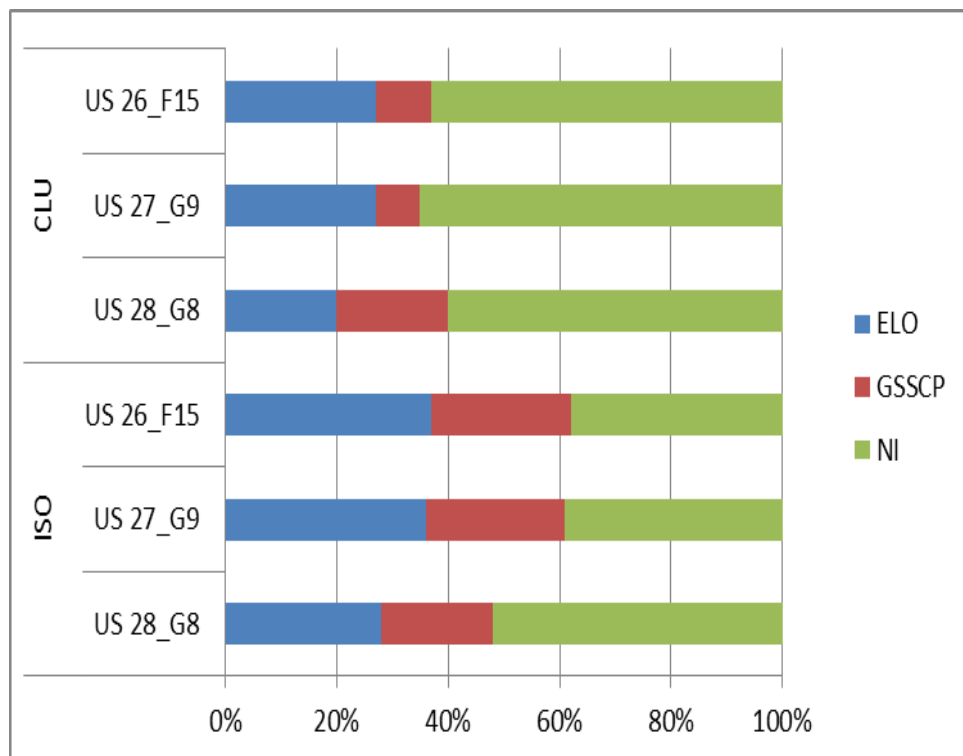


Fig. 12 : Fréquences relatives des 3 grandes catégories morphologiques (ELONGATE, GSSCP et Non Identifié) pour chaque modèle de distribution pour chacune des US étudiées.

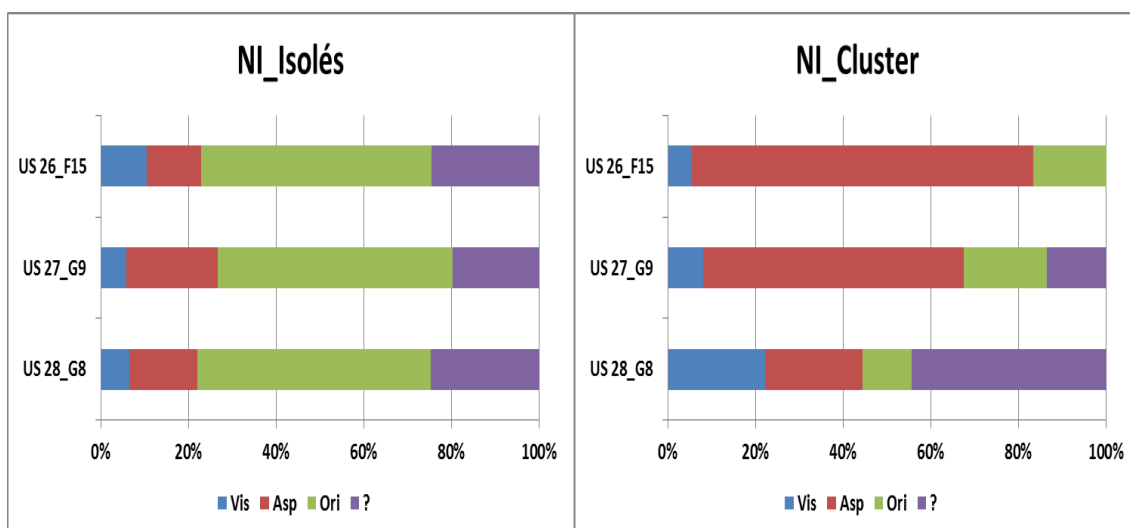


Fig 13 : Proportions des cas simples de phytolithes isolés et en cluster pour lesquels il n'a pas été possible de présenter une identification morphologique. Vis : visibilité ; Asp : Aspect ; Ori : orientation ; ? : sans explication.

La Fig. 13 détaille les cas simples de phytolithes isolés et en cluster pour lesquels il n'a pas été possible de présenter une identification morphologique⁵⁰. Pour les phytolithes isolés, nettement, l'orientation des phytolithes rend le plus fréquemment compte du défaut d'identification morphologique. Pour les clusters, le compte rendu diffère selon l'US considérée. Pour l'horizon de transition (US 28), ni Visibilité, ni Aspect ou orientation ne sont prépondérants, les pourcentages respectifs de Visibilité et Aspect étant équivalents (22,22%). Par contre pour les 2 unités de terres noires (US 26 et 27), l'Aspect des phytolithes domine avec respectivement 59,46% des cas pour l'US 27 et 77,79% pour l'US 26. Il paraît raisonnable d'attribuer ces différences aux perturbations physiques à l'origine de la formation des clusters qui par voie de conséquences induiraient des altérations physiques des phytolithes.

3.3.3 Distribution isolée

Les ELONGATE isolés se distribuent en 3 morphotypes, les ELONGATE ENTIRE (ELO_ENT) (Fig. 10), ELONGATE DENDRITIC/DENTATE (ELO_DEN/DET) (Fig. 10) et les ELONGATE SINUOUS (ELO_SIN). Les GSSCP reprennent les RONDEL (RON), BILOBATE (BIL) (Fig. 11), TRAPEZOID (TRZ) et CRENATE (CRE) (Figs. 9 et 11). Quelques ACUTE BULBOSUS s'observent également (ICPT (Neumann et al.) in press).

De nettes tendances sont suggérées pour les ELONGATE et les GSSCP (Fig. 14). Si la fréquence des ELONGATE ENTIRE (ELO_ENT) paraît comparable pour les 3 US étudiées, celle des ELONGATE DENDRITIC/DENTATE (ELO_DEN/DET) demeure stable avec les US 27 et 28 (US 28 : 18,75%; US 27 : 18,66%) pour décroître légèrement avec l'US 26 (15,15%). Simultanément, les US 27 et 26 enregistrent

- l'apparition des ELONGATE SINUATE (ELO_SIN)
- une diminution des pourcentages de RONDELS (RON) et CRENATE (CRE) ;
- une augmentation des pourcentages de TRAPEZOID (TRZ) (Fig. 14).

Un continuum morphologique existe entre les ELONGATE DENTATE et les ELONGATE DENDRITIC ; impliquant que selon le contexte, ils peuvent s'assimiler pour identifier du matériel phytolitharien dérivant des céréales (ICPT (Neumann et al.) in press). C'est la position qui pour l'heure est adoptée. Elle implique que la représentation des céréales est largement comparable pour les US 27 et 28 et légèrement moins marquée avec l'US 26 (Fig. 14).

⁵⁰ Par cas simples, il est entendu les cas où visibilité, aspect et/ou orientation ne se combinent pas pour handicaper l'identification morphologique.

Les RONDEL sont un morphotype redondant pour toutes les sous-familles de Poaceae. Par suite l'usage qui les assimile à des marqueurs de la sous-famille de Pooideae implique la prise en compte du contexte (ICPT (Neumann et al.) in press) qui, ici, ne pose pas problème, d'autant que CRENATE et TRAPZOID, 2 autres marqueurs de la sous-famille des Pooideae, s'enregistrent. De plus, bonne part des céréales cultivées relèvent de cette même sous-famille.

Les variations simultanées de plusieurs morphotypes (Fig. 14) interpellent. Se pourrait-il qu'elles résultent de modifications de la couverture végétale et/ou de variations dans la représentation d'organes? D'après le matériel étudié par Brown (1984), les RONDEL se forment dans les feuilles et les tiges, les CRENATE dans les feuilles, et les TRAPEZOID, dans tous les organes des Poaceae. Mais avant d'en avancer quelque interprétation que ce soit, il est requis de mieux les documenter afin de vérifier si ces tendances se confirment.

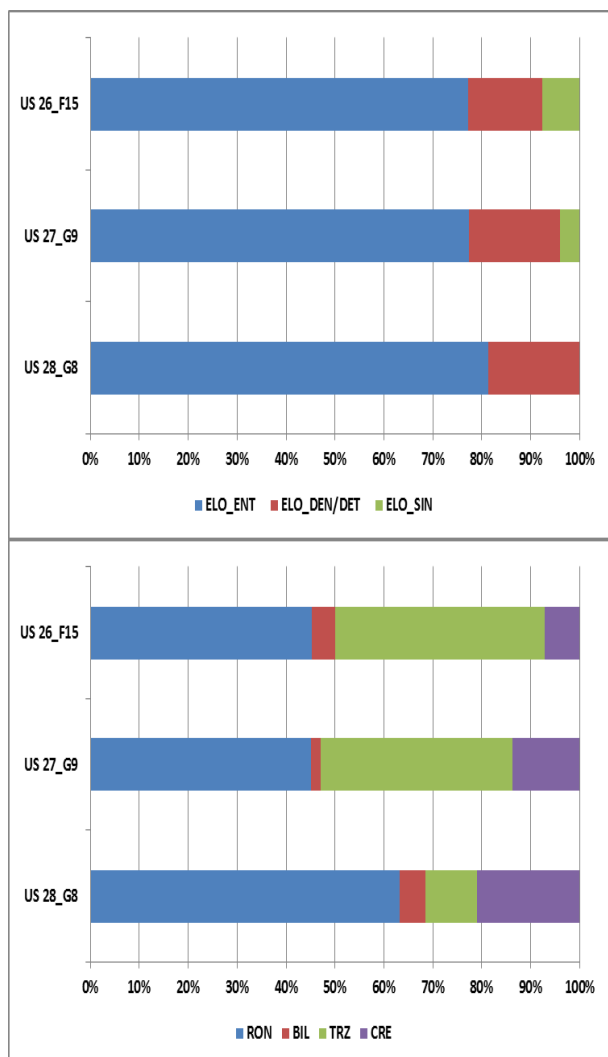


Fig. 14 : Composition des assemblages d'ELONGATE et de GSSCP isolés pour les US 26, 27 et 28. ELO_ENT : ELONGATE ENTIRE ; ELO_DEN/DET : ELONGATE DENDRITIC/DENTATE ; ELO-SIN : ELONGATE SINUOUS ; RON : RONDEL ; BIL : BILOBATE ; TRZ : TRAPEZOID ; CRE : CRENATE.

3.3.4 Distribution en Cluster

Les populations de phytolithes des Clusters morphologiquement identifiés étant par trop restreintes pour être fiables (elles se composent respectivement de 4 (US 28), 17 (US 27) et 8 (US 28) phytolithes), ces assemblages en peuvent pas être discutés.

4. Conclusions et perspectives

Les US 26, 27 et 28 du site de la Rue des Boîteux/Rue d'Argent (BR 295) ont été soumis à des analyses de phytolithes en lames mince de sol. A ce jour, seul un carré de 5x5 mm de côté par US a été analysé. Par la suite, l'ensemble des résultats obtenus à ce jour ne sont pas définitifs. Il est néanmoins clairement établi que l'ensemble des phytolithes observés ne partagent pas la même taphonomie, des phytolithes s'observant dans fragment de tissus et d'organes végétaux, des excréments et la matrice du sol pour les US 26 et 27.

L'étude de faisabilité établi que :

- la Visibilité des phytolithes et des diatomées de l'US 26 se démarque de celle des US 27 et 28
- une tendance vers une plus grande visibilité (phytolithes et diatomées) paraît se marquer de l'US 28 à l'US 26. Cette croissance s'imputerait à l'oxydation de la matière organique ;
- si l'aspect des phytolithes ne varierait pas significativement pour les 3 US, celle des diatomées irait en s'améliorant, l'US 26 attestant de la meilleure préservation physique des diatomées. Phytolithes et des diatomées n'attestent donc pas d'un parallélisme d'aspect comparable à celui de leur visibilité.

L'analyse intégrée du contenu en phytolithe de la matrice du sol, elle suggère :

- à la suite de la nette prévalence de la distribution Isolée, de fortes perturbations post-dépositionnelles sont suggérées. Les MNPh étant plus importants pour les US 26 et 27, il ne peut être exclus que ces perturbations sont en fait liées à des activités anthropiques. L'aspect des phytolithes composant les clusters de ces 2 US et l'absence de phytolithes au sein des restes excrémentiels ne viendrait pas contredire pas cette option.
- dans leur ensemble, les phytolithes isolés attestent d'une signature graminéennes avec une présence de graminée cultivées. Cependant, selon l'US et le modèle de distribution considéré, l'inventaire des phytolithes attestant de cette présence varie

La poursuite des analyses devrait infirmer ou confirmer les tendances établies et, espérons-le, apporté des données afin de rendre compte des variations observées.

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