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An Analysis of Microremains from the Dental Calculus of Individuals at the Late Iron Age Inhumation Cemetery at Kukruse, Estonia

MA thesis

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Contents

Introduction

The importance of food cannot be understated; therefore, it needs to be understood. In order to understand ancient foodways, new methods need to be used. These new methods need time to be refined and made to work. In this thesis, I will be studying ancient dental calculus from the individuals buried at Kukruse Late Iron Age burial site in Estonia, with the hopes to better understand these individuals' diets and environment.

Microremains from dental calculus have not yet been analysed on this scale in Estonia. With the exception of the author's bachelor's thesis (Unt 2021), where the dental calculus of two Medieval individuals were analyised, the method is underutilised. While dietary studies are commonplace in the Estonian archaeological discourse, the hunt for evidence of plant consumption in dietary studies continues. Plant macroremains are not commonly gathered during archaeological excavations and soil sampling is not a standard practice as of yet. The more established analytical methods of dietary studies in Estonia are lipid residue analysis of pottery food crust and ceramic matrix, as well as stable isotope analysis, of which only the latter is obtained directly from the individual's skeletal remains. These methods have their strengths and weaknesses – one being that isotope analysis leads to mainly proteins being found, and the lipid analysis finds, as is evident from the name name, lipids. Microremains analysis from dental calculus provides an opportunity to complement other studies, with a special focus on detecting plant consumption. Elsewhere in the world, dental calculus analysis is a widely used method for understanding the diet and environment of ancient peoples. Dental calculus occurs commonly on skeletal remains, and, depending on the time and place of the burial, it can be quite abundant. Therefore, the method, although destructive, leaves material for future researchers.

Humans need to put in time and effort to grow or acquire food. Food is impacted by the environment – plants and animals flourish in climates and environments best suited to them. To understand what people ate, we must understand the larger context of the local environment: landscapes, soils, weather conditions, the climate, availability of clean drinking water, etc. Humans get most of their needed calories by consuming plants, animals and, to a lesser extent, fungi. Therefore, it is fitting to consider all of these categories when looking into the lives of ancient people through dental calculus analysis. A comprehensive reference collection of microremains is used for the analysis of dental calculus and it should aim to consider entire ancient environments. It ought to be a purpose-built reference collection, made to answer questions related to the period of time and place. (MacKenzie et al. 2021: 4) It should consist of microremains that are a part of living nature as well as the not-living nature. In addition, plants, animals (and even fungi) provide humans with construction materials, nutrients, medicine, fuel and studying them can teach us about economics, practices and culture. (Vanhanen 2019: 4)

The foodways of prehistoric Estonia have been studied with different methods. Some archaeological studies have concentrated on animal bones (Maldre 2008; Rannamäe 2015, Ehrlich 2022) some on plant macrofossils (Tammet 1988; Sillasoo 1989; Sillasoo 1995; Sillasoo and Hiie 2007; Tvauri and Vanhanen 2016; Vanhanen et al. 2023). Archaeochemical analyses have included lipids (Oras et al. 2016a; 2017; 2018; Chen et al. 2023), isotopes from bone collagen (Lightfoot et al. 2016; Oras et al. 2016b; Tõrv 2016; Aguraiuja-Lätti and Lõugas 2019; Ilves 2023), works also combine methods (Chen et al. 2023; Niinesalu-Moon et al. 2023). Archaeological studies are complemented by ethnographical parallels (Moora 1980; Viires and Vunder 1998; Kalle and Sõukand 2012; Kalle and Sõukand 2013; Bardone 2013; Kaljuste et al. 2016). Medieval written sources provide valuable insights into ancient foodways as well (e.g. Põltsam 2002; Sillasoo and Hiie 2007).

Clearly, foodways have not escaped the attention of Estonian archaeologists. In the hopes to add to this heap of information, I will be studying ten burials from Kukruse, a burial site in northern Estonia, dated to the 12th and 13th centuries. It should be noted that dental calculus studies are best suited for studying large numbers of individuals as on a smaller scale data may be inaccurate. The deposition of debris to dental calculus as well as the formation of calculus differs per individual (see for example Leonard et al. 2015: 456). For this reason, I believe ten burials (in 35 samples) to be a representative selection, as the chosen individuals have been studied before (Oras et al. 2018).

In this thesis, the following **methodological aims** are posed:

1. To establish and to set in motion the correct utilisation of the clean laboratory at the University of Tartu for dental calculus analysis.
2. To create a dental calculus extraction method best suited for the facilities at the University of Tartu archaeobotanical clean laboratory.
3. To contribute to, analyse, arrange and methodically grow the archaeobotanical reference collection at the University of Tartu.

The following **research aims** are posed:

1. To methodically obtain and analyse the microremains from Kukruse individuals' dental calculus whilst using the reference collection to help with identification.
2. To contextualise the results – what can the results tell us about the foodways and the environment of individuals buried at Kukruse?

The wider methodological and research aims lead to the more specific research **hypotheses** that will be tackled in the thesis: 'Dental calculus analysis can detect more plant matter than the previous studies done on Kukruse.' and 'It is possible to reach a tribe level with the identification of the microremains'.

These aims will be achieved by cleaning, mounting and analysing dental calculus with a polarising light microscope Olympus BX51. Work with a reference collection will be done in tandem. I expect to find plant matter, and, hopefully starch granules that can be identified to a taxon. In addition, fibres, wood debris, and fungal matter will likely be encountered. I fully expect to find microremains that I cannot identify and I will record these as such.

The thesis is divided into five chapters. In the first chapter, I will give an overview of current trends in ancient dietary research as well as common microremains found in dental calculus. In the second chapter, Kukruse burial site will be introduced as well as Late Iron Age foodways in Estonia: cultivated, gathered and imported plants as well as weeds are introduced. The third chapter is on methodology; the fourth outlines the results of the laboratory work. The fifth and final chapter will discuss the broader meanings of the results. This is followed by the summary, references, the résumé in Estonian and the appendix.

In my thesis, I will be using various terms that need to be clarified. These are listed here.

Foodways – not just the food that was eaten, but also what could have been done with it before consuming it, how was it cooked, stored and what is its origin. Foodways can even encompass the meaning behind certain foods, although this is not discussed in the thesis as the method used cannot answer this.

Foodstuffs – a substance suitable for eating as food.

Triticeae – a botanical tribe consisting of wheat, barley and rye genera, in addition to other species.

Fabaceae – a botanical family, which produce legumes as fruits, e.g. pea (*Pisum sativum*) and the Genus *Vicia*.

Avena – a botanical genus, known commonly as 'oats', e.g. oat (*Avena sativa*).

Plant macroremains – remains of plant parts visible to the unassisted eye, e.g. seeds, leaves, stems, roots. These are commonly encountered as charred remains; or, in extreme conditions like waterlogged or severely dry contexts.

Microremains – remains in fragments that are too small to see with the unassisted eye. In this thesist, this means matter that may be identified to a botanical kingdom, or if not, then categorised as unidentified debris. Synonyms: microdebris, microparticles.

I used Chat GPT 3.5 to improve my English when writing. In addition, I used it to rephrase some ideas from original texts to fit them into my work. Chat GPT also proved helpful when I had a lot of information from different sources, I used it to combine information. All of its work was checked and adjusted to make sure no errors occurred. I have promptly referenced to it in places where I have used it. I used Bing AI to search for information and to educate myself on topics I needed references for. For improving my English, I also used Grammarly.

I want to thank my supervisors Kristiina Johanson and Anita Radini for their guidance, help and kind words whilst helping me discover the world of microremains. In addition, I want to thank Linda Vilumets for helping identify the teeth, Marge Konsa, Mairi

Kaseorg, Sandra Sammler and the whole of the Archemy for their unwavering support. I am forever grateful!

1. Studying Ancient Foodways

1.1. Methods Used in Archaeology for Studying Ancient Foodways

Archaeological remains found on the larger scale are easier to find and preserve. Such remains include **archaeobotanical macroremains** and **faunal remains**, which serve as valuable resources for studying ancient foodways. **Finds** associated with the preparation or consumption of food are also significant, for example in the studies of archaeological cutlery (see for example Symonds et al. 2002; Barkai et al. 2010;) or specific types of vessels (Yasur-Landau 2005). Additionally, **written sources, historical images** and ethnographical parallels can provide helpful supporting information in archaeological research when relevant info is available (see for example Põltsam 2002). In the recent years, microremains, including organic residues, have been analysed for the study of ancient foodways. Archaeologists study foodways using different methods, for example osteoarchaeological methods of animal and human bones, chemical analyses of bones and pottery food crust. All of the methods posess their pros and cons, so combining methods is usually a good practise.

Samples of **archaeobotanical macroremains** can be obtained by looking carefully through the soil when excavating. Samples can be taken from gut contents, coprolites or from the soil. For the latter, a floatation method and sieves with small mesh sizes are fitting for extracting archaeobotanical macroremains when in the field. (Holden 1991; Nesbitt 2006)

In Estonia, archaeobotanical macroremains have been mainly studied from Medieval and Early Modern (13^{th}–15^{th}/16^{th} centuries) cesspits. These exhibit a suitable environment for the preservation of organic material and therefore it is possible to identify the species of the plants found. (Sillasoo 2001: 8; Haak and Russow 2012) Specialised studies of plant macroremains have been made on Finland (Vanhanen 2019, e.g. pg 30; Lempiäinen-Avci et al. 2021) and Northern Europe in general (Vanhanen and Lagerås 2020). In their overview article Grikpėdis and Matuzeviciute (2020: 161) discuss the cultivated plants of the Eastern Baltic region from the first plant remains to appear in archaeological record in the 3^{rd} millennium BC up until the 13^{th}–14^{th} centuries AD. In case no archaeobotanical microremains can be found, **impressions on ceramics** have also been studied (see for example McClatchie and Fuller 2016). In Estonia, grain impressions on ceramics from Asva and Iru prehistoric sites were found (Sillasoo and Hiie 2007: 73)

Zooarchaeological analyses can give insight into which animals were used by humans and thereby answer questions about foodways. Animals were kept for food, transportation, materials and for labour. Animals lived mostly outside. By tooth wear analysis, it has been deducted that the cattle (*Bos taurus*) and horses (*Equus caballus*) on the Late Iron Age Pähklimägi ate alder- (genus *Aldus*) and birch (genus *Betula*) branches as well as rye (*Secale cerale*) stems. (Kriiska et al. 2020: 383) An overview of Estonia's zooarchaeological research can be found in Lõugas and Rannamäe (2020). Faunal remains have been studied from multiple Iron Age and Medieval sites (e.g. Maldre 2007, 2008; Rannamäe 2015). A recent doctoral thesis was defended at the University of Tartu on birds in Estonian archaeology (Ehrlich 2022).

Osteoarchaeological analysis of human bones can help with diet reconstruction. For example, pathologies such as scurvy, rickets and iron deficiencies can be detected on human bones (Ortner 2011). **Dental pathologies** can shed light on ancient diet – dental caries is often associated with high rates of carbohydrate consumption (Koca et al. 2006: 216) Teeth were also used as a 'third hand' – helpful for assisting in everyday activities, this can be seen already in Neanderthals (Estalrrich and Rosas 2015: 51). This practice could potentially create some confusion on the interpretation of the microremains. This will be further discussed in Chapter 5. Teeth can be analysed for **macro- and microwear** to gather an understanding of foodways – the wear of teeth is significant of diet and the use of teeth in everyday life (Walker et al. 1978; Teaford 1994: 17; Mahajan 2019: 1). Microwear can give insight into plant consumption or the physical properties of plants eaten (Leonard et al. 2015: 449).

Food crust from pottery and bone collagen can be sampled for the application of different modern analytical techniques that can help address archaeological questions on molecular and elemental levels, such is for example **organic residue analysis** (ORA). An aspect of ORA involves the extraction and analysis of lipid residues found from various archaeological records such as pottery. The lipids can be extracted and analysed using different analytical techniques such as gas chromatography-mass spectrometry (GC-MS), elemental analyser-isotope ratio mass spectrometry (EA-IRMS) and gas chromatography-combustion-isotope ratio mass spectrometry (GC-c-IRMS). It is possible to trace the origins of these lipid molecules to different commodities such as animal fats (either from terrestrial or aquatic sources), plant oils and waxes, beeswax, resins and tars.

This is often combined with stable isotope analysis at bulk or compound-specific level. EA-IRMS can measure the average isotope values of carbon $\delta(^{13}C)$ and nitrogen $\delta(^{15}N)$ from food crust and bone collagen samples. GC-c-IRMS can separate molecules and measure the isotope values of targeted elements from isolated molecules. The combination of molecular analysis with stable isotope analyses can further differentiate the origins of lipid residues, such as non-ruminant animal fat, ruminant animal adipose fat, ruminant animal dairy fat, marine fish oil, freshwater fish oil, plant oils from C3 and C4 crops. (Oras et al. 2016a, 2017, 2018) In light of plant use, $\delta^{13}C$ values give insight into processes associated with photosynthesis – this means it is possible to differentiate C3 and C4 plants (see more in O'Leary 1981; Furbank and Taylor 1995). Piezonka et al. (2016) used EA-IRMS and found aquatic biomarkers from the food crust of North European Stone Age pottery. Chen et al. (2023) gave insight into plant usage at the Pre-Viking Age Pada hillfort by way of food crust analysis. They found C3 plants from both lipid biomarkers and by analysing microremains from food crust. Sammler (2020) carried out a study on macrobotanical plant remains from the Iru settlement site with EA-IRMS, finding that some plants were most likely fertilised. EA-IRMS method from human bone collagen was used by Tõrv (2016) to find information about the Estonian Stone Age hunter gatherers' foodways; Lightfoot et al. (2016) and Aguraiuja-Lätti and Lõugas (2019) analysed the eating habits of the inhabitants of Tallinn.

It is said that combining microfossil analysis with other methods should be standard practice in archaeological analysis. (García-Granero et al. 2015; Leonard et al. 2015) These multi-proxy works can enhance the quality of studies and provide a wider understanding of cultures, historical environments, ancient people's health, and behaviours. (Juhola et al. 2019).

1.2. What is Dental Calculus?

Dental calculus is a complex mineralised matrix found on teeth, made up of organic and inorganic components (Lieverse 1999: 219–220). Dental calculus contains microremains of what was eaten and what the mouth came in contact with, and even pathogens found in the mouth (Fox et al. 1996; Hardy et al. 2012, 2016; Warinner et al. 2014; Cummings et al. 2018; Fiorin et al. 2019; Radini et al. 2019; MacKenzie et al. 2021). Dental calculus forms differently in individuals, some having more, some less. The reasons for this are not well understood, it is thought to be a mixture of genetic, dietary and other factors. (Hillson 2005: 289)

Dental calculus formation begins when plaque fluid covers the teeth. This fluid is quickly colonised by microorganisms present in the mouth; the mineralisation begins soon after the colonisation event. (Lieverse 1990: 220–221). It is not known what triggers the mineralisation of the plaque fluid, however, the first parts to mineralise are the cell walls of the bacteria living in the mouth. Following this, a matrix begins to form. Oftentimes, dental calculus will be found in areas of the mouth near the salivary glands – in humans, the largest deposits can be found near the buccal surfaces of upper molars, the lingual surfaces of incisors and canines, decreasing towards the third molars. (Parfitt 1960: 200–203; Hillson 2005: 288–289) Calculus is also found where it is protected from mechanical friction, for example inbetween two teeth. (Marcotte and Lavoie 1998: 73; Jin and Yip 2002: 426; Hillson 2005: 288–289; Weyrich et al. 2015: 119; Radini et al. 2017: 72). Main microbial organisms making up supra- and subgingival dental calculus are *Actinomyes* spp. and *streptococci* (Marcotte and Lavoie 1998: 73; Jin and Yip 2002: 426; Weyrich et al. 2015: 119; Radini et al. 2017: 72). The exact microbial composition of dental plaque is not the same for every individual and varies within a specific individual's mouth, depending on the site of the deposition (Marcotte and Lavoie 1998: 73; Jin and Yip 2002; Hillson 2005: 288–289). In addition to all the microorganisms and minerals, dental calculus contains cells from the mouth's oral mucosa lining that have been shed (Hillson 2005: 290).[1]

From the vantage point of archaeologists, dental calculus can therefore contain microremains of what was eaten or what the mouth came into contact with. Geneticists have tried to help us with understanding what was eaten, as dental calculus can contain aDNA (Hillson 2005: 290). Preus et al. (2011) extracted aDNA of bacteria from dental calculus and Mann et al. (2020) tried to distinguish plants and animals that could have been eaten through the analysis of aDNA from human dental calculus, but found that high genetic similarity within eukaryotic groups such as mammals did not allow for exact taxonomic identification.

It should also be noted that dental caries and periodontal diseases develop due to the microorganisms of dental plaque (Marcotte and Lavoie 1998: 75). Dental calculus can be decreased or increased by non-dietary factors such as chewing some plants, using teeth as a third hand taking care of one's oral hygiene. The fact that abrasive chewing could increase dental calculus is true for South Americans chewing coca leaves which were commonly chewed with lime – this in turn contains calcium oxide and adds substantial amounts of minerals, increasing calculus formation (Klepinger et al. 1977: 506; Lieverse 1999: 230). If teeth are regularly cleaned and/or if teeth are used as a third hand in a way

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[1] Chat GPT 3.5 helped with wording for this sentence. In this instance I will explain how I used it. I will not go into such detail further in the text. In places where Chat GPT or another language model was used, a footnote will say: 'Chat GPT 3.5 was used to help with wording/paraphrasing/other'.

I gave it a prompt to rephrase Simon Hillson's sentence 'Also incorporated into the calculus are shed cells from the oral mucosa lining in the mouth', which I rephrased as 'Dental calculus also contains shed cells from the oral mucosa lining in the mouth.' The first try at rephrasing gave the sentence: 'Dental calculus includes cells that have been sloughed off from the lining of the oral mucosa within the mouth', which did not sound formal enough. The second try with my prompt 'rephrase it for my master's thesis, so, more formally', it rephrased it so: 'Dental calculus comprises exfoliated cells originating from the oral mucosal lining within the buccal cavity.' As we can see, GPT added 'buccal cavity', a part not present in the original line. In addition, this last sentence was far too formal in my opinion, and thus I reworded it, making the sentence stand here as: 'In addition, dental calculus contains cells from the mouth's oral mucosa lining that have been shed.'

that can mechanically remove dental calculus, the calculus cannot form. (Lieverse 1999: 229)

1.3. Microremains From Dental Calculus as a Means of Studying Ancient Foodways and Environment

In this chapter, I will give an overview on the history of dental calculus analysis and introduce the main microremains that can be found, i.e. what I am looking for from dental calculus – starch granules, phytoliths, calcium oxalate crystals, pollen granules, fungal debris and other microremains.

1.3.1. An Overview

Dental calculus can contain organic and inorganic materials from the environment and food. It can give insight into what was eaten by studying plant microremains such as phytoliths, starch granules, calcium oxalates, other plant parts, fungal matter and animal remains that is trapped inside the calculus. Dental calculus can shed light on what could have been inhaled or accidentally consumed, originating from the environment: spores, pollen, charcoal, wood, fibres, etc. (Hardy et al. 2009, 2012, 2016; Tromp and Dudgeon 2015; Leonard et al. 2015: 450; Radini et al. 2017: 73–78; Zhang et al. 2017; Cummings et al. 2018) This is possible because the calculus provides a safe environment for microremains as they are sealed off. For example, starch can survive in dental calculus for thousands of years (Piperno et al. 2004; Henry et al. 2011; Power et al. 2015).

One of the first to study the contents of dental calculus with an eye for understanding foodways was Philip Armitage, he identified plant microremains and phytoliths from soil in the dental calculus of cattle (Armitage 1975: 187). Keith Dobney and Don Brothwell came up with a method for evaluating the amount of dental calculus on teeth from archaeological sites (1987) and analysed the contents of dental calculus using a scanning-electron microscope (SEM) the following year (1988). Their revolutionary work is the basis of dental calculus analyses that were to come.

Since then, dental calculus has been used for studying foodways all over the world. Dental calculus is a resource that is quite abundant in many archaeological contexts. To test the applicability and effectiveness of studying microremains from dental calculus, an experiment was carried out with the help of forager-horticulturalists, the Twe people (Leonard et al. 2015). For the study, the most common plant foods of the Twe were documented and the corresponding plants studied. Dental calculus was sampled from the bucco-mesial surface of the bottom left canines. (Leonard et al. 2015: 450–452) As the women of Twe people make palm leaf baskets and chew the leaves to soften the fibres, Leonard et al. expected to find palm leaf phytoliths in women, however, these were observed in only three samples (Leonard et al. 2015: 454). Ultimately, they found large amounts of individual variation in plant representation in dental calculus – even though the Twe eat rather similar foods, samples did not share all plants (Leonard et al. 2015: 454–455). They concluded that the identified starch granules and phytoliths in Twe dental calculus give an incomplete picture of Twe diet.

They believe the reasons for this are: a) not all the plants eaten by the Twe produce phytoliths and starch granules; b) many of the plants that do produce phytoliths and starch granules were not found in dental calculus; individual variation is significant. Therefore, understanding the foodways of a specific group of people works better when many samples from the same group are considered. The dental calculus method should be used in tandem with other suitable methods for studying foodways and it can answer broader questions instead of more specific ones. (Leonard et al. 2015: 455–457)

Another limitation of the dental calculus method is the fact that eating events are not distinctive within an individual's dental calculus. Examining dental calculus in layers is difficult due to the fact that dental calculus can fall off during an individual's lifetime and regrow over time. The layers of dental calculus are not strictly horizontal, but wavy, and therefore it is almost impossible to differentiate between the layers, not to mention, extract and analyse them. This complexity does not allow to attribute a single layer to a specific stage in life.[2] A study was done on how to build dental calculus *in vitro*. They found a number of interesting results, for example that large starch grains (larger than 20 microns) were underrepresented in the samples by a factor of 10. (Bartholdy et al. 2020) It is clear

[2] Chat GPT 3.5 was used to help with wording.

this topic needs much more investigation as there are biases when it comes to analysing dental calculus that we do not see with archaeological samples. As mentioned above, Leonard et al. (2015) emphasise that dental calculus analysis for starch granules and phytoliths offers little in the way of bigger picture questions regarding diet such as exploitation intensity. However, this method is suited to tell us about the presence or absence of specific plants in the diet.

So, what microremains can be found from dental calculus? I will now break down the microremains that can be found in dental calculus.

1.3.2. Starch Granules

Starch is a common dietary staple in most cultures and it can be found in almost every type of plant tissue – it is mainly found in seeds, roots and tubers, but also in leaves, stems, fruits, and pollen. (BeMiller and Whistler 2009: 84, 150) Starch is a polycarbohydrate (also known as polysaccharide) that plants produce during photosynthesis and each starch grain is made of amylose and amylopectin – two kinds of polymers of D-glucose. Amylose is a larger and a more linear molecule, whereas amylopectin is highly branched. Starch granules have a semi-crystalline structure as the two polymers (amylose and amylopectin) are arranged in alternating layers – amorphous and crystalline layers. The latter is made up of mainly glucosyl from the amylopectin polymer and it forms helices, organised into crystalline clusters. Thanks to the crystalline cluster arrangement, starch shows its characteristic birefringent 'Maltese cross' or 'extinction cross' under cross-polarised light when looked at through light microscopy. (BeMiller and Whistler 2009: 194; Hardy et al. 2009: 248; Masakuni et al. 2014: 280; Leonard et al. 2015: 450; Copeland and Hardy 2018: 1–2; Kovárník and Beneš 2018: 85)

Higher plants produce two types of starch: transitory (also known as temporary) and storage starch. Transitory starch is usually formed in the chloroplasts and is stored in the leaves as it can only be produced during the day by photosynthesis and used during the night. (BeMiller and Whistler 2009: 26; Weise et al. 2011: 3109; MacNeill et al. 2017: 4434) Transitory starch is not used in the study of ancient foodways, because firstly, it is used up quite quickly by plants and, secondly, because it has an undiagnostic shape (BeMiller and Whistler 2009: 26).

Storage starch is used by plants for storing energy for longer periods of time (MacNeill et al. 2017: 4434). For studying ancient foodways, storage starch is used due to the differences in its morphology depending on species (BeMiller and Whistler 2009: 26). The starch granule's structure, the amount and nature of lipid and protein molecules in the granules varies with the botanical source of the starch making each type of starch unique (BeMiller and Whistler 2009: 149).

Starch is great for those consuming it because can be broken down easily. Starch-rich foods are easily stored in a dry state and starch remains stable (useful for when grain needs to be stored), – apply enzymes or dilute acids to the starch grains and the crystalline structure starts to break down, the bonds between the glucose units are released. (Leonard et al. 2015: 450; Copeland and Hardy 2018: 1–2) This process begins in the mouth – human saliva contains the enzyme α-amylase which starts the process of breaking down of starch grains into sugars (Radini et al. 2017: 72).

Starch is insoluble in cold water but heating it with water to at least 60 °C begins a process known as gelatinisation. Gelatinisation breaks the molecular structure of starch making it swell, changing its rheological behaviour and, instead of the granules being separate as is the case in the natural state of starch, a gel network structure begins to form. (BeMiller and Whistler 2009: 301) The semi-crystalline structure begins to break down and the birefringent Maltese cross under cross-polarised light begins to disappear. The more starch is heated in water, the less of its original and diagnostic features remain. If stirring or mixing occurs, the extent and rate of gelatinisation may be influenced. (BeMiller and Whistler 2009: 150, 342; Hardy et al. 2009: 249; Unt 2021: 26) If gelatinised starch is allowed to cool, retrogradation can occur – this is when the molecular order of starch begins to restore. (Velde et al. 2002; BeMiller and Whistler 2009: 304; Hardy et al. 2009: 249–250) A damaged starch grain's taxon is much more difficult to determine as some of its features are lost. Depending on the grade of damage, some features might still be available that allow identification (Figure 1).

In terms of shape, bimodality is present in wheat, rye and barley starch granules, meaning the endosperms of these plants contain starch granules that come in two categories of sizes and shapes, named A- and B-type starch granules (Figure 2). The main difference lies in the size of the starch granule – A-type wheat starch is typically between sizes 28–45 μm, rarely above 50 μm; whilst B-type wheat starch is normally 2–9 μm. (BeMiller and Whistler 2009: 452, 582, 591, 607) Oats have compound starch ganules (BeMiller and Whistler, 2009: 195). Starch sizes and characteristics have been studied (Winton and Moeller 1906: 64; Evers, 1971: 157; Kukk, 1996: 38; Ao and Jane, 2007: 46–48; BeMiller and Whistler, 2009: 452, 582, 591, 607; Wrigley, Batey and Bekels 2010: 165–167; Saccomanno et al. 2017).

Figure 1. From Henry et al. (2009: 918, Fig. 1) 'Comparisons of raw and boiled starch grains showing damage to extinction crosses. (a) Wheat starch grains. Left side, raw wheat starch grain; right side, wheat starch grain boiled for 10 min. Notice there very little change to the grain under regular light, but the extinction cross is much faded and with a very wide center. (b) Mung bean starch grains. Left side, raw mung bean starch grains; right side, mung bean starch grains boiled for 10 min. Once again, the cross is faded around the outside and less distinct, though there is very little change visible under regular light. Each image is 50 μm wide.'

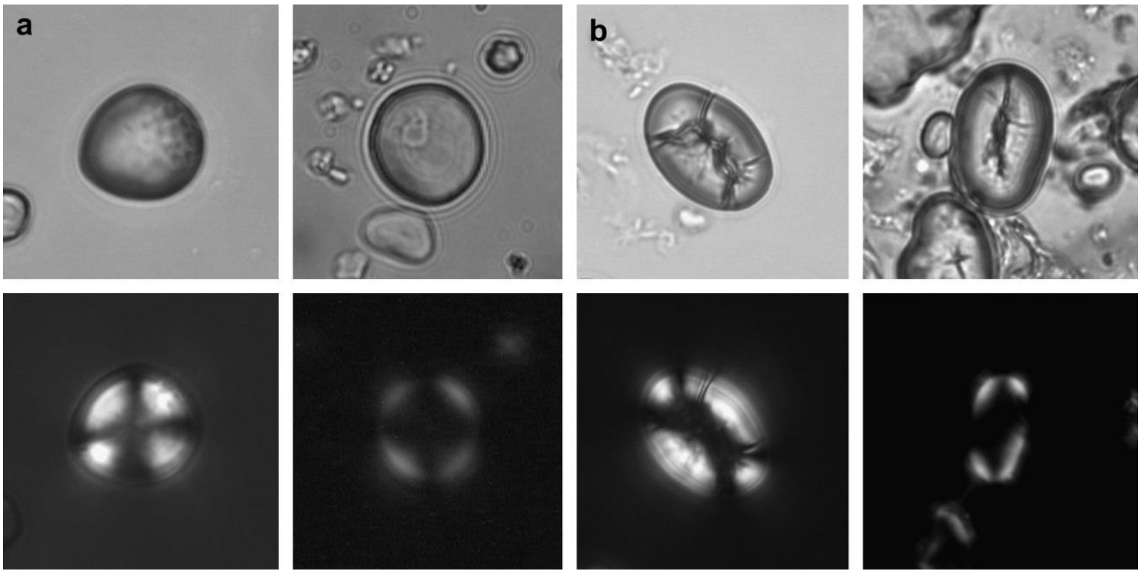
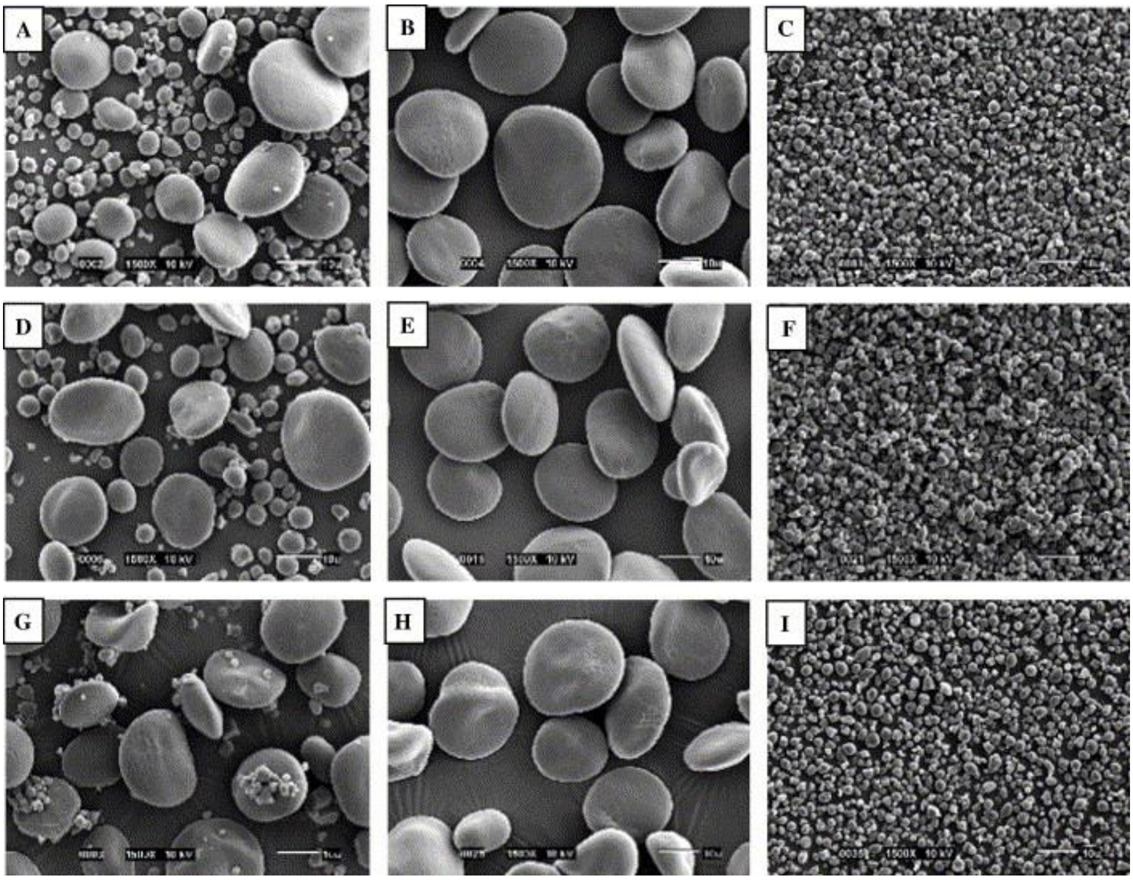


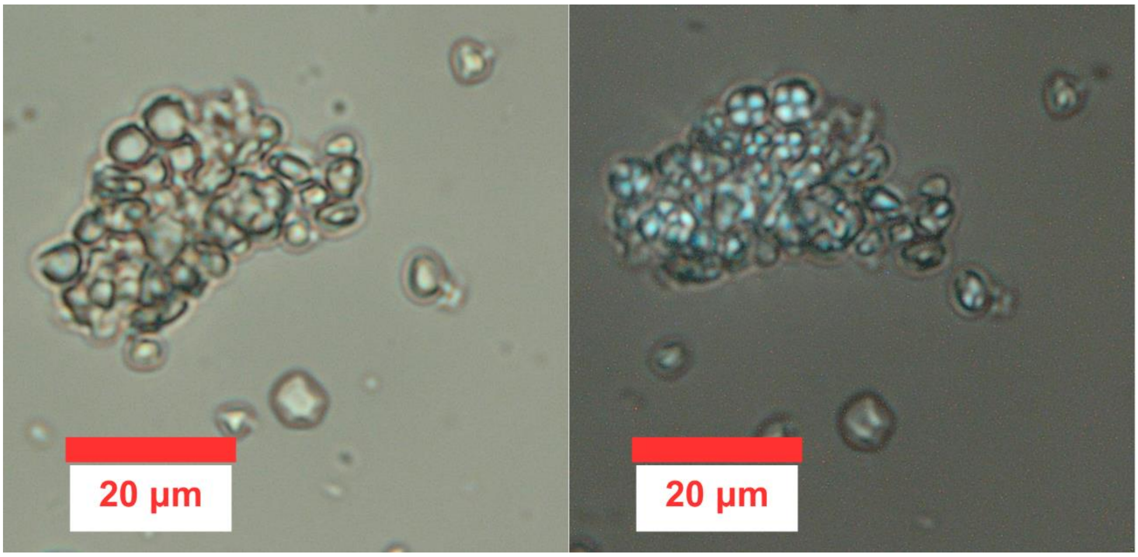
Figure 2 From Ao and Jane (2007: 48, Fig. 1) ‘Scanning electron micrographs of native wheat (A), triticale (D), and barley (G) starch granules, and their fractionated large, A-granules (B, E, and H, respectively) and small, B-granules (C, F, and I, respectively) (Scale bar = 10 μm).’



For identifying starch (be it on a species or a higher classification level), one has to look at many morphological features – its shape, its hilum (the central point of the grain where the formation of the starch grain begins), lamellae, cracks, fissures and the features of the birefringent cross are all necessary when trying to distinguish between different taxa. (Leonard et al. 2015: 450) Staining the starch is also possible (Hardy et al. 2009). The staining technique was not used due to this practice being out of the scope of this thesis, however, it is a practice I want to try in the future. Adding α-amylase to starch is another sure way to test it (Hardy et al. 2009: 249), however, it should be noted that α-amylase breaks the starch down and it cannot be ‘put back together’. This method of identification can also be difficult because an entire sample will likely be compromised.

Malting is a process which alters the look of seeds and it may also change the look of starch. Larsson et al. (2019) found malted barley from 5^{th}–6^{th} century Sweden; Cordes et al. (2021) studied malted barley and its starch granules to understand the changes that malting has on starch. Malting has not yet been identified on archaeological starch granules in Estonia. In addition, grinding, boiling, chewing, roasting – all can alter the look of starch when it appears in dental calculus.

Figure 3. *Avena sativa* starch in a cluster.



More images of starch granules can be seen in Chapter 4.1.

1.3.3. Phytoliths

Phytoliths (also called 'opaline phytoliths', 'opaline silica', 'plant opal') are solid particles of silicon dioxide (SiO_2) found in many angiosperms' vegetative and reproductive organs (Piperno et al. 2002: 10 923; Shakoor et al. 2015: 10). There are many explanations as to why some plants produce phytoliths (and why some do not produce them at all), the most prevailing of which seems to be that phytoliths are found in plants because they support the plant's structure; help protect plants from herbivores and fungal infestations – high silica content makes plants more abrasive to teeth and difficult to chew; phytoliths improve water balance in the plant and help with growth and yield, reproduction, photosynthesis. Silica is also known to protect plants from biotic and abiotic stresses. (Piperno 2006: 13; Hunt et al. 2008; Shakoor et al. 2015: 10, 18)

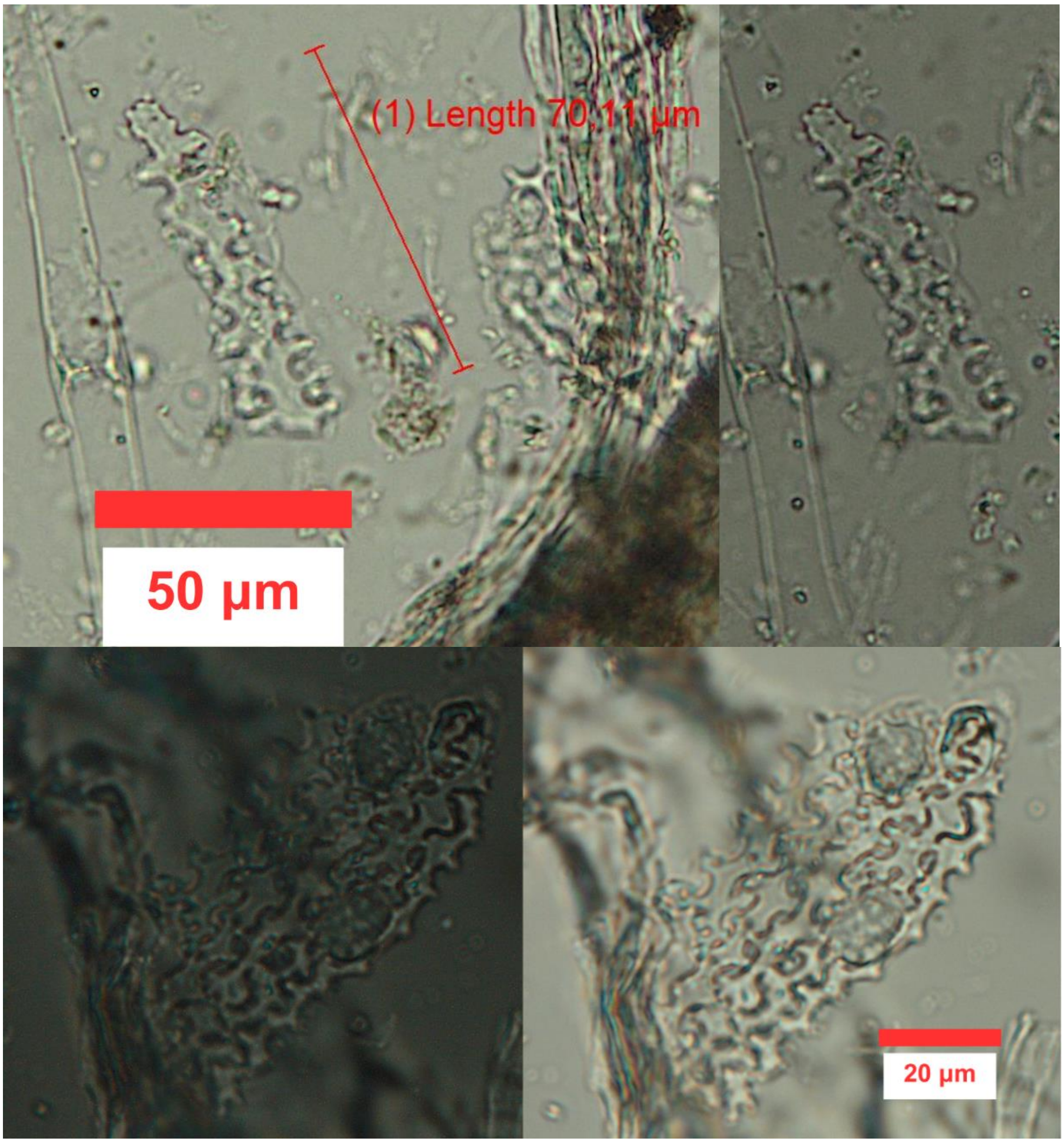
Phytoliths are created when plants take up monosilicic acid (H_4SiO_4) from the soil. Silicon dioxide (SiO_2) is stored in cell membranes or inside cells and in empty places in-between cells. Silica flows into the empty plant parts as silica gel. Once in the area of deposition, the silica hardens and takes the form of whatever it is filling which is why phytoliths have a characteristic shape and size relating to a taxon. This helps with taxonomic analyses of different plant groups. As there are many different shapes and varieties of cells inside one plant, phytoliths are formed in a multitude of shapes and sizes depending on the location of the deposition as well as the age of the plant. Phytoliths can remain in the soil after a plant dies, giving us insight about past environments. (Piperno 2006: 5; Shakoor et al. 2015: 10–11) It should be noted that plants do not use silica for any of its metabolic processes, it is only deposited in the cavities in its structure (Shakoor et al. 2015: 10). Phytolith production is influenced by many factors, such as the water content and the temperature of the soil, the acidity and the prevalence of monosilicic acid in the soil, the age of the plant, the climate and the taxon of a plant (Piperno 2006: 5; Leonard et al. 2015: 450)

Phytolith analysis is used for a variety of different research topics in addition to archaeology: paleoecology, evolution and helping solve taxonomic and climatological problems (International Committee for Phytolith Taxonomy (ICPT) 2019: 189). Phytolith can provide a direct record of plants consumed by past humans. (Henry et al. 2011: 486; Dickau et al. 2012; Tromp and Dudgeon 2015; Leonard et al. 2015; Zhang et al. 2017)

Phytoliths’ inorganic silica body is chemically quite stable, phytolith can withstand high temperatures from cooking and even dry-ashing (a method used to separate phytolith from other organic matter) (Wu et al. 2012: 852; Zhang et al. 2017: 44). The shape of phytoliths begins to change in temperatures upwards of 500 ºC, but according to some results, phytoliths are still distinguishable up to temperatures of 800 ºC (Piperno 2006; Shillito 2013: 72). Wu et al. (2012: 854) heated phytoliths up to 1100 ºC in a muffle oven, noting that certain phytoliths were indistinguishable when heated above 800 ºC. It seems the cut-off point is around 800 ºC, where researchers begin to see changes in morphology and colour. Parr (2006) noticed that the morphology of phytoliths can survive above 800 ºC, but the phytoliths may become discoloured. So, it is good to know that in food-related studies, the phytoliths should be well preserved as cooking temperatures seldom rise above 500 º C. If phytoliths end up embedded into dental calculus, they are protected and therefore provide an excellent source of information about foodways of past humans (Zhang et al. 2017: 44). To understand the taxonomical classification of a phytolith[3], research needs to be done by way of a reference collection and by using other publications.

The shape and size of the phytolith needs to be analysed to understand the taxon (see dendritic phytoliths in Fig. 4), which is why one must know the corresponding

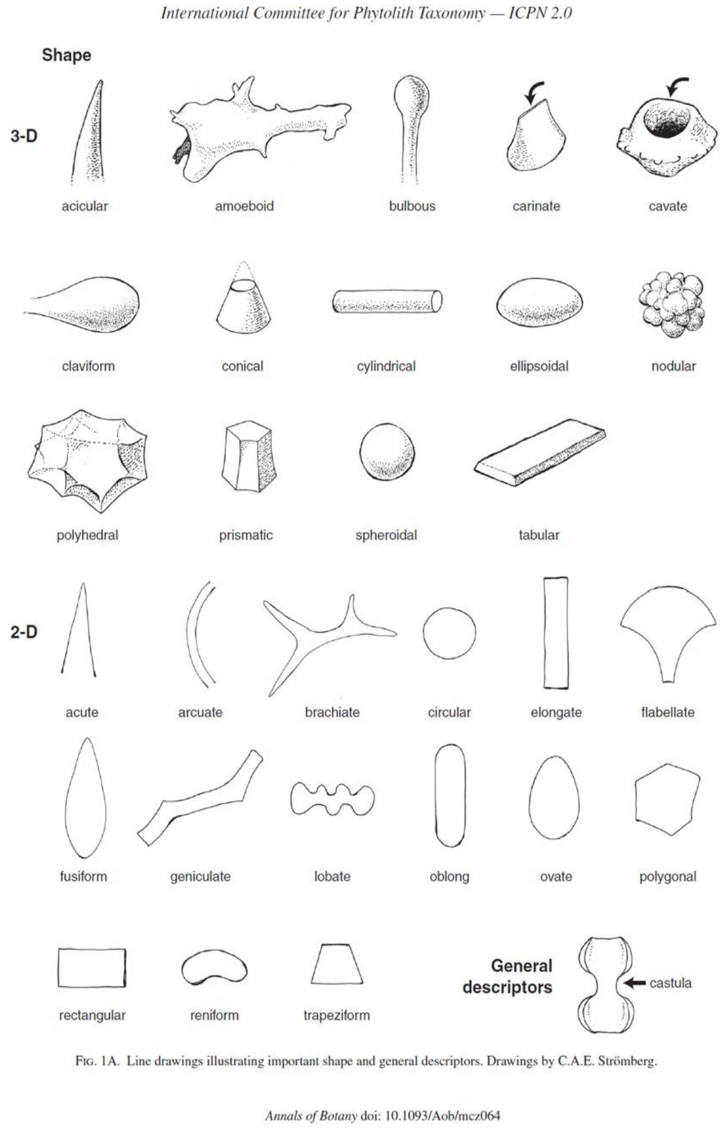
Figure 4. *Avena fatua* dendritic phytolith from a dry-ashed seed.



[3] Chat GPT 3.5 was used here to help with wording.

nomenclature. To describe phytolith shapes (see Fig. 5), the International Code for Phytolith Nomenclature 1.0 and 2.0 can be consulted (Madella et al. 2005; International Committee for Phytolith Taxonomy (ICPT) 2019). PhytCore DB can help with identification – this is an online database of phytoliths from all over the world. Researchers can upload photos of their phytoliths (either archaeological or modern) with information about the origin of the phytolith.

Figure 5 International Code for Phytolith Nomenclature (ICPN) 2.0 from page 192. Line drawings of shapes of phytoliths with agreed upon

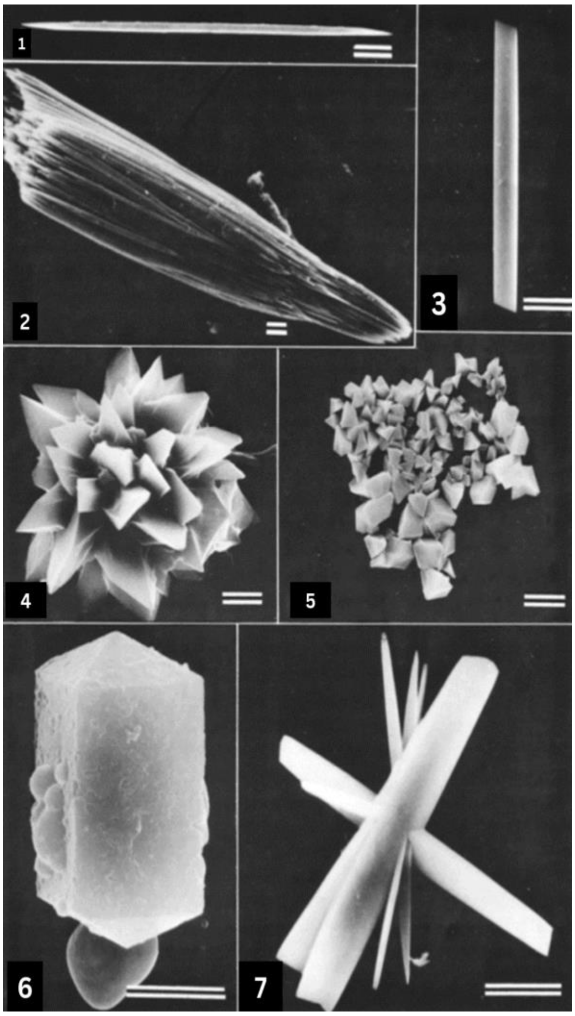


As stated before, the shapes of phytoliths can differ within a single plant, this can make distinguishing between plants difficult. In such a case, it is pertinent to understand the context. For example, it is much more likely that the phytoliths from the inflorescence bracts of typical cereals ended up in dental calculus rather than the phytoliths from the stem of the same plants. Not impossible, of course, but much more unlikely. Nevertheless, phytolith are a good tool to apply in dental calculus analysis due their stable nature (Shillito 2013: 72).

1.3.4. Calcium Oxalate Crystals

Calcium oxalates are microscopic crystals that can be found in virtually all and any parts of plants, varying in size and shape (Figure 6) (Crowther 2009: 103). Calcium oxalates are formed in plants to regulate calcium in tissues, protect plants from herbivores and from metal detoxification (Nakata 2003: 901). However, there are not too many variations found in the plant kingdom which makes oxalates difficult to match with a taxon as most crystals can be classified (based on morphology) as belonging to one of five categories

Figure 6. Modified from Franceschi and Horner (1980: 380–381) 'Scanning electron micrographs of fresh, isolated calcium oxalate single crystals and crystal aggregations from plants.' 1 - Single raphide crystal. 2 – Leaf raphid crystal bundle. 3 – Styloid crystal. 4 – Druse crystal. 5 – Crystal sand. 6 – Prismatic crystal. 7 – Aggregate crystal complex. All line scales equal 5 µm.

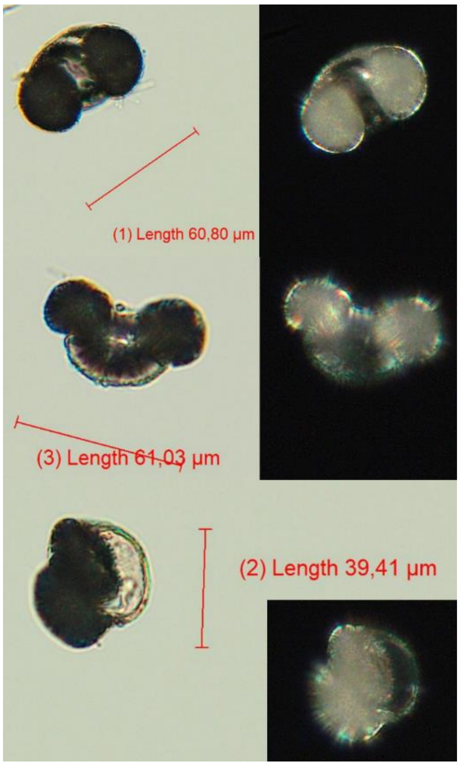


(Nakata 2003: 901). Tromp (2012: 13–14) finds that calcium oxalates are uncommon in dental calculus.

1.3.5. Pollen

Pollen is a microscopic male seed cell of a plant (Figure 7). This seed is 'designed' to travel, sometimes quite far, be it by wind, animals or water. Pollen has a strong outer wall made of sporopollenin, it is resistant to mechanical and chemical damage; only some fungi and bacteria in favourable conditions can break it down. This outer wall is diagnostic and of interest to archaeologists as it is stable and can fossilise. (Bakels 2020: 203). It is possible to find pollen in dental calculus, though it is not common. Cummings et al. (2018: 888) found three pollen grains from the dental calculus of individuals found at a Neolithic site in Iraq. They identified the pollen grains as Cerealia, Brassicaceae and 'cheno-am' (*Chenopodium* spp. or *Amaranthus* spp,). Pollen can be useful for understanding foodways as well as the environment (Radini and Nikita 2022: 6), at times proving that Stone Age peoples could have used honeybee products and/or conifer resins (D'Agostino et al. 2021: 1). Rarely is identification up to plant species possible, more commonly the genus is identified (Bakels 2020: 204).

Figure 7. *Pinus sylvestris* pollen.



1.3.6. Fungal Debris

Fungi are filamentous, heterotrophic organisms that depend on external sources of organic carbon, they absorb nutrients through their cell membrane (Sorenson 1999: 1). Fungal spores are (often airborne) units of reproduction. 'Fungal debris' is a term used for spores and other parts of fungi that can end up in dental calculus, be it by air, deliberate or accidental ingestion. (Afonso-Vargas et al. 2015; Power et al. 2015; Radini et al. 2017: 76). Fungi are a part of the human oral microbiome as well (Ghannoum et al. 2010), so a fungus in calculus might not always be from a dietary source. In such a case, it is necessary to be aware of the fungi found in the oral microbiomes. (Power et al. 2015: 43) Fungi live in the soil as well, meaning fungal debris can be found on and in dental calculus, settling there after the person's death. I found Glomeromycota-type fungal debris in dental calculus samples from Medieval mixed contexts in Estonia (Unt 2021: 32). Glomeromycota-type fungal matter can originate for example from unwashed food that was in contact with the soil (Chen et al. 2023). Consumption of fungi is rarely seen in archaeology, which is why studying fungal debris is important. Iceman 'Ötzi' had three fungal objects with him (Peintner and Pöder 2000). Microscopic fungal matter can be distinguished for example by hyphae and spores.

1.3.7. Other Microremains: Animal Debris, Wood, Diatoms, Fibres etc.

There are many other microremains, which I cannot expand on in such detail due to the limitations of the length of the thesis. As stated before, dental calculus can potentially hold anything from food or the environment that is small enough to be embedded into the matrix. For that reason, wood, animal hairs and pieces of bones, insect parts, dust mites, bacteria, diatoms, fibres – virtually anything can be embedded into it. These 'auxillary' microremains which might appear in dental calculus, are difficult to foresee. For example, I found a moth/butterfly wing tip in the dental calculus of a Medieval individual (Unt 2021: 33). Including all of the 'other' specimens into the reference collection and being able to analyse them may give a broader understanding of past ecosystems and human interactions with their environment.

2. Kukruse cemetery and Late Iron Age foodways

First, I will expand on the Kukruse archaeological site. Secondly, I will describe the known foodways of Late Iron Age, setting the stage for my reference collection. The ideas in this chapter will be used to contextualise the results.

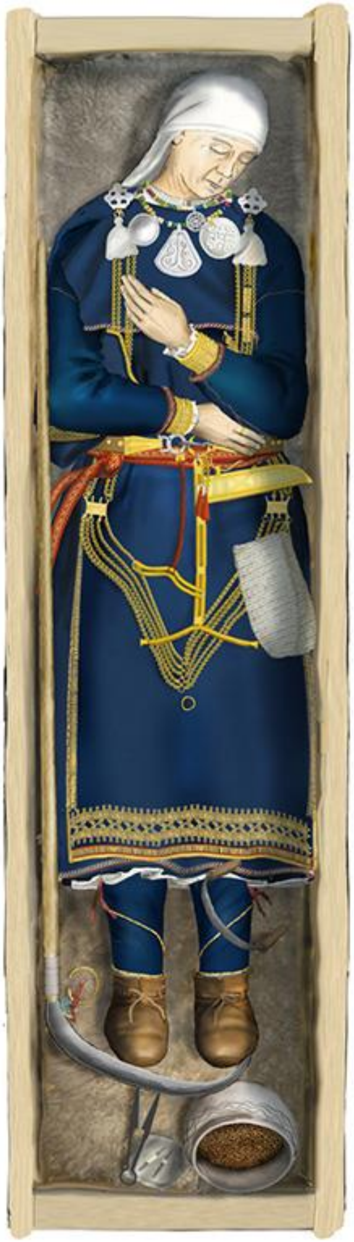
2.1. Kukruse historiography

Kukruse is a cemetery from the 12th to the 13th centuries AD, located in North-Eastern Estonia. The site was discovered due to roadworks and excavated in the winter of 2009–2010. 40 individuals in 35 graves including men, women and children were discovered. (Lõhmus et al. 2011: 103, 107; Randoja 2016: 27) Most were single graves, five were double burials. During fieldwork in May 2010, a multiple burial (XLV) was excavated and five additional graves were found. (Lõhmus et al. 2011: 107) The Kukruse site had been in use during different periods: first, a cremation burial field was created, then the inhumation cemetery and the last cultural layer was a cobblestone road. For this thesis, the individuals from the inhumation cemetery were analysed.

The cultural layer below the cobblestone road was 20–45 cm thick and contained cremated bones and single artefacts which were mostly burnt and small. Artefacts resembled those from the inhumation graves below. The beginning of the cremation could be several centuries earlier than the inhumation cemetery, evidence supporting this is from one possible earlier artefact in the cremation layer (a needle spiral, possible part of a 1st to 11th century fibula); and, the fact that single cremated bones were found in inhumation graves – the inhumation graves having been dug through the cremation burials. (Lõhmus et al. 2011: 106) Funerary equipment was common in the burials, mainly being present in the eastern part of the cemetery (Appendix 1). Lavish jewellery, tools, weapons, personal objects and dress accessories were found, in addition to ceramic pots which had food crust. The burials analysed in this thesis which contained a ceramic vessel were: XII, XXX, IX, I, XV, VII, VI, XLIII. The burials that did not contain a ceramic vessel were: XXXIII, XXXIV. (Appendix 1)

One of the most famous burials, burial VI (named ‘Kukruse memm’, Fig. 8), is on display in the Estonian National Museum. This is a burial of a 40–50 year-old female whose grave goods included bracelets, bronze spirals, breast pins, a beaded necklace with silver plates and a rich selection of tools at her feet (a pot, a scythe, an iron tool and iron scissors) (Jonuks and Lõhmus 2010; Oras et al. 2018: 91)

Figure 8 Jaana Ratas created this drawing of the burial VI based on the data from the excavations. Image from: https://blog.erm.ee/?p=2401 [Accessed 03.01.2024]



The burials at Kukruse have been relatively well-studied, an extensive multi-proxy dietary analysis was made by Oras et al. (2018), combining organic residue analysis, bulk isotope analysis and microfossil analysis for ceramic vessels and stable isotope analysis of human bones. The organic residue analysis showed that the foodstuffs made in Kukruse ceramic vessels are both from aquatic and terrestrial animals. Individuals at Kukruse kept domestic animals, as hinted by dairy residues in the pots and the animal bone analysis, which showed mainly cattle, sheep/goats (*Ovis aries/Capra hircus*) and horses (Maldre 2014). Possible plant biomarkers were found (Oras et al. 2018: 94), and the main protein source was found to be C3 plants and/or animals fed by C3 plants (Oras et al. 2018: 97). However, it is interesting that few plant microfossils from the food crust of the pots were found, although human bone stable isotope analysis showed that plants were eaten. Kukruse is also noteworthy for its gender-based food consumption, demonstrating notable differences in the protein intake between males and females. The findings reveal that the males' food was more commonly of a higher trophic level (e.g. omnivore meat or fish) than those of females.[4] Due to the elderly women's foodways resembling those of the men, it can be assumed that their social position was comparable to the men's in their society. (Oras et al. 2018)

So far, there has been a challenge in understanding the 'planty' component of the Kukruse diet. This could be tackled by way of dental calculus analysis which was not done at the time of the previous studies.

2.2. Late Iron Age – early Medieval foodways in Estonia

I will look into the foodways of this time period broadly as there were not too many changes during the Late Iron Age to the early Medieval period, with the main difference coming from imported goods during the Medieval period. The larger administrative area around Kukruse known as Virumaa has one of the most fertile soils in all of Estonia – this area was densely populated by already the Pre-Viking and Viking Age[5] peoples. (Kriiska et al. 2020: 305)

[4] Chat GPT 3.5 was used to help with wording for rephrasing original ideas.

[5] Estonian Older Iron Age from Kriiska et al. (2020: 17):

500–250 BC Early Pre-Roman Iron Age;

250 BC–50 AD Late Pre-Roman Iron Age;

The main sustenance strategy of Iron Age Estonia was plant cultivation and animal husbandry, to a lesser extent hunting, fishing and gathering. Paleo-fields have been found from four places in Northern Estonia and two places from Western Estonia which befall under Pre- and Viking Age dates. (Kriiska et al. 2020: 304)

Plant names in Estonian, English and Latin are given in the Appendix (Appendix 3).

2.2.1. Cultivated plants

The main cereals eaten during the Iron and Medieval Ages were barley (*Hordeum vulgare* and its subspecies), rye (*Secale cereale*), wheat (*Triticum aestivum/dicoccon*) and oat (*Avena sativa*). Common legumes were peas (*Pisum sativum*). Hemp (*Cannabis sativa*) and flax (*Linum usistatissimu*m) were grown for making textiles – hemp and flax seeds are also edible, and it is possible those crops were grown for food as well. (Tammet 1988: 97–100; Sillasoo and Hiie 2007: 72; Tvauri and Vanhanen 2016; Kriiska et al. 2020: 306–307) The first written record for buckwheat (*Fagopyrum esculentum*) is from 14th century Livonia, having been grown in fields around Riga; the macrobotanical remains are from 13th/14th and later deposits (Sillasoo and Hiie 2007: 76, 78; Tvauri and Vanhanen 2016). The first indication of of millet (*Panicum miliaceum*) consumption is available from the Middle Ages as well.

The main cereal in Estonia during the Iron Age was **barley**, it can be seen from pollen grains in bog and lake sediments and is evident from macroremains from archaeological contexts. (Sillasoo and Hiie 2007: 76; Tvauri and Vanhanen 2016: 67; Kriiska et al. 2020:

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50 AD–200 AD Early Roman Iron Age;

200–450 AD Late Roman Iron Age;

450–550 AD Migration Period.

Estonian Younger Iron Age:

550–800 AD Pre-Viking Age;

800–1050 AD Viking Age;

1050–1225 AD Late Iron Age

1225–1500 AD Middle Ages

306, 382; Niinesalu-Moon et al. 2023) The oldest dated cereal grains from Estonia are from the Pre-Roman Iron Age (500 BC – 50 AD) (Niinesalu-Moon et al. 2023) and are predominantly barley. Iron Age cereal grains have been found from the 11th century Kuusalu Pajulinn hillfort, which revealed charred plant macroremains, consisting of mainly barley (two- and four row), some wheat, rye and peas (Schmiedehelm 1939: 129). These are excellent examples of staple foods from this period in Estonia. Iru hillfort has revealed the charred remains of barley, wheat and peas. It is pertinent to note that Sandra Sammler analysed the isotopic values of these charred remains, finding that fertilisers were used at this particular hillfort (Sammler 2020: 32–33). From Tartu's Pre-Viking Age contexts, barley was the most common cereal, altogether comprising of 155 gains, 67 of which were hulled barley (Tvauri and Vanhanen 2016: 39). Uncharred barley grains have been found from the cesspits of Estonian medieval towns (Sillasoo 1995: 117; Sillasoo and Hiie 2007: 76–77).

Up until the beginning of the 20th century, people in Southern Estonia (an area largely less modernised than other regions of Estonia) still ate a dish made of barley grains, where a mortar and pestle were used to get rid of the husks and the remaining flour was boiled. A porridge and *leem* made from barley *tangud* and flour was one of the most revered dishes. Barley flour was used to make different types of baked goods (*käkk, karask, paistekakk*) as well as drinks – beer, kvass and *taar* were made from barley. (Viires and Vunder 1998: 349). Estonian ethnographs suggest that the most common food made from flour was black bread (*leib*). This was made from cereals that were currently available, barley and rye were most commonly used. (Viires and Vunder 1998: 347)

There are different subspecies of **barley** that have been cultivated in Europe during different time periods. *Hordeum vulgare subsp. vulgare*, domesticated or hulled barley (in Estonian *mitmerealine/sõkalteraline oder*) tolerates damp and cool conditions well, both in terms of growth and storage (Mooney and Guðmundsdóttir 2020: 7). This subspecies of barley was the principal crop during the Bronze Age in Sweden (Lagerås and Larsson 2020: 172). *Hordeum vulgare var. nudum*, naked or hulless barley (in Estonian *kaherealine/paljasteraline oder*) has a loosely attached hull and is therefore much easier to remove whilst suffering minimal bran loss, making it easier to cultivate and consume (Shaveta et al. 2019: 114). South-Western Finnish Iron Age archaeobotanical remains show that barley was the main cultivated cereal; and that hulled and naked barley were grown in about similar amounts (Vanhanen 2020: 131, 134). Hulled barley continued to be the dominant cereal during the Iron Age (and later) in southern Sweden, according to Lagerås and Larsson (2020: 172).

Wide-scale **rye** cultivation took off in Estonia during the Early Iron Age and Roman periods, gaining importance in the northern parts of the Roman Empire and north of the limes, expanding to the Baltics (Grikpėdis and Matuzevičiūtė 2016: 602). Rye is a plant that can endure difficult climates and poorer soils than other cereals, this makes it a good fit for the Estonian climate. In Lithuania, rye was a cultivated crop as early as 2nd–3rd centuries AD and it is possible that during this period, the plant spread to Latvia, Estonia and Finland (Grikpėdis and Matuzevičiūtė 2016: 608). Kriiska et al. (2020: 306–307) suggested that rye becomes a staple cereal in Estonia around the 6th century AD – it is possible that the climate catastrophe of the year 536 could be the reason for widespread rye cultivation; charred rye remains have been found from Iru (Sillasoo and Hiie 2007: 73). Rye is a common archaeobotanical find in the Pre-Viking Age contexts (Tvauri and Vanhanen 2016: 33) and in Medieval cesspits (Sillasoo and Hiie 2007: 78), corresponding with written sources that rye and barley were the predominant cereals during this time period (Sillasoo and Hiie 2007: 80). Late Iron Age saw rye gaining economic importance; during the Viking age and onward it was one of the principal crops along with barley in Sweden (Lagerås and Larsson 2020: 172). Rye was the second most common cereal from Tartu's Pre-Viking Age contexts, comprising of 65 grains (Tvauri and Vanhanen 2016: 39).

During Estonian prehistory, wheat and oat were less commonly eaten. **Oats** (*Avena* spp.) came to Estonia most likely as a weed of wheat and barley (Kriiska et al. 2020: 177). Oats are represented in Medieval tax lists less than rye and barley (Sillasoo and Hiie 2007: 76). Oats were most likely used in towns as horse fodder; in the countryside, people would have eaten it as well (Sillasoo and Hiie 2007: 89). There is pollen evidence for oats from the Iron Age. (Kriiska et al. 2020: 306–307) Oats are mentioned as being a minor crop in the Finnish Iron Age, however it was difficult for Vanhanen (2020: 131, 134) to tell whether it was cultivated or a weed. Iceland, which cannot endure too much cereal cultivation due to its geographical location, sees oat (as well as barley) remains from 10th–12th century deposits (Mooney and Guðmundsdóttir 2020: 10). Tvauri and Vanhanen (2016: 39) found only two grains of oat and seven grains of bread or club wheat. 19th century ethnographic research shows Estonians eating oat flour *kama*[6] and other dishes made of oat flour (see more from Viires and Vunder 1998: 351–352)

Wheat (*Triticum* spp.) species were one of the cultivated plants with which oat and rye travelled as weeds. (Kriiska et al. 2020: 177) Wheat has many different subspecies of hulled and naked variants. Emmer wheat (*Triticum diococcum*) was the main cultivated cereal in continental Europe during the Neolithic and the Bronze Age; it was replaced during the first millennium BC by spelt (*Triticum spelta*) (Lagerås and Larsson 2020: 173), which was preferred by Romans who traded with northern territories in Europe. Hulled wheats were cultivated up until the 6th century AD in the Eastern Baltic region (Lagerås and Larsson 2020: 174).

The hulled wheats (*Triticum monococcum,* einkorn; *T. dicoccum,* emmer; and *T. spelta,* spelt) have glumes that tightly enclose the grain and are inedible; after threshing they need to be pounded and parched to separate the grains from the glumes (Lagerås and Larsson 2020: 173 and references therein) Naked wheats do not need to be pounded after threshing and separating the grains from the glumes is not as difficult (ibid.).

Indentations of wheat grains have been found on pottery from Asva, a Bronze Age fortified settlement in Saaremaa. Wheat-type pollen is known from the Neolithic in Estonia and continues to be seen during the Bronze and Pre–Roman Iron ages (Kriiska et al. 2020: 184). The Viking age assemblage of charred plant remains from Kuusalu hillfort consists of some wheat (Kriiska et al. 2020: 306). The findings at Iru hillfort from the 9th to the 10th centuries include evidence of wheat, in addition to barley and rye (Sillasoo and Hiie 2007: 73). The 11th century Soontagana hillfort cultural layer consisted of some wheat as well (Sillasoo and Hiie 2007: 74). Sillasoo and Hiie (2008: 80) name wheat as

[6] *Kama* – a traditional finely mixed roasted flour mixture can contain any number of cereal flours. To eat kama, one can mix it with fat or a milk product. This is still eaten in Estonia.

a less significant cereal in Medieval Estonia. The fact that wheat was a less cultivated crop during the Iron and Middle Ages is evident from the neighbouring areas too: the Finnish Iron Age saw emmer/spelt wheat as a minor crop (Vanhanen 2020: 134); Latvian medieval contexts have shown some wheat among other plants (Sillasoo and Hiie 2007: 85); Lagerås and Larsson (2020: 172) name wheat and oats as minor crops during the Late Iron Age in Sweden. Wheat cultivation took off in Estonia during the 17th century (Põltsam 2002: 10).

Consumption of cereals during Estonian prehistory is further supported by the combined studies of lipids and microfossils from pottery food crust and ceramic matrix from Pada Pre-Viking Age settlement site (Chen et al. (2023). The findings suggest a significant intake of C3 grains, specifically *Hordeum* and *Triticum*, which were at times combined with products derived from animals (Chen et al. 2023).

Millet *(Panicum miliaceum*) was most likely not cultivated in Estonia nor Latvia in the Iron Age, however, it is appearing more and more in Lithuanian prehistory, which is some hundreds of kilometres to the south of Estonia (Motuzaite-Matuzeviciute et al. 2013). Sillasoo and Hiie (2007: 82) suggest that millet was not cultivated in Late Medieval Livonia, but imported and the remains of it appear in latrines, refuse and cultural layers in Estonia. Stable isotope analysis has showed us that a C4 plant, most likely millet, made its way onto the table in Estonia during the Middle Ages. It is generally thought that since millet was imported, it was eaten only by the people with higher status in Estonia. (Lightfoot et al. 2016: 1)

Legumes (Fabaceae) were a common food staple during the Iron and Middle Ages in Estonia. It is said legumes helped survive famines – these plants are less ‘picky’ and can grow in poorer soils (Põltsam 2002: 12). Iru hillfort revealed several charred peas (*Pisum sativum*) and broad beans (*Vicia faba*); peas were also found from Kuusalu hillfort (Kriiska et al. 2020: 306). Peas and broad beans were found from Pre-Viking Age Tartu assemblages (Tvauri and Vanhanen 2016: 67) Middle Age town assemblages contain peas, beans and lentils (Sillasoo and Hiie 2007: 80).

I am differentiating here between **grown fruits**, these do not include gathered fruits. No indication of grown fruits is available from prehistoric Estonia. Granted, it is not always easy to differentiate between grown and gathered fruits. *Malus sp.*, apple (*Malus domestica*); blackcurrant (*Ribes nigrum*), redcurrant (*Ribes rubrum*), the common pear (*Pyrus communis*), sour cherry (*Cerasus vulgaris*), damson plum (*Prunus insititia*), plum (*Prunus domestica*) are among the macrobotanical finds from medieval contexts from Estonia (Sillasoo 1995: 117; Sillasoo and Hiie 2007: 78–79; Tammet 1988: 97–101)

Plants were not cultivated only for food, some were cultivated for making textiles or oil. Oils have been used in medicine, as binding agents in putty, pigments and cosmetics as well as providing light when burned. (Karg 2012: 17) **Oil plants** from Estonian medieval contexts are hemp (*Cannabis sativa*), flax (*Linum usitatissimum*) and opium poppy (*Papaver somniferum*). A commonly cultivated plant for oil and textiles is flax (*Linum usitatissimum*). Archaeobotanical data of this plant has been found in many sites throughout southern Scandinavia during the Roman Iron Age (0–400 BC). (Larsson 2013: 509) Gold-of-pleasure (*Camelina sativa*) was believed to have been cultivated in Scandinavia as well, not as a weed amongst flax as previously thought. (Larsson 2013: 509) Hemp (*Cannabis sativa*) was cultivated for its fibres' durability and strength (Larsson and Lagerås 2014: 1). It was grown for making ropes, and for its seeds which are rich in nutrients. According to pollen analysis, hemp found its way to Estonia during the Viking Age. (Kriiska et al. 2020: 307) *Brassica rapa* seeds have been found from the 13^{th}–16^{th} century deposits and *Brassica* sp. from $13^{th}/14^{th}$–$16^{th}/17^{th}$ century deposits (Sillasoo and Hiie 2007: 78). *Brassica* can come in different subspecies, e.g. as cabbage or turnip.[7]

The selection of cultivated plants could naturally have been larger during the Late Iron Age than the mentioned cereals, pulses, oil plants and tubers. It ought to be noted that Larsson and Ingemark (2015) found traces of Roman horticulture in Uppåkra, Sweden (dated to 1–400 AD). The macrofossil evidence indicates that several garden plants, like dill (*Anethum graveolens*), garden parsley (*Petroselinum crispum*), garden cress

[7] https://taimenimed.ut.ee/cgi-bin/taimenimed.cgi?query=brassica+rapa&lang=ld Searching "brassica rapa" reveals just how many subspecies carry this name. Last accessed 03.01.2024.

(*Lepidium sativum*), elecampane (*Inula helenium*), parsnip (*Pastinaca sativa*), carrot (*Daucus carota* subsp. *sativus*), turnip (*Brassica rapa* subsp. *rapa*), rapeseed (*Brassica napus* subsp. *napus*), cabbage (*Brassica oleracea*), black mustard (*Rhamphospermum nigrum*), white mustard (*Sinapis alba*) and opium poppy (*Papaver somniferum*), initially believed to have been introduced in the 12th century, were instead introduced much earlier. The romans used these plants as condiments served for both culinary and medicinal purposes (Larsson and Ingemark 2015: 393). More information for the Estonian area is available from the Medieval period. Written sources mention the trade of the seeds of onion (*Allium cepa*), carrot, radish (*Raphanus raphanistrum*) and parsley, thus probably grown already locally. Medieval cesspits have yielded also seeds of caraway (*Carum carvi*), dill (*Anethum graveolens*), cucumber (*Cucumis sativa*), celery (*Apium graveolens*) and parsnip (Sillasoo and Hiie 2007).

2.2.2. Gathered plants[8]

With the coming of agriculture, gathering plants surely became a less important sustenance strategy, however, we can assume that gathering plants was still relevant to the Late Iron Age people of Kukruse. Due to a lack of archaeobotanical information on gathered plants from the Estonian prehistory, apart from some (Tvauri and Vanhanen 2016; Niinesalu-Moon et al. 2023; Vanhanen et al. 2023), it is difficult to assume which exact plants were gathered. For that reason, works on Medieval materials need to be consulted (Tammet 1988; Sillasoo and Hiie 2007).

Hazelnut (*Corylus avellana*) emerges consistently in various archaeological studies since the Stone Age (Vanhanen et al. 2023), finds or nut shells are also available from later periods (Tammet 1988; Sillasoo and Hiie 2007; Kihno and Hiie 2008; Tvauri and Vanhanen 2016). It is interesting to note that Moilanen et al. (2022) reveal the use of junipers and mosses to colour graves green and provide padding for softer coffins during Medieval times in Finland. Charred plant remains around the graves suggest the use of Scots pine (*Pinus sylvestris*) or Norway spruce (*Picea abies*). This is interesting from a

[8] Chat GPT 3.5 was used to help condense information in this subchapter

dental calculus analysts' perspective – this plant debris from gathered plants may end up in dental calculus as airborne particles.

Recurring uncultivated plants are difficult to encounter in archaeological material. From the prehistoric period we have some raspberry seeds from Aindu, wild strawberry and raspberry from Tartu Küütri street and a single find of an oak acorn from Tartu fort (Lossi 36) (Tvauri and Vahnanen 2016: 44). From different Estonian Medieval sites, the following species of gathered plants have been found: wild strawberry (*Fragaria vesca*), red raspberry (*Rubus idaeus*), hazelnut (*Corylus avellana*), *Vaccinium* sp., rowan (*Sorbus aucuparia*), cloudberry (*Rubus chamaemorus*), European dewberry (*Rubus caesius*), crowberry (*Empetrum nigrum*), bearberry (*Arctostaphylos uva-ursi*) and many more. (Tammet 1988; Abakumova 1990; Sillasoo and Hiie 2007; Kihno and Hiie 2008) Kalle and Sõukand (2013) provide an extensive list of edible uncultivated plants compiled by ethnographers and biologists.

2.2.3 Imported plants

Looking at Medieval foodways in Estonia, it should be noted that the social structure in Medieval Estonian towns dictated the foodways of either group – *Deutsch* and the *Undeutsch* differed and usually did not mix. The ruling class, *Deutsch*, could afford imported goods and therefore had a different diet than those of the lower classes. (Sillasoo and Hiie 2007: 75) Exotic imported foods are to be expected from the Middle Ages – written sources prove this as well (Mänd 1999). Hence, imported goods direct us more towards the *Deutsch*. Examples of imported goods are: fig (*Ficus carica*) from the 14th and 15th/16th centuries; *Panicum miliaceum* from the 15th/16th centuries; rice (*Oryza sativa*) and lentils (*Lens culinaris*) from the 14th and 15th centuries and green cardamom (*Eleattaria cardamomum*) from the 15th century (Sillasoo and Hiie 2007: 78, 79). Tammet (1988: 98) describes imported plants from Medieval cesspits as well, notable being black pepper (*Piper nigrum*), Persian walnut (*Juglans regia*) and common grape vine (*Vitis vinifera*) (Tammet 1988: 98). Whilst these spices were most likely very uncommon in the lives of Kukruse individuals, trade in the prehistoric world was a common occurrence and it is not impossible they may have tasted a few of these spices during their lifetimes. A burial with cherry seeds from the 11th century Latvian cemetery of Vampenieši II should be mentioned in this connection, showing that imported fruits had found their way into our region already back then. (Berga 2017). A parallel from further away is an example of plant remains from a 15th century shipwreck in the Baltic Sea (Larsson and Foley 2023). They found imported foods such a ginger (*Zingiber officinale*), saffron (*Crocus sativus*), clove (*Syzygium aromaticum*), black pepper (*Piper nigrum*) and almonds (*Prunus dulcis*).

2.2.4 Weeds

We interpret the past through what has survived and make assumptions based on what seems likeliest in the present moment. For that reason, what we might consider weeds today might not have been weeds in the past – the usage of plants shifts in time. Until recently, ground elder (*Aegopodium podagraria*) was seen as a weed until it started to be recognised as a valuable source of vitamins that can be obtained during early spring in Estonia when vegetation is still waiting to bloom. We need to be careful and not assume a plant might have only had one purpose. For that reason, the division of plants into these subheadings (gathered, cultivated, weeds etc) is tentative. Weeds and other wild plants from archaeological contexts give us information about the environment as well as possible cultivated crops in midst of whom they might have grown. (Madella 2014: 146 and references therein)

More commonly mentioned plants that have been considered weeds from the Estonian archaeobotanical record include: pale persicaria (*Polygonum lapathifolium*), red sorrel (*Rumex acetosella*), white campion (*Melandrium album*), corn spurry (*Spergula arvensis*), chickweed (*Stellaria media*), field pennycress (*Thlaspi arvense*) (See more in (Tammet 1988; Abakumova 1990; Sillasoo 1995; Sillasoo and Hiie 2007; Kihno and Hiie 2008; Kadakas, U. et al. 2010; Valk et al. 2013)[9] Looking to further parallels, in the archaeological context of Lækjargata, Iceland (a settlement dated to the 9th–11th centuries), segetal weeds such as hemp-nettle/large-flowered hemp-nettle (G*aleopsis bifida/speciose*), corn spurry (*Spergula arvensis*) and chickweed (*Stellaria media*) were discovered. Guðmundsson et al. (2012: 115) categorise these species as ‘archetypical

[9] Chat GPT 3.5 was used to help with wording in this paragraph.

weeds of crops' commonly found in Icelandic assemblages. These are thought to have come as weeds in poorly cleaned imported grain. (See more in Kristinsson 2010; Guðmundsson et al. 2012; Wasowicz et al. 2013; Mooney and Guðmundsdóttir 2020)

2.2.5 Animals in the Late Iron Age

Late Iron Age peoples kept bees, went hunting and fishing, in addition to looking after domestic animals. Animal herding was commonplace, with some regional variances in Estonia. (Kriiska et al 2020: 383–386)

The main species of animals kept during the Late Iron Age in Estonia were cattle, sheep/goats, less common were pigs (*Sus domesticus*) and horses (horse bones were less common during the Late Iron Age than during previous times in archaeological record). (Kriiska et al. 2020: 383). For example, Pada (populated mainly during the $7^{th}/8^{th}$–$10^{th}/11^{th}$ centuries) faunal remains have been analysed in Maldre (2007). The analysis reports mostly domestic animals, with a moderate representation of wild animals and seals. The main emphasis of domestic animals lay on cattle, sheep/goats were second by the number of bone fragments.

Kukruse animal bones were analysed (Maldre 2014). According to her identifications, the material is generally scarce in animal remains, predominantly comprising of animal teeth. The main finds are cattle, sheep/goats, some horse bones, a few rodent bone fragments, some fish backbones. Burial XVI contained burned horse skull fragments and horse teeth fragments. It is important to note that this burial is not included in the dental calculus analysis. An interesting find is a fragment of the distal phalanx (*os unguiculare*) from the bird osprey (*Pandion haliaetus*).[10]

In general, common birds since the Viking Age in the Estonian archaeological material were domestic chickens, geese and ducks (Ehrlich 2022: 36). In general, fish bones are scarce in the archaeological record, as fish bones are small and were probably not extensively gathered during excavations.

[10] Chat GPT 3.5 was used to help with wording in this paragraph.

In addition to animal bones, meat consumption is further proved by chemical analyses, e.g. organic residues from pottery food crust and ceramic matrix (e.g. Chen et al. 2023) as well as stable isotope studies from human bone collagen. Multiple pots contained indications of terrestrial and aquatic animal resources (Chen et al. 2023). According to Oras et al. (2018), the diet at Kukruse comprised a variety of sources, including both aquatic and terrestrial animals, encompassing herbivores and omnivores. Particularly notable are the significant contributions of aquatic resources to the dietary practices at Kukruse (Oras et al. 2018: 97). Pada Late Iron Age burials contained ceramic vessels with food crust, analysed by Kristi Ilves (Ilves 2020) by way of stable isotope analysis. The food crust samples yielded information on either terrestrial, aquatic or plant-based resources being cooked in said vessels. It is noteworthy that one vessel seemed to contain a C3 plant-based food. (Ilves 2020: 44).

Rauši settlement site (11^{th}–13^{th} century) in Latvia has been analysed by Gunnarssone et al. (2020). Their findings reveal that the lipids extracted from the pottery contained residues indicative of fish, beef, and milk. Notably, pork was presumed to be prepared through methods such as drying, curing, or fermentation rather than cooking in vessels. It is noteworthy that they did not find any plant matter; advocating that cultivated crops were consumed as a supplement to the protein-rich diet. Rauši has been compared as having cultural ties with Saaremaa (Mägi 2005).

This work is not supposed to be a catalogue of all plants found from archaeological contexts, though many are referenced. A collective work outlining the historiography of archaeobotany in Estonia is definitely needed.

3. Methods

In this chapter, I will give an overview of the methods used for dental calculus extraction and explain the ways the reference collection was created, updated and used.

3.1. Dental calculus removal

Dental calculus was extracted from ten individuals' teeth from Kukruse cemetery. The Department of Archaeology at the University of Tartu houses the recently created archaeobotanical research facilities where the dental calculus was analysed. Decontamination protocol for dental calculus removal was created and followed (Appendix 2) following established protocols (Warinner et al. 2014, supplementary material 60–65, Cristiani et al. 2016, 2018; MacKenzie et al. 2021). The decontamination procedure was followed by analysis using light optical microscopy. Teeth were chosen by the amount of dental calculus as well as previous works conducted on the same burials. Therefore, I chose the teeth of some of the individuals sampled in Oras et al. (2018). Of these, I selected the ones which had the most dental calculus (Table 1). As a beginner, it is easier to clean larger calculus deposits. The following ten individuals were chosen:

Tabel 1 Table modified after Oras et al. (2018) showing the sampled individuals' information

Context	Type of tooth*	Weight of tooth before	Sex (Oras et al 2018)	Age (years, Oras et al 2018)	Micro-fossils of plant origin (Oras et al 2018)	Weight of tooth after cleaning
Kukruse burial XII	upper right first premolar	**	male	40–50	no	0.8626 g
Kukruse burial XXX	lower right second incisor	**	male	22–26	no	0.6129 g
Kukruse burial IX	upper right second molar	** dry 11.2718 g	male	25–35	yes	2,1049 g (only the sampled tooth)
Kukruse burial I	upper right second incisor	dry 0.6034 g	female	25–40	yes	0,5990 g
Kukruse burial XV	upper left canine	dry 0.8488 g	female	30–40	no	0.8531 g
Kukruse burial VII	upper right canine	dry wet 0.9512 g	female	50+	yes	0.8772 g
Kukruse burial VI	upper right canine?	dry 0.8625 g	female	40–50	no	0.8431 g

Kukruse burial XLIII	lower left second incisor	wet 0.6952 g	male	30–45	no	0.6255 g
Kukruse burial XXXIII	lower left second incisor	wet 0.5860 g	possibl y male	12–18	no	0.5241 g
Kukruse burial XXXIV	upper left second incisor	wet 0.5789 g	male	40–50	no	0.5292 g

* The types of teeth were checked by Linda Vilumets in December 2023.

** Errors were made here. I did not weigh these the teeth before dental calculus extraction. In addition, with the case of the teeth from burial IX, I should have weighed the tooth separately from the mandible as the weights now do not match up. I regret my mistakes.

Dry/wet – this was another error. All teeth should have been weighed when fully dry.

The burials of these individuals have been thoroughly recorded. A table with the information on each burials' burial goods is found in the appendix (Appendix 1).

A laboratory dedicated to cleaning dental calculus was created. The room was used only for dental calculus analysis and was constantly monitored for contaminants. Several important equipment items were bought for the analysis, such as a stereomicroscope with sufficient magnifications to be able to clean the dental calculus, a laboratory scale, a sonificator, an automatic pipette and other necessary items.

For the integrity of the analysis, I wore no natural fibres, no makeup and inside shoes in the clean laboratory. I wore a brightly coloured hair net made of synthetic material to allow for identification of its debris should it appear in samples, powder free nitrile gloves and protective glasses. Teeth were weighed, photographed from each side and soaked in ultrapure water in a sealed container for 2–3 days in order to loosen the calculus and the soil on top of it. After soaking, the calculus was transported onto a clean Petri dish and photographed before cleaning using a DinoLite camera with the DinoCapture 2.0 programme. The cleaning process was done by using a Nexius Zoom Evo stereomicroscope with maginifications up to 110x. The soil and dirt was removed from the outside of the dental calculus using a clean acupuncture needle dipped in 0.1 M HCl. The acid would begin to dissolve the dirt, once the process had gone on enough, I added ultrapure water to stop the chemical reaction. Then, I scraped the surface of the calculus with the acupuncture needle and repeated the process as needed. The calculus was deemed clean when I could not see any more dirt on it through the microscope. A debris sample was kept from the cleaning process to allow for later reference if needed. The clean dental calculus was photographed and put into a 2 ml Eppendorf tube with a drop of 0.1 HCl. The outer layer of the calculus was then dissolved to get rid of any remaining dirt still adhering to the fleck. This was done by putting the Eppendorf with the calculus-acid mixture to the sonicator for 30 seconds. The liquid was then pipetted out and mounted carefully onto a clean slide. This process was repeated until the whole fleck had dissolved and could be pipetted out of the Eppendorf. The precise steps of the protocol are outlined in the appendix (Appendix 2).

All debris from the dental calculus was **recorded** and selectively photographed due to the limitations of storage. Images were organised and kept in my personal OneDrive cloud of the University of Tartu. Microdebris has characteristics that are best observed under a microscope, where the debris can be rotated and viewed from various angles. A 'flat' two-dimensional photograph often does not capture all the essential characteristics.[11]

3.2. Selection for the reference collection

A basis for my reference collection lies in many publications done on Estonian archaeological material, as well as studies from neighbouring countries. From there, I chose plants, animals, fungi and ‘things’ that I deemed pertinent to the individuals’ diets, environments, economic activities and medicinal purposes as well as the sampling procedure. From the archaeobotanical collection at the University of Tartu (housing over 400 plant specimens along with some animal and fungal matter), I selected the necessary specimens and added more as was needed. The choice of which specimens to sample and which needed to be added for the Late Iron Age’s case study reference collection was done by studying works done on the usage of plants and animals in the past (Tammet 1988; Abakumova 1990; Sillasoo 1995, 2001; Motuzaite Matuzeviciute 2006; Maldre 2007, 2008; Sillasoo and Hiie 2007; Kihno and Hiie 2008; Kalle and Sõukand 2012; Kalle

[11] Chat GPT 3.5 was used to help with wording in this paragraph.

and Sõukand 2013; Lightfoot et al. 2016; Hardy et al. 2016; Oras et al. 2016, 2018; Grikpėdis and Matuzevičiūtė 2016; Kalle 2017; Grikpėdis and Matuzeviciute 2020; Cagnato et al. 2021; Ehrlich 2022; Vanhanen et al. 2023; Chen et al. 2023). The reference collection created for the Late Iron Age case study is presented in the Appedix (Appendix 3).

The choice of plants, animals and 'things' were made according to data compiled in Chapter 2.2. These were categorised into kingdoms and analysed in tandem with dental calculus analysis. See the reference collection table in the appendix (Appendix 3). In short, the choice covers cultivated and gathered plants, some weeds, some animals and possible modern contaminants.

3.3. Microscopy

The primary method for studying microremains is done using microscopes. In my work, I used the polarising microscope Olympus BX51 at the archaeology laboratory in Jakobi 2, Tartu. Slides were created so that microremains could move freely under the microscope and could therefore be turned, flipped and moved to understand their characteristics. The program CellSens Entry was used to take pictures of the finds.

4. Results

Altogether 10 teeth were sampled of which 35 samples were made (Table 2).

Table 2. Number of samples from each individual.

Burial	No of samples
XII	5
XXX	6
VII	4
IX	3
XV	4
I	3
XLIII	3
XXXIII	2
XXXIV	1
VI	4
Sum	**35**

1164 microdebris were counted and recorded (Table 3). Here I present the data from dental calculus, which are categorised by biological kingdoms. After mentioning each category, in brackets a total number of said debris will be presented, with another number next to it signifying the cf.-s. Many debris are categorised with 'cf.', latin for *confer/conferatur*, meaning 'compare'. See the images of microdebris corresponding to each category in the appendix (Appendix 4).

Table 3. Debris divided by kingdoms.

Kingdom	Debris
Plantae	333
Animalia	81
Fungi	91
Non-living	142
Problematic	511
Other	6
All debris	**1164**

4.1. Kingdom Plantae

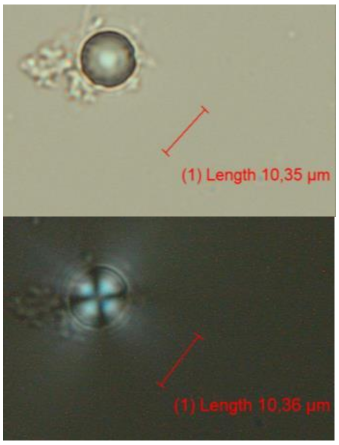
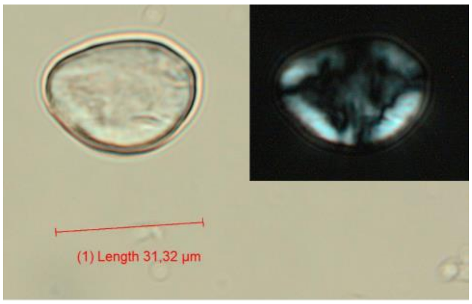
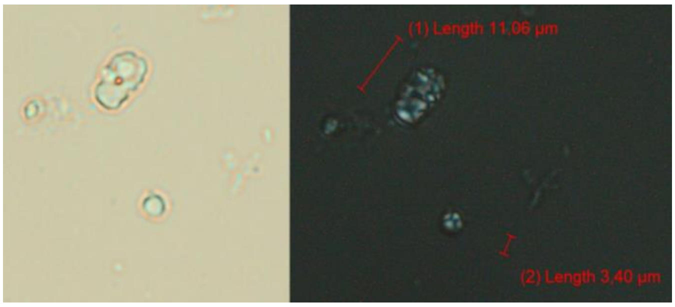
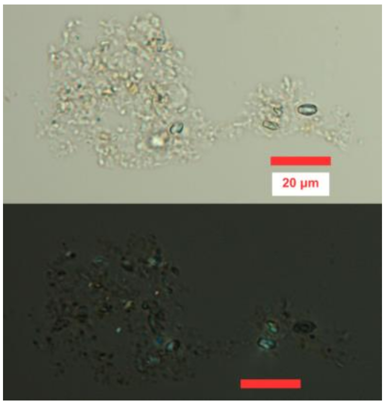
Kingdom Plantae yielded altogether 333 debris, of which 77 debris was unidentified, leaving 256 debris to be identified. The most numerous of identified plant debris (Table 4) were starch grains, these were documented and organised by morphology (Table 5). Starch was found from all individuals, most notably from burial XII. This burial was of a 40–50-year-old male, from whose pot no plant microfossils were found (Oras et al. 2018).

Table 4. Kingdom Plantae debris.

Debris	XII	XXX	VII	IX	XV	I	XLIII	XXXIII	XXXIV	VI	Sum
Starch, not identified further	46	1	5	1	2	4	1	1	0	2	63
Legume Starch	3	0	0	0	1	0	0	0	0	0	4
Cf. Legume Starch	4	0	0	0	0	0	1	0	0	1	6
Triticeae Starch	2	0	0	0	0	1	0	0	0	0	3
Cf. Triticeae Starch	6	1	0	0	0	0	0	0	0	0	7
Cf. *Avena* Starch	3	0	0	0	0	0	0	0	1	0	4
Compound Starch	4	0	0	0	0	0	0	0	0	0	4
Cf. Compound Starch	0	0	0	0	0	1	0	1	0	0	2
Cf. Starch	1	2	4	0	0	0	0	0	0	3	10
Phytolith	1	0	0	2	0	0	0	0	0	0	3
Cf. Phytolith	1	2	0	0	0	1	0	0	0	1	5
Fibre	9	5	5	0	7	7	2	3	1	12	51
Cf. Fibre	0	2	4	0	0	0	0	0	0	0	6
Cf. Plant Cell	1	2	0	0	0	2	9	1	0	0	15
Unidentified Plant Debris	15	22	10	7	9	2	2	4	0	4	75
Cf. Unidentified Plant Debris	0	0	1	0	0	1	0	0	0	0	2
Wood Debris	5	2	9	1	5	1	0	2	1	0	26
Cf. Wood Debris	2	4	2	0	1	2	1	2	2	0	16
Fruit Stone	0	0	0	13	0	0	0	0	0	0	13
Cf. Fruit Stone	0	1	0	1	0	0	0	0	0	0	2
Cf. Root	1	0	0	0	0	0	0	0	0	0	1
Microcharcoal	1	0	4	0	0	0	0	0	0	2	7
Cf. Microcharcoal	0	0	1	0	0	0	0	0	0	0	1
Plant Hair	1	2	1	1	0	0	0	0	0	0	5
Pollen	0	0	0	0	1	0	0	0	0	0	1
Cf. Pollen	0	0	0	0	0	1	0	0	0	0	1
Sum	106	46	46	26	26	23	16	14	5	25	**333**

Altogether 106 starch granules were found (this number includes the cf.-s). Starch was identified to taxons Triticeae, Fabaceae and genus *Avena*. There are more categories of starch granules that could not be associated with a specific taxon (Table 5). The dental calculus of burial XII contained significantly more starch than any other individual's samples – 69 starch granules counted, Fig. 9 shows an example of small starch granules from this sample.

Table 5. Starch granules categorised by morphology.

Morphologies of starch granules from Kukruse burials			
No	**Description of morphology**	**Identification and references**	**Example**
1	A- and B-type grains present. Shape oval to round, granules are simple. Central hilum, the extinction cross appears clear and X-shaped under cross-polarised light. Lamellae can be visible. Cracks and fissures may be visible on the surface.	**Triticeae** (D'Agostino et al, 2023; MacKenzie et al, 2021; Gismondi et al, 2018; Cristiani et al. 2016; BeMiller and Whistler, 2009; Henry et al, 2009; Winton and Moeller, 1906)	
2	Elliptical, simple grains, round, kidney- or oval-shaped. Sunken hilum at the centre. Cracks and fissures often present. Lamellae can be visible. Extinction cross with possibly multiple 'arms'.	**Fabaceae** (Punia et al., 2019; Gismondi et al, 2018; Cristiani et al, 2016; Henry et al, 2009; Ratnayake et al, 2001; Winton and Moeller, 1906)	
3	Compound grains, polyhedral in shape, stuck together. Extinction cross and a central hilum. Lamellae are not visible.	Compound starch - possibly Avena (Gismondi et al. 2018; Saccomanno et al, 2017; Matushima, 2015; Mariotti Lippi et al, 2015)	
4	Other	Possibly these are starches from wild gathered plants. Possibilities include but are not limited to *Quercus, Typha latifolia* . (Cagnato et al, 2021 SI materials)	

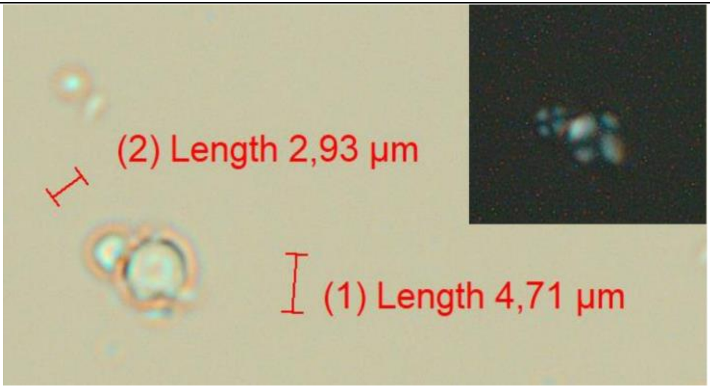
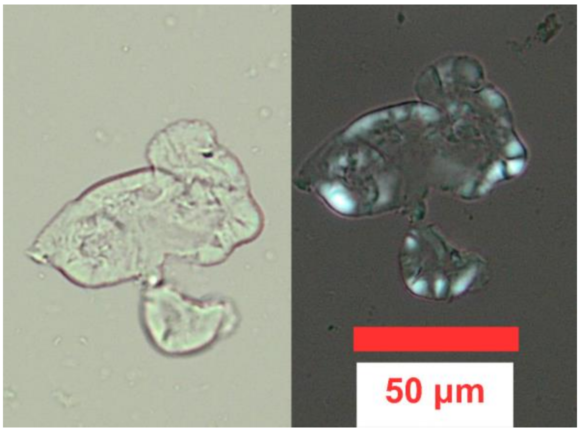
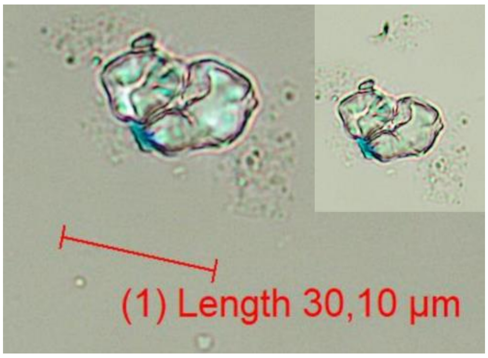
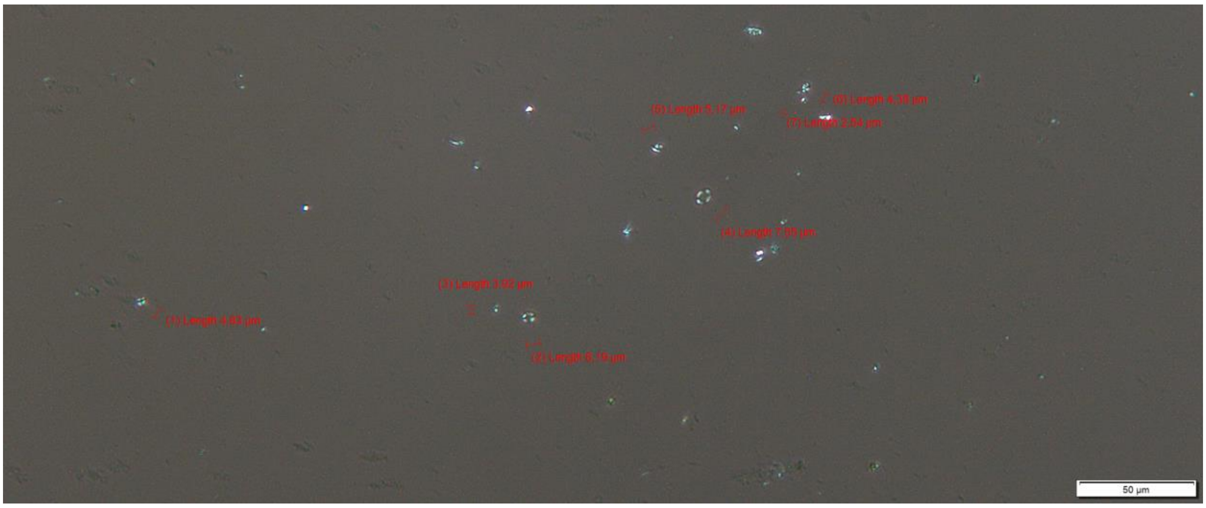
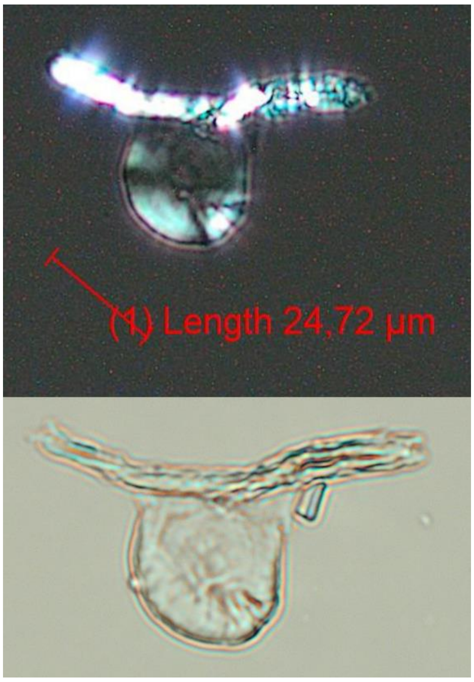
5	Very small starch grains, size around 4 µm.	Could be small grains of Triticeae starch, small grains from gathered plants such as *Phragmites australis, Nuphar, Butomus umbellatus* or others. These could also be unformed starch from a young storage organ or, these are not storage, but transitory starch grains which cannot be identified to species level. (Cagnato et al, 2021 SI materials, BeMiller and Whistler, 2009)	
6	Deteriorated starch grains	Unable to identify to species level due to not enough features. Deteriorated most likely due to processing. (Chantran and Cagnato, 2021; Juhola et al, 2014).	
7	Unidentified	Not enough data to classify into a taxon.	

Figure 9 Small starch grains together, measured. No taxonomic distinction was made for these starch granules. Sample XII_3_3_075-076.



The next largest category, ‘unidentified plant debris’ (Fig. 10), contained plant debris that could not be identified either due to a lack of identifiable characteristics (‘undiagnostic’, i.e. lacking diagnostic features) or due to my lack of experience (‘unidentified’). Therefore, no differentiation between ‘unidentified’ and ‘undiagnostic’, was made.

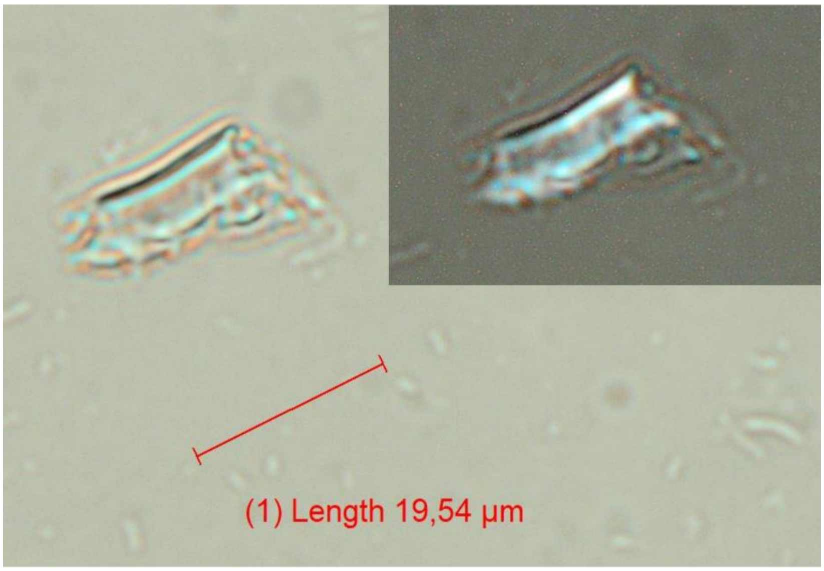
Figure 10 An example of unidentified plant debris: sample name XV_4_018 shows a starch granule that is attached to a fibrous looking microparticle.



Unidentified plant debris could be a part of the plant that had been heavily processed either by cooking, chewing or other ways of treatment.

Remains from woody plants in dental calculus were categorised as: ‘wood debris’ (42: 16 cf.)[12] and ‘microcharcoal’ (8: 1 cf.). Debris was counted into the latter category only if diagnostic features suggesting plant origin were found. If not, such burnt debris (in which I could not tell if it was from plants) fell under category ‘Burnt Debris’ (220: 2 cf.). Wood debris contained potential conifer wood pieces.

Figure 11. Cf. conifer debris from sample XXX_4_053.



Quite a few fibres were recorded (57: 6 cf.), these were categorised as belonging to Kingdom Plantae. Many were heavily processed and deteriorated. It is interesting that not many phytolith (8: 5 cf.) were found in the samples. This was unexpected as the food crust samples from similar periods often yield phytoliths (Chen et al. 2023). The explanation for their low amount of inclusion needs to be investigated further, this is discussed in Chapter 5.

[12] Here and hereafter: 42 was the whole number of wood derbis; within this number, 16 were categorised as ’cf wood debris’, i.e. it was not definite.

The rest of plant debris constituted a rather small part of total microdebris – plant root debris (1 cf.), plant hairs (5), pollen (2: 1 cf., one being conifer pollen) and fruit stones (15: 2 cf.). Plant cells (15 cf.) were found, these could not be identified to a taxonomic level other than the kingdom.

4.2. Kingdom Animalia

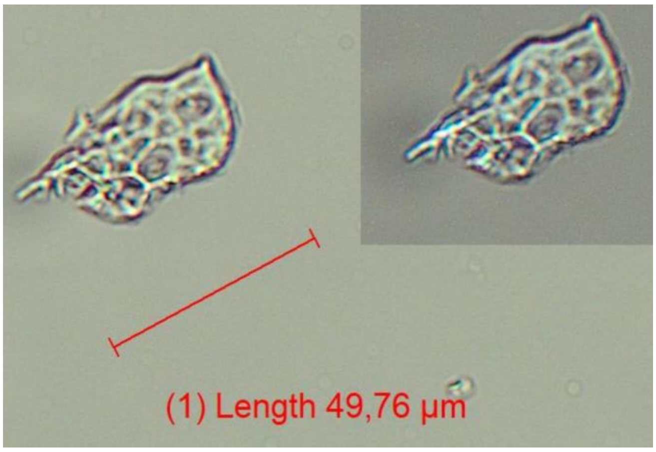
Kingdom Animalia yielded altogether 81 microremains (Table 6).

Table 6. Kingdom Animalia microremains.

Debris	XII	XXX	VII	IX	XV	I	XLIII	XXXIII	XXXIV	VI	Sum
Insect Debris	1	1	15	0	2	1	0	0	0	1	21
Cf. Insect Debris	1	2	2	0	0	0	0	0	0	0	5
Bone	1	0	1	0	0	0	0	0	0	0	2
Cf. Bone	0	1	1	0	0	0	0	0	0	0	2
Cf. Flesh	1	2	0	0	0	0	2	1	0	2	8
Hyaline	7	4	4	0	1	6	5	0	3	12	42
Cf. Hyaline	0	0	0	0	0	0	0	0	0	1	1
Sum	11	10	23	0	3	7	7	1	3	16	**81**

Most of kingdom Animalia's microremains were found to be hyaline tissue (43: 1 cf.). Hyaline refers to the colour of the debris, which is white-blueish in hue (Fig. 12). The debris categorised as hyaline have no evidence of structures common in plants (i.e. strongly reinforced cell walls). These hyaline structures are likely from animal cartilage, which, broadly, is a tissue found around bones of joints that are free to move (Britannica 2023).

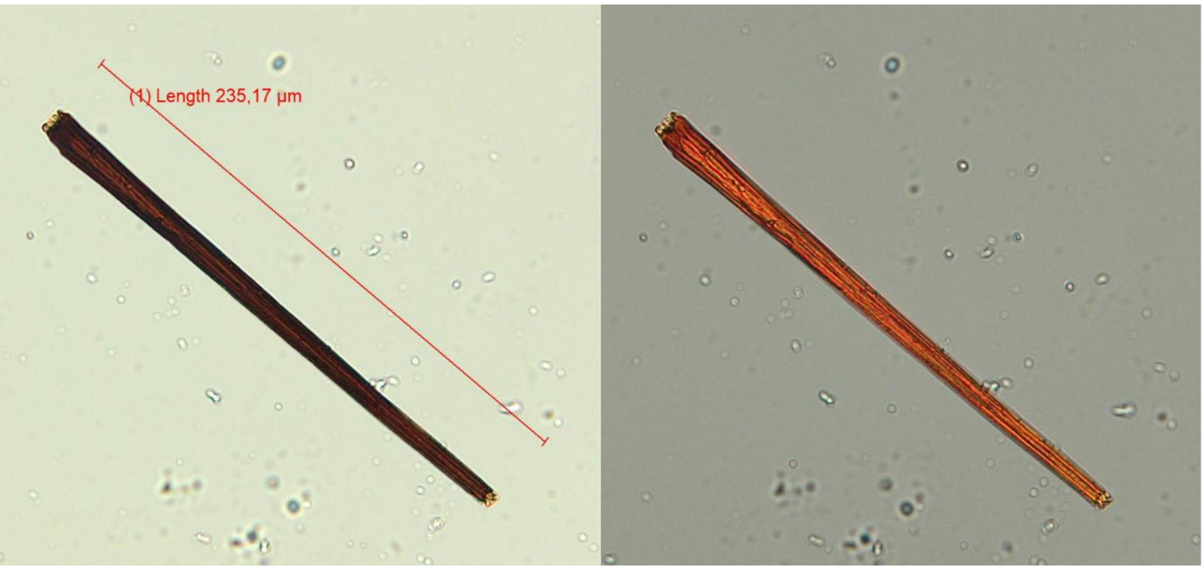
Figure 12 Hyaline structures from sample XV_2_053.



Insect debris (26: 5 cf.) was most abundant in sample VII, outnumbering all other samples in terms of insect debris (Fig. 13). It contained insect hairs and some larval casings. The debris I found was too big to be included via eating, it is generally said that particles larger than 200 microns will not be included into the calculus matrix. This is evident from other works on dental calculus – very rarely do particles larger than 200 microns appear (Radini 2016).

An explanation for the abundance of insect debris in burial VII samples can be found in Selin (2017: 21). During excavations at Kukruse, several larval casings were found, and the burials with most insect debris inside the coffins were burials IX, VIIb, XLIV and XV. Selin (2017) states that burial VIIb contained the most pupae, possibly belonging to Calliphoridae and Muscidae insects. These insects could have climbed onto the dead bodies a few days after death; the dead had to be buried around late spring or summer as the insects could not have laid their eggs on the dead so numerously in the colder periods of the year. In addition, categorised under 'insect debris', two (2) moth or butterfly wing scales were found.

Figure 13 Insect debris from sample VII_1_055. Note the legth - 200 microns!



It ought to be noted that the outermost sample (Table 7) of VII dental calculus had the most insect debris (11), whilst the innermost only had one (1). This could be indicative of the calculus not having been completely clean. This could not have been contamination as no such debris were detected in the monitoring contamination samples. Some possible bone fragments (2) were found, as well as possible pieces of flesh (8).

Table 7. Burial VII samples and their insect debris content (cf.-s included).

VII			
1st	**2nd**	**3rd**	**4th**
11	3	2	1

XII 6th sample contained two blue microdebris – one looked very much like a hyaline structure. High phosphate content in calculus can make it appear blue under light microscopy. Unfortunately, this cannot be proved by elemental analysers because dental calculus contains phosphate in places where it does not appear blue. See more on phosphate and blue colour in dental calculus in Radini (2016: 126).

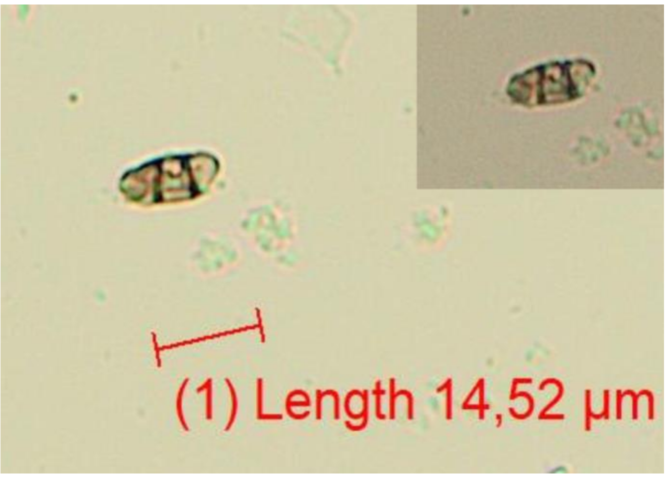
4.3. Kingdom Fungi

Fungal debris was quite numerous (Table 8). The main category is broadly fungal debris (53: 9 cf.), these could not be identified any further. Some fungal debris was categorised by type, such as Glomeromycota-type and *Alternaria*-type (Figure 14). *Alternaria* are known plant pathogens and have been found in dental calculus (Radini 2016: 143, Fig. 44.3). A few possible *Curvularia*-type fungal debris were found.

Table 8. Fungal debris.

Debris	**XII**	**XXX**	**VII**	**IX**	**XV**	**I**	**XLIII**	**XXXIII**	**XXXIV**	**VI**	**Sum**
Glomeromycota-Type	3	0	0	0	0	0	0	0	0	0	3
Cf. Glomeromycota-Type	2	0	0	0	0	0	0	0	0	0	2
Alternaria-Type	1	1	0	0	0	0	0	0	0	0	2
Cf. *Alternaria*-Type	0	1	0	0	0	0	0	0	0	0	1
Fungi	23	3	13	1	0	1	1	0	0	2	44
Cf. Fungi	1	0	2	0	0	0	4	0	0	2	9
Hypha	7	0	0	1	0	0	0	0	0	1	9
Cf. Hypha	0	1	0	0	0	0	0	0	0	0	1
Spore	0	3	1	0	1	2	2	0	0	10	19
Cf. Spore	0	0	0	0	0	1	0	0	0	0	1
Sum	37	9	16	2	1	4	7	0	0	15	**91**

Figure 14 *Alternaria*-type fungal debris, XII_3_54.



Hyphae (10: 1 cf.) are common fungal parts, which are are distinctive of active, growing fungi. Spores are not so suggestive of a natural process as spores are found everywhere, hyphas only where fungi are growing. This could be indicative of eating a mushroom either deliberately or accidentally via contaminated or not properly washed food. Another pathway of inclusion could be through fungal matter that was growing once the bodies were buried. Unfortunately, no differentiation between the pathways of inclusion is possible with current tools on hand.

4.4. Non-living nature

Minerals (131) constituted a large portion of this category (Table 9). Mineral grit is a natural part of dental calculus and is therefore expected in a sample. Some of the minerals may be from soil, i.e. from not completely clean calculus; unclean food or some other pathway. The category of non-living nature includes also undissolved dental calculus. It was present in many samples and could not be counted as it was often in clumps. Samples also contained cube-shaped crystals (6), potentially formed through crystallisation during cooking procedures (Dietrich et al. 2012). Experimental work is definitely needed to better understand the formation of the crystals. Phosphates were discussed above in chapter 4.2.

Table 9. Debris from non-living nature.

Debris	XII	XXX	VII	IX	XV	I	XLIII	XXXIII	XXXIV	VI	Sum
Mineral	0	9	40	p	7	11	38	7	5	14	131
Calculus	p	p	p	p	p	p	p	p	p	p	p
Cf. Calculus	1	1	0	0	1	0	0	0	0	0	3
Crystal	0	0	1	0	0	0	1	0	0	4	6
Phosphate	0	0	0	0	1	1	0	0	0	0	2
Sum	2	10	41	0	10	13	39	7	5	18	**142**
p - present											

4.5. Problematic debris

Problematic debris (Table 10) constituted of debris that could not be assigned to a kingdom of life, nor could it be certainly said it was from non-living nature. Numerous samples revealed the presence of burnt debris. A plausible explanation for this is the likelihood that cooking over a hearth resulted in some debris, such as soot and burnt debris, that found its way into the food, or the food was highly processed. This needs to be investigated through experimental work. Additionally, considering that people used wooden crockery (Viires and Vunder 1998: 347), the possibility of such debris accumulating in dental calculus is likely. Contaminants (41: 3 cf.) were mainly large fibres that could be identified as either from the clean laboratory room which was being constantly monitored or from the protective clothing.

Another find in this category are epithelial cells (83: 8 cf.). These are present in many animal tissues. Epithelial cells shed from the mouth's inner lining and can end up trapped inside dental calculus. The development of dental calculus and epithelial mouth cells are often associated (Tinanoff and Gross 1976). Some examples of epithelial cells can be found from Blondiaux and Charlier (2008: 8).

Table 1 Problematic debris.

Debris	XII	XXX	VII	IX	XV	I	XLIII	XXXIII	XXXIV	VI	Sum
Burnt Debris	40	12	50	11	7	13	29	3	12	43	220
Cf. Burnt Debris	1	0	1	0	0	0	0	0	0	0	2
Contamination	8	10	6	0	3	2	3	5	1	5	43
Cf. Contamination	1	0	0	0	1	1	0	0	0	1	4
Problematic	5	2	3	1	0	0	1	0	0	0	12
Epithelial	2	4	18	1	5	6	14	21	0	4	75
Cf. Epithelial	6	0	1	0	0	0	1	0	0	0	8
Unidentified	24	39	15	0	11	4	21	8	2	19	143
Cf. Food	0	0	0	1	0	0	0	0	0	0	1
Hair	0	0	0	0	1	0	0	0	0	0	1
Cf. Hair	0	0	1	0	0	0	0	0	0	0	1
Ink	0	1	0	0	0	0	0	0	0	0	1
Sum	87	68	95	14	28	26	69	37	15	72	**511**

4.6. Other debris

This category houses debris from the slides (glass), an interesting effect of a dried slide, a possible bacterial remain as well as a speck of oil. Seeing as these debris are few and offer little in way of dietary or environmental reconstruction, these will not be discussed further (Table 11).

Table 2 Other debris.

Debris	XII	XXX	VII	IX	XV	I	XLIII	XXXIII	XXXIV	VI	Sum
Glass	0	p	p	0	0	0	0	1	0	2	3
Dried slide	0	0	0	1	0	0	0	0	0	0	1
Cf. Bacteria	0	0	1	0	0	0	0	0	0	0	1
Cf. Oil	0	0	0	0	0	1	0	0	0	0	1
Sum	1	0	1	1	0	1	0	1	0	2	**6**
p - present											

5. Discussion

This chapter is divided into two parts – methodological and archaeological implications. Each subchapter tackles a specific idea or a problem regarding the larger question at hand. Seeing as a Master's thesis is not a detective novel, I will outline the research aims and the corresponding results here. Altogether, research aims were achieved and the proposed hypotheses were proved right.

The aims of the thesis		
Methodological aims		
1.	To establish and to set in motion the correct utilisation of the clean laboratory at the University of Tartu for dental calculus analysis.	This was acheived - the laboratory was created and used to successfully extract and analyse dental calculus.
2.	To create a dental calculus extraction method best suited for the facilities at the University of Tartu archaeobotanical clean laboratory.	The method was created and applied successfully.
3.	To contribute to, analyse, arrange and methodically grow the archaeobotanical reference collection at the University of Tartu.	The archaeobotanical collection saw new plants added and processed; some animal and fungal matter was added to the reference collection.
Research aims		
1.	To methodically obtain and analyse the microremains from Kukruse individuals' dental calculus whilst using the reference collection to help with identification.	The microremains were analysed from the individuals' dental calculus, the reference collection was used to help with identification.
2.	To contextualise the results – what can the results tell us about the foodways and the environment of individuals buried at Kukruse?	The method was used to uncover some plant use in Kukruse - Triticeae, Fabaceae and genus *Avena* starch was present in dental calculus samples. In addition, wood debris was found, likely relating to the environment.
Hypotheses		
1.	'Dental calculus analysis can detect more plant matter than the previous studies done on Kukruse.'	This was acheived - plant debris was found from Kukruse individuals' dental calculus, whilst the analyses done on the ceramic vessel's food crust showed few plant microfossils.

2.	'It is possible to reach a tribe level with the identification of the microremains'	This was acheived – Triticeae, Fabaceae and even genus *Avena* starch was found. Unfortunately, it is not yet possible to distinguish between different Triticeae, Fabaceae and geenus *Avena* species, nor animal products and their meats.

5.1. Methodological implications

I will discuss the methodological implications by the successes and challenges I faced along the way.

5.1.1. Successes

The clean laboratory was successfully created from scratch and used for dental calculus analysis. The room was sealed off from the outside by blocking the vents and covering the walls with plastic to prevent contaminants. The clean laboratory was effective in minimising contaminants, and it was possible to identify them in samples with the added practise of taking airborne contaminant samples and monitoring the analysts' clothes. The creation of such a laboratory is sure to bring in more dental calculus analyses to the University of Tartu in the future.

For dental calculus analysis I created a working **protocol** (Appendix 2), which followed the **methodologies** of other accomplished researchers, such as Warinner et al. (2014) and MacKenzie et al. (2021). For my own protocol, I had to adjust the methodological steps of other researchers to fit the facilities of the laboratory and the local material. For example, it became apparent that the hydrochloric acid with a concentration of 0.06 MOL was too weak to be able to break down the dental calculus. Therefore, it was upped to a 0.1 MOL concentration to better dissolve the calculus during the decalcyfing stage; the reason for this need should be examined further. Other small steps such as this, e.g. developing a sure way of marking down each microfossil on a printed piece of paper (Appendix 2), had to be taken in order for the methodology to work properly.

While most of the studies on dental calculus only target specific debris, e.g. starch (Tromp and Dudgeon 2015), I recorded all of the debris that I saw. As the discipline moves forward, more researchers begin to record all data from dental calculus samples (Radini

2016; MacKenzie et al. 2021). This is important because debris might be overlooked when targeting only a specific type. This practice makes the analyst's life more difficult – having to know and effectively identify not just plant matter, but other kingdoms of life and non-living nature. For this reason, I created a **reference collection** consisting of photographs of possible debris specifically for this thesis, where in addition to the plant remains from different species, samples of animal and fish flesh, bones, parts of insects, potential contaminants, etc were made. (Appendix 3)

5.1.2. Challenges

One challenge to face was the **cleanliness of the calculus**. It became evident that some dental calculus samples, while appearing clean, were not fully so. This can be seen in sample VII – it contained a high concentration of insect debris primarily in the outermost sample, diminishing as I progressed inward. As discussed in Chapter 4.2., this insect debris most likely originated from the insects that happened to be buried with the individual. Consequently, the innermost samples were deemed the most accurate.

The cleanliness of the dental calculus is an issue that needs to be investigated further. With the help of debris samples from the calculus cleaning as well as the monitoring the laboratory, the issues of contamination can be minimised. However, the question remains – when can a speck of calculus be deemed fully 'clean'? The information lying on top of the calculus may also serve as important markers of diet and environment as the case of the insect debris of burial VII. In all honesty, the question is much larger than the scope of this thesis, and I believe this warrants further investigation. As of yet, I believe I have not found a better method for dental calculus analysis, hence these questions will currently remain.

Humans tend to use their **teeth as a third hand** when the situation calls for it, and this practice makes dental calculus analysis more difficult and can pose interpretational problems when looking for dietary remains. Although Kukruse is a well-studied burial complex, tooth wear analysis (e.g. Mahajan 2019), has not been conducted on these teeth. It is not confirmed whether or not these individuals used their teeth as a third hand; therefore, this possibility will not be investigated further within this thesis.

Unfortunately, from the pursuit to identify all debris from dental calculus samples as stated above, stems the **high number of unidentified debris** in the results. The reason lies not only in my skills, but also in the preservation state of the debris. Many microdebris were just too highly processed to be identifiable. In works of more seasoned experts, they differentiate between 'unidentified' and 'undiagnostic' debris. This distinction was not made in the case of this thesis due to the fact that perhaps something I consider 'undiagostic' is recognisable by a true expert. Therefore, I will reserve the right to make such distinctions in the future of my career.[13]

Distinguishing between microdebris **of dietary and non-dietary** origin proved challenging. For example, Fabaceae i.e. legume starch (not identified to lower levels of taxa) could be from deliberately eating peas or from a legume family weed found commonly in other crops such as bird vetch (*Vicia cracca*).[14] Therefore, when looking at a specific legume starch granule, it is difficult to determine whether it is from deliberate or non-deliberate consumption. If the scarcity of phytoliths (see more on this topic below) leaves us thinking they cleaned their food rather vigorously, rather than the explanation of the soil's low silica content, then it would be unlikely they would have left weeds into their food, meaning that the legume starch would most likely originate from deliberately eaten peas or beans, rather than from weeds in crops. As the legume starch was not identified any further than this level of taxonomic ranking, I cannot confidently confirm the pathways of inclusion. However, it can be stated that most starch granules are likely from food, be it deliberate or non-deliberate. Starch granules associated with the Triticeae tribe of plants are likely from staple foods that were deliberately eaten. Some of the grains have visible damage – this could be from the many different forms of cooking.

Connected to the issue of dietary vs non-dietary origin of microdebris lies the problem of the identification of the **pathways of inclusion** i.e. the question of how a specific microdebris ended up in the dental calculus. This matter has been discussed by experts (Radini et al. 2017; Delaney et al. 2023). The question of 'Why is this specific microparticle in this individual's teeth?' is one of the most important questions to ask

[13] Chat GPT 3.5 was used to help with wording in this sentence.

[14] Chat GPT 3.5 was used to help with wording.

when contextualising the results. We can assume the pathways of inclusion, however, there will always be doubts. A strong reference collection can help with identifiying the pathways and experimental work is crucial (Leonard et al. 2015). I happened upon this challenge, e.g. when discussing the possible weeds, fungi or wood debris in Kukruse dental calculus samples (see below). The precise pathways of inclusion remain unanswered.

5.2. Archaeological implications

Firstly, I will outline the main results of my analysis and then contextualise them to fit the broader view of Iron Age foodways with the help of previous studies from Kukruse and similar sites.

5.2.1. The interpretation of the microremains from the dental calculus samples from Kukruse

Altogether 1164 microremains were found from the 35 samples. These could be divided into dietary vs non-dietary although the differentiation is hardly always clear. While the starch and different particles from animal tissue are likely of dietary origin, wood particles, microcharcoal, fungal matter and insect remains originate probably from the environment.

Plant consumption

Starch granules were found from all individuals, most abundantly were starch grains present in burial XII. Legume starch[15] was found from four individuals; Triticeae starch from three individuals; cf. genus *Avena* starch from two individuals. The more 'mysterious' starch granules were compound starch grains, the ones categorised as 'the smaller ones' and processed starch granules which do not correspond to a specific taxon.

A number of small **starch granules** were not given a more precise identification as these could be transitory starch granules (not morphologically distinctive of taxa); B-type starch grains of the tribe Triticeae; a smaller tuber or other gatherable plant, or, not fully

[15] Here and hereafter: the cf identifications, i.e. the 'possibles', are included in this chapter.

formed larger starch granules. Seeing as these small grains are shaped differently and do not appear uniformly circular as B-type Triticeae, I believe that at least some originate from gathered plants. This is probable as people most likely still ate gathered plants.

Compound starch grains were found, morphologically resembling genus *Avena*-type starch – sticking together or, oblong in shape. These could be *Avena sativa*, possibly deliberately cultivated, or common wild oat (*Avena fatua*), a common crop weed (See more on compound starch granules in French 1984: 186). This is a great illustration on how we should consider weeds as an important part of the reference collection. Just like with the legume starch granules, we cannot differentiate the pathway of inclusion for these compound starch granules.

Deteriorated starch grains show that food was processed in some ways. Not surprising either are the finds of fruit stones, present in two individuals (XXX, IX). It is known from the macroremains from medieval cesspits that people ate wild or cultivated fruits.

It is no surprise that individuals at Kukruse ate legumes and cereals since the cultivation and consumption is proved by the macrofossil finds of cereals and legumes from the Iron Age hillforts. In addition, microfossil and lipid analyses from the pottery from the Iron Age (Chen et al. 2023) provide more proof. Chen et al. (2023) studied the pots from Pada Pre-Viking Age settlement site, looking specifically for **plant** matter and found considerable consumption of C3 cereals (*Hordeum* spp. and *Triticum* spp.). This is also supported by Ilves (2020), who found a similar result from studying Pada Late Iron Age cemetery pots. No evidence for C4 plant consumption was found by Chen et al. (2023), although, millet consumption is discussed in the Pre-Viking Age times in Lithuania (Grikpėdis and Matuzeviciute 2020).

Although the time period of Chen et al. (2023) case study is earlier, several findings overlap. For example, C3 plant consumption of Kukruse has been suggested, backed up by dendritic phytoliths found from Pada settlement site’s pots. Even though phytoliths were not found from Kukruse dental calculus, starch with characteristics of the Triticeae tribe were found. Moreover, Chen et al. (2023) demonstrate the combination of animal products with C3 plants, a phenomenon interpreted in my samples through the presence of hyaline and bone tissue debris.

Finnish archaeobotanists have found that in addition to the main cereals having been cultivated during the times of the Merovingian period, Viking age and the Crusade period, oat was present in small numbers with flax, hemp and gold-of-pleasure being cultivated as well. (Vanhanen 2019: 68) No evidence of oil plants were found from Kukruse dental calculus samples, apart from one possible oil speck.

An interesting discovery was the scarcity of phytoliths in the samples. Phytoliths were only found in the dental calculus of four individuals out of ten (XII, XXX, IX, VI). This poses questions about the soil's silica content or the practices of food preparation – it could be that the people at Kukruse just cleaned their food vigorously, leaving no chaffs, seed coats or other plant parts into the food. The scarcity is unfortunate as dendritic phytoliths are great indicators of species of the tribe Triticeae and could have aided in identifying starch granules. This finding should be investigated further, for example by taking soil samples from Kukruse for plant microremains analysis (a method not currently practised at the University of Tartu).[16] Leonard et al. (2015) studied the foodways of Twe horticulturalists and analysed their dental calculus for microremains, fully knowing what to expect. To their surprise, few phytoliths were found. This is seen from other dental calculus studies as well (Leonard et al. 2015: 449 and references therein).

Wood for food or something else?

Wood debris is certainly interesting as it is quite numerous in the dataset (42: 16 cf.). Wood debris, including microcharcoal, was found from all individuals. The pathways of inclusion are practically endless – from woodworking, using wooden cutlery or crockery, making a fire, to the now unconventional practice of eating wood inner bark. There is written evidence of the Sámi having eaten bark from the Middle ages (Bergman et al. 2004). Identification of wood debris to a specific taxon proved difficult as debris was often highly processed or broken, although wood-pits indicative of coniferous wood were present in some examples. In my opinion, a likely pathway for a wood particle to end up

[16] Chat GPT 3.5 was used to help with wording in this paragraph.

in dental calculus can be via tableware. Estonian Medieval wooden plates were almost exclusively made of soft spruce (Vissak and Mäesalu 1999). According to ethnographic sources (e.g. Viires and Vunder (1998: 347) bowls were often made from small-leaved lime (*Tilia cordata*; *pärn*), European aspen (*Populus tremula*; *haab*) or black alder (*Alnus glutinosa*; *sanglepp*). Medieval Polish wooden and shrub material was analysed, the findings confirm the use of *Pinus sylvestris*, oak (genus *Quercus*), European ash (*Fraxinus excelsior*) and *Alnus* for everyday wooden objects (Cywa 2018).

Fungi

Fungal debris were found from eight out of ten individuals' dental calculus, with hyphae as well as spores being represented in the dataset. The question whether the fungal matter originated from deliberately eaten mushrooms, remains unanswered with the current tools on hand. I would assume it might be possible if some structural cells from mushrooms were found in dental calculus, however, as of right now, no such evidence has been published to my knowledge. Glomeromycota-type fungal matter is presumed to originate from the soil, either from uncleaned food or a speck of dirt left on the calculus. *Alternaria*-type fungi are likely from fungal parasites, commonly growing on crops. Fungal debris can be airborne – its pathways of inclusion in dental calculus are diverse.

Insects from the enironment

Insect debris was numerous, appearing in six out of ten individuals sampled. The pathway of inclusion for insect debris cannot be identified, however, I doubt they ate insects deliberately. It is far more likely the debris has ended up in the dental calculus from their environment or, like the case of burial VII, their burial conditions.

Meat consumption – hyaline structures

Hyaline structures were the most tangible record of **animal** consumption in dental calculus within these samples. Hyaline structures were present in all samples but one. As these structures lack strong cell walls, they are likely originating from animals. Seeing as most material in the dental calculus samples was deteriorated, no distinction between taxa could be made, meaning no distinction between different animals could be made.

The animal consumption in Kukruse is proved by the finds of the bones of domesticated animals (cattle, sheep/goats, horse) and fish (*Pisces*) (Maldre 2014). Also, meat consumption is further indicated by the lipid analysis of Kukruse ceramic vessels (Oras et al. 2018) These revealed the presence of biomarkers from both from aquatic and terrestrial animals. Individuals at Kukruse kept domestic animals, as is further proved by dairy residues in the pots.

A lack of plant matter was noted in the study of Rauši settlement site (11^{th}–13^{th} century) in Latvia. Gunnarssone et al. (2020) found that the pottery contained residues of fish, beef and milk, however, they saw no plant matter.

5.2.2. Comparisons

Here I will compare the dental calculus results with the organic residue analysis of pottery and stable isotope values of human collagen from Oras et al. (2018).

5.2.2.1. Dental calculus results and pottery lipids

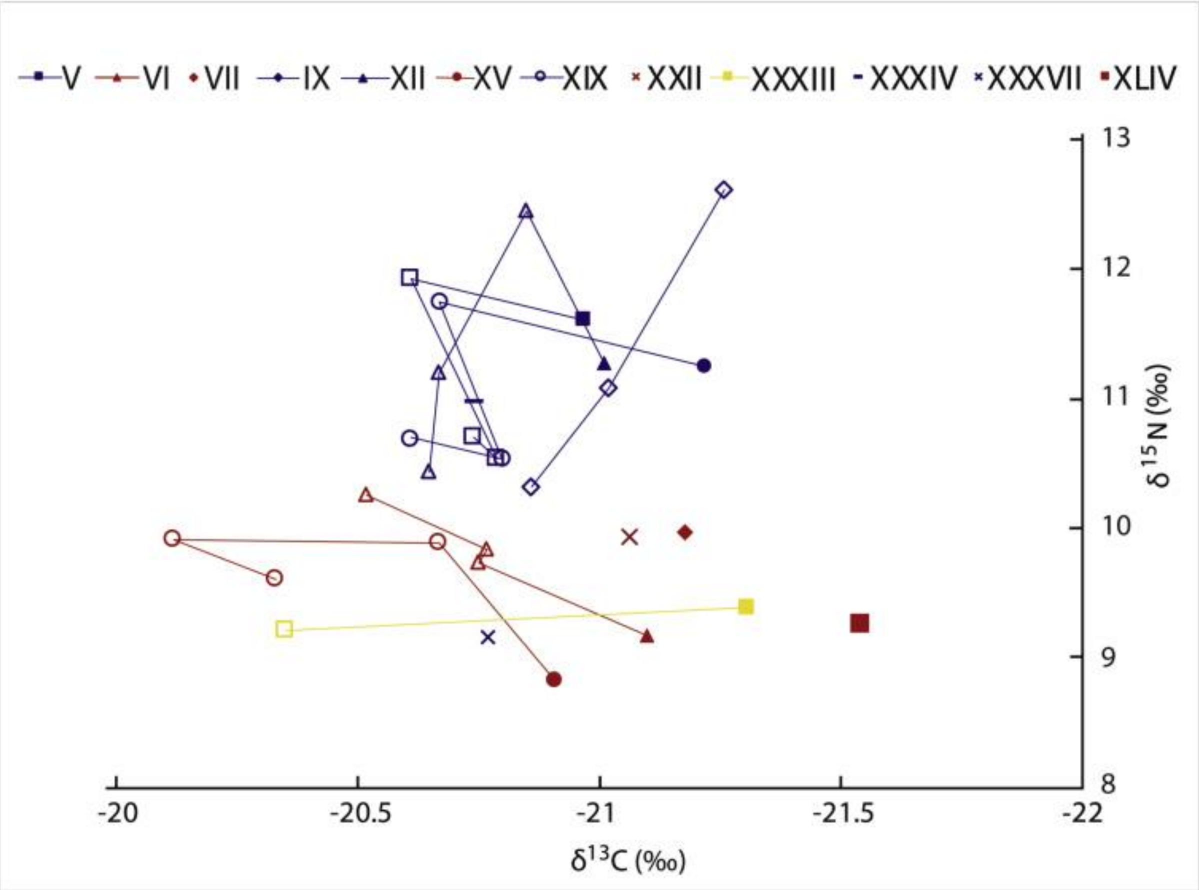
My findings are in accordance with other studies made on the Kukruse burial site (Oras et al. 2018). As noted above, no clearly identifiable plant microfossils from pottery food crusts were found by Oras et al. (2018). Although lipid residues showed possible plant biomarkers, no clear indication of considerable consumption of plant-derived foods was found. As the pots are, in a way, an extension of dental calculus in terms of debris, it could help explain why so much of the material remained unidentified in the dental calculus samples. The people at Kukruse might have been vigilant in preparing their food – cutting, chewing and boiling could have been done with care.

Joannes Dekker gave a talk at the ISBA10 conference on an experiment designed to recover proteins from food crust. They found that carbohydrate-rich foods were underrepresented in samples when animal proteins were present. (Dekker, Collins and Hendy 2023) In light of this, data from previous analyses at Kukruse may need to be revisited.

5.2.2.2 Dental calculus and stable isotopes from human bone collagen

The data for human bone collagen analysis (Figure 15) was retrieved from Oras et al. (2018). In the article, they analysed the C:N ratios of the individuals. This info is not too easily compared to microremains analysis; however, it is possible. A more in-depth analysis of the data from this thesis and the previous studies of Kukruse is definitely needed. Such an analysis did not fit the scope of this thesis; however, some more noticeable tendencies will be analysed here. For example, burial VI shows a strong inclination towards plants (Oras et al. 2018). However, the dental calculus samples show only 25 microparticles from kingdom Plantae for burial VI. In comparison, burial XII showed an animal-based biomarker in Oras et al. (2018), at the same time, this is the individual from whose dental calculus the most plant remains (106) were found.

Figure 15. From Oras et al. (2018) 'Fig. 5. The carbon and nitrogen stable isotope data from human bone (filled signs) and dentine (open signs) collagen from Kukruse cemetery. The values for each individual are represented in order of collagen formation, with the last value plotted with a filled symbol. Red marks females, blue males and yellow represents a subadult whose sex was determined by the statistical analysis of grave goods; the Roman numerals mark the grave numbers. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)'



In the case of the individual in burial XXXIV, the isotope data suggest a more protein-based diet. The dental calculus shows that plant debris for this individual was scarce, with only one possible genus *Avena*-type starch granule being found. Three (3) hyaline fragments were found. Altogether, this sample contained few microparticles (28 altogether).

Other studies from the Late Iron Age burial contexts have revealed significant consumption of animals and animal products (Oras et al. 2018; Gunnarssonne 2020; Ilves 2020), whilst the dental calculus analysis done in this thesis indicates to considerable plant consumption as well.

Summary

For this thesis, dental calculus from ten individuals (altogether 35 samples) at the Late Iron Age Kukruse cemetery in Estonia were analyised. To do this, a working dental calculus analysis method was applied and changed accordingly to suit the facilities at the University of Tartu.

Kukruse is a 12th–13th century burial site in Northern Estonia, it was excavated in the winter of 2009–2010. The burials analysed in this thesis are from the inhumation layer of the burial complex: burials numbered I, VI, VII, IX, XII, XV, XXX, XXXIII, XXXIV, XLIII. For the analysis of dental calculus, a clean laboratory was created at the University of Tartu, along with the dental calculus analysis method. This was modified and applied to suit the Kukruse material. One of the novelties of this work lies in the methodology – all encountered debris was counted and recorded. This is different from many other works done on dental calculus – often, a specific type of debris is targeted.

For the interpretation of the microremains from the dental calculus, I compiled information about Late Iron Age foodways (Chapter 2.2). Using the reference collection (consisting of around 400 plants and other specimens) at the University of Tartu, I created a targeted reference collection, focusing on the Late Iron Age foodways and environment (Appendix 4).

From the dental calculus, I expected to find microremains such as starch granules, phytoliths, calcium oxalates, pollen granules, fungal debris and many more (Chapter 1.3. explores these further). Every one of the ten individual's samples contained microremains. The found microremains (altogether 1164 were counted) were categorised by kingdoms of life – kingdom Plantae yielded 333 microremains; kingdom Animalia 81 microremains; kingdom Fungi 91. Additional categories were problematic debris, non-living nature and other debris. The **starch granules** (kingdom Plantae), most likely originating from food, belonged to taxa such as Triticeae (10: 7 cf.), Fabaceae (10: 6 cf.) and *Avena* (4 cf.). The more 'mysterious' starch granules consisted of unidentifiable small granules, compound starch granules as well as damaged granules. The latter category has characteristics that can be interpreted as possessing evidence of cooking. The scarcity of

phytoliths from dental calculus is noteworthy. Only 8 phytoliths (8: 5 cf.) were found. Kingdom Animalia contained hyaline tissues (43: 1 cf.), being the most tangible connection to evidence of animals having been eaten. Fungal debris was numerous (91), being present in 8 out of 10 samples.

One of the main challenges of a dental calculus analyst is determining the precise **pathways of inclusion**, i.e. the question 'How did this microparticle end up in dental calculus?'. For kingdom Plantae, the interpretation can be muddied by accidental weeds ending up in the food, as can be the case with Fabaceae starch granules – probably one of the species of the genus *Vicia* (*Vicia faba*, broad bean, produces similar starch granules as *Vicia cracca*, a common weed). In addition, determining the pathways of inclusion of different wood debris is challenging, as these can be present from tableware, manual labor, crafts or even form eating wood inner bark as the Sami were known to do even up until Medieval times.

Another challenge lies in the high number of unidentified debris. This can be explained by the research paper made on Kukruse by Oras et al. (2018), who found few microremains from pottery food crust, possibly meaning that the food they prepared at Kukruse over 800 years ago, might have just been very heavily processed. Their results from the human stable isotopes show the individuals consuming plants and animals, some to a greater degree than other. The dental calculus analysis results support this, with more plant matter visible than the previous works.

This study demonstrates that dental calculus analysis helps recover information that cannot be done by other means. Microremains offer insight into the lives of ancient people[17] and help compliment other methods targeting foodways or environment reconstructions. In future dental calculus research, the method and facilities created during the course of this thesis can be applied and used to fit different research questions or for other case studies. Future directions of the topic include trying to understand the scarcity of phytoliths from Kukruse, for example by taking soil samples and analysing

[17] Chat GPT 3.5 was used to help with wording

them for microremains; and, analysing in more depth the connections between the isotopic data from Kukrue and the dental calculus analysis.

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Resümee

Pealkiri: „Mikrojäänuste analüüs Kukruse hilisrauaaegse matmispaiga indiviidide hambakivist“.

Töö eesmärk oli uurida Kukruse matmispaiga (12–13. sajand) kümne indiviidi hambakivi (Lisa 1/Appendix 1). Tegemist on olulise matmispaigaga Eesti arheoloogilises materjalis ning sinna maetute toitumist on varasemalt uuritud (Oras et al. 2018), kuid mitte käesolevas töös esitatud meetodiga. Kuna eelnevad uuringud ei ole Kukruse inimeste toitumises kuigivõrd taimi tuvastanud, leiti hambakivi uurimises taimede otsimiseks suurepärane võimalus. Hambakivi ei ole Eestis sellisel skaalal uuritud, väiksema valimiga on avaldatud vaid autori bakalaureusetöö (Unt, 2021).

Tööl oli mitu eesmärki. **Metodoloogilisi eesmärke** oli kolm:

1. Luua Tartu Ülikooli hambakivi analüüsimiseks sobiv puhaslabor ning kasutada seda hambakivi analüüsimiseks.
2. Luua hambakivi analüüsimiseks sobiv meetod, mis sobiks Tartu Ülikoolis olevale laborikeskkonnale.
3. Tartu Ülikooli võrdluskogu metodoloogiline kasutamine, täiendamine, korrastamine ja analüüsimine.

Uurimise seisukohalt püstitati kaks eesmärki:

1. Meetodipõhiselt eraldada ja analüüsida Kukruse indiviidide hambakivist pärit mikrojäänuseid, kasutades võrdluskogu mikrojäänuste määramise abiks.
2. Tulemuste konteksti seadmine – mida ütlevad analüüsi tulemused Kukruse indiviidide toitumise ja keskkonna kohta?

Töö oli ka kaks **hüpoteesi**: „Hambakivi analüüsiga saab tuvastada rohkem taimseid jäänuseid kui seda on varasemad uuringud Kukruse kohta tuvastanud”, ning „Mikrojäänuste analüüsiga on võimalik jõuda botaanilise hõimu tasandile”

Selleks, et kõiki neid eesmärke saavutada ja hüpoteese tõestada, esitan kõigepealt infot selle kohta, kuidas toitumist uuritakse; mis on hambakivi ning mida ja kuidas hambakivist

leida saab. Peatükis 1.3. avan tausta – mis on peamised osakesed, mida hambakivist leida võib. Laiemalt on kirjutatud tärklisest, fütoliitidest, kaltsiumoksalaadi kristallidest, õietolmust, seeneosakestest ja teistest osakestest.

Hambakivi on mineraliseerunud hambakatt, mis kivistub umbes kahe nädalaga. Selle sisse võivad kinni jääda osakesed inimese toidust ja keskkonnast. (Marcotte and Lavoie 1998; Lieverse 1999; Hillson 2005; Radini et al. 2017) Hambakivist on võimalik leida tärkliseosakesi, fütoliite, kaltsiumoksalaadi kristalle, õietolmuosakesi, seeneosakesi ja pea lugematul arvul teisi osakesi.

Peamised mikrojäänused, mida tihtipeale hambakivist otsitakse on tärkliseosakesed ja fütoliidid. Taimed toodavad **tärklist** fotosünteesi käigus, tootes seda päeval ja kasutades öösel (Weise et al. 2011: 3109). Tärklise liigiliseks määramiseks on vaja uurida selle kuju, algme armi, kasvurõngaid, pragusid, lõhesid ja valguse kaksikmurdumise teel tekkivat risti, ning omakorda selle sümmeetriat ja kuju (Leonard et al. 2015: 450). Tärklise kuju ja omadusi võivad moondada erinevad toidutegemistehnikad, mistõttu on oluline uurida tärklist ka töödeldud kujul (Henry et al. 2009). **Fütoliidid** on taimedes leiduvad osakesed, mis koosnevad ränist. Neid peetakse oluliseks taime kaitsel ja taime kuju toetamisel. Fütoliidid tekkivad, kui taim võtab mullas leiduvat ortoränihapet (H_4SiO_4) ning ladestab sellest toodetud ränioksiidi (SiO_2) rakkudesse, rakukestadesse või rakkude vahelistesse tühimikesse. (Piperno et al. 2002: 10 923; Piperno 2006: 5). Vastavalt ladestuskohale võtab ränioksiid omapärase kuju ning tekkib fütoliit. Nende kujud erinevad nii taime sees kui ka liigiti. (Shakoor et al. 2015: 10). Fütoliitide seostamiseks kindla taimega on vajalik uurida nende ehitust, kuju, suurust, värvust ja muid omadusi. Fütoliidid on äärmiselt vastupidavad ning võivad säilida muutumatutena milojoneid aastaid. (Shakoor et al. 2015; Zhang et al. 2017: 43–44)

Teises peatükis räägin Kukrusest ja hilisrauaaegsest toitumisest. Kukruse on hilisrauaaegne matmispaik, mis asub Põhja-Eestis. Sealt leitud kalmistu on üks olulisemaid hilisrauaaegseid arheoloogilisi mälestisi. Kukruse on küllaltki hästi uuritud muistis. Käesolevas töös võrdlen tulemusi Oras et al. (2018) tehtud analüüsidega, mis kujutavad endast Kukruse savinõudest tehtud lipiidianalüüside ja inimluudest tehtud isotoopuuringute võrdlemist ja koondamist. Kuna tehtud analüüsidest ei paistnud taimed kuigivõrd hästi välja, on käesoleva töö hambakiviuuringud mõeldud just selle teadmistes oleva „augu" katmiseks.

Hilisrauaaegne toitumine tuli enne töö tegemist kaardistada. Selleks kasutasin tulemusi, mida on Eestis ja lähimaades tehtud nii mikro- kui ka makroskoopiliste taimejäänuste, inim- ja loomaluude uuringute, lipiidi- ja isotoopanalüüside põhjal. Kasutasin ka etnograafilisi ja mõningaid kirjalikke allikaid. Hilisrauaaja inimesed tegelesid põllumajandusega, **kasvatades** otra (*Hordeum vulgare* ja selle alaliigid), rukist (*Secale cereale*), vähemal määral nisu (*Triticum aestivum/dicoccon*) ja kaera (*Avena sativa*). Kasvatati ka kaunvilju, näiteks herneid (*Pisum sativum*) ja põldube (*Vicia faba*). Kanepit (*Cannabis sativa*) ja lina (*Linum usistatissimum*) kasvatati tekstiilide ja õlide valmistamiseks, samuti on nende taimede seemed söödavad. Keskaegsetest kontekstidest on leitud puuviljade seemneid, seda kinnitavad ka kirjalikud allikad. **Korilusega** tegeleti kindlasti ka hilisrauaajal, sarapuupähkli (*Corylus avellana*) jäänuseid on leitud kiviajast kuni keskajani Eesti arheoloogilistest kontekstidest. **Imporditud** toiduained ilmuvad Eestisse suuresti keskajal, kuid ka varem toimus kaubandus teiste paikadega. Näiteks on tõenäoline, et ka Eesti aladele jõudis hirss (*Panicum miliaceum*) muinasajal, mida kasvatati Leedus. On arvatud, et keskaegsetes Eesti linnades sõid hirssi kõrgema sotsiaalse staatusega inimesed. Hilisrauaaja inimesi ümbritsesid ka taimed, mida nad ei soovinud, s.t umbrohud. Neid on leitud keskaegsetest jäätmekastidest, näiteks kahar kirbutatar (*Polygonum lapathifolium*). Ka neist tuleb teadlik olla.

Hilisrauaaja inimene pidas kindlasti ka loomi, tegeles kalastamise ja jahilkäiguga ning hoolitses mesilaste eest. Kukruselt leiti veise-, (*Bos taurus*) lamba/kitse-, (*Ovis aries/Capra hircus*) kalade (Pisces) ning hobuseluid (*Equus caballus*). On teada, et hilisrauaajal söödi Eestis kanu (*Gallus domesticus*), parte (Anatidae) ja hanesid (*Anser*).

Kolmandas peatükis on juttu meetoditest. Töö eesmärkide saavutamiseks kasutati levinud meetodeid (Warinner et al. 2014; MacKenzie et al. 2021) ja kohandati need Kukruse materjalile ja Tartu Ülikooli hambakivi uurimise puhaslaborile sobivaks. Hambakivi uurimiseks loodi puhaslabor Tartu Ülikooli, selle puhtuse tagamiseks uuriti ruumi sattuvaid võimalikke saasteosakesi. Selleks, et tunda ära hambakivis esinevaid osakesi, kasutati Tartu Ülikooli mikro- ja makrojäänuste võrdluskogu ning lisati sinna uusi liike, töödeldi neid ja uuriti vastavalt rauaaegse toitumise eeldustele. Meetodid on välja toodud lisades (Lisa 3/Appendix 3).

Neljas peatükk käsitleb tulemusi. Töös uuritud kümne indiviidi (I, VI, VII, IX, XII, XV, XXX, XXXIII, XXXIV) hambakivist tehti kokku 35 proovi ja leiti 1164 mikrojäänust (Tabel 2; Tabel 3). Kõik mikrojäänused pandi kirja ning määrati kategooriatesse botaaniliste riikide (taimed, loomad, seened) või muude omaduste põhjal. Taimeriigist pärinevaid mikrojäänuseid oli 333, loomariiki kuuluvaid 81 ning seeneriiki 91. Ülejäänud kategooriad olid problemaatilised osakesed, elutu loodus ja muud osakesed.

Taimse toiduga kõige tugevamalt seotud mikrojäänused olid **tärkliseosakesed**, mis määrati omaduste põhjal erinevatesse tüüpidesse (Tabel 5). Märkimisväärsed on Triticeae (10: 7 cf.)[19], Fabaceae (10: 6 cf.) ja *Avena* (4 cf.). Fütoliite ei leidunud proovides palju (8: 5 cf.). Puiduosakesi (42: 16 cf.) leiti pea kõigist proovidest. Mõne osakese puhul sai öelda, et tegemist on okaspuult pärit puiduga.

Loomse toiduga saab kõige kindlamalt siduda **hüaliinjäänuseid** (43: 1 cf.). Tegemist on tõenäoliselt loomsete jäänustega. Seeneriigist pärit jäänuste puhul ei ole võimalik öelda, kas neid söödi tahtlikult või kogemata. Mikrojäänuse teekonda hambakivisse on väga keeruline tõestada ning seente puhul ei ole võimalik öelda, kas osakene võis sattuda suhu pesemata või halvaks läinud toidult, meelega söödud seenelt, inimese keskkonnast või hoopis matusemullast (millisel juhul jäi osake puhastamisel märkamata).

Viiendas peatükis toimub arutelu. Töö tulemustest oli üks olulisemaid meetodi kasutamine ja töökeskkonna loomine hambakivi puhastamiseks ja uurimiseks. Samuti on oluline, et märkisin üles kõik mikrojäänused; tihtipeale keskendutakse mõnele kindlale

[19] Siin ja edaspidi: esimene number on koguarv, teine number ja cf. näitab mitu osakest on koguarvust n-ö ebakindla määranguga (ladina keeles *confer/conferatur*, tähendab „võrdle". Terminit kasutatakse botaanikas siis, kui soovitakse isendit määrata, kuid ei leidu piisavalt informatsiooni, et seda kindalt öelda). Siinkohal leiti kümme tärkliseosakest triibusest Triticeae, millest ebakindel määrang oli seitsmel.

mikrojäänuse kategooriale, näiteks tärklistele või fütoliitidele. Tööl oli ka väljakutseid. Näiteks ilmnes, et mõni hambakiviproov polnud piisavalt puhas, nii juhtus näiteks matuse VII puhul – hambakivist tuli välja väga palju putukaosakesi. Selgituse võib leida sama matuse kohta tehtud arheoentomoloogilisest bakalaureusetööst (Selin 2017), milles leiti matusest VIIb putukaid ja nende nukke. Ilmselt ronisid putukad surnukehadele ning nende jäänuseid nägin mina hambakivist. Võimalikud määrangud on samuti töös välja toodud – *Calliphoridae* ja *Muscidae.*

Inimluudest eraldatud kollageeni põhjal tehtud isotoopanalüüsidega (Oras et al. 2018) võrreldes on näha mõningaid kattuvusi. Näiteks on matuse VI indiviidi isotoopväärtused taimede poole kaldu, küll aga leidsin selle sama indiviidi hambakivist vaid 25 mikrojäänust mis kuuluvad taimekuningriiki. Samas, indiviidi XII puhul näitavad isotoopväärtused pigem loomset toitu; minu tulemustes on sama indiviidi hambakivis kõige enam justnimelt taimejäänuseid (106). (Oras et al. 2018)

Keraamika põhjal tehtud analüüsides võib peituda vastus suurele kogusele määramata jäänud mikrojäänustele. Nimelt leiti kõrbekihist väga vähe mikrojäänuseid, üldpilt koosnes tugevalt töödeldud materjalist. Potid on tahes tahtmata maetud indiviididega seotud, mis võib kinnitada, et hambakivis olevad määramata jäänud osakesed olidki lihtsalt liiga tugevasti töödeldud, et neid oleks saanud määrata.

Leidsin igale töös esitatud eesmärgile vastuse. Lisaks labori ja meetodi loomisele ja kasutamisele lõin olemasoleva võrdluskogu põhjal (milles leidub üle 400 taime, lisaks vähemal määral looma- ja seeneproove) hilisrauaaja uuringuteks sobiva võrdluskogu. Seda võrdluskogu kasutasin hambakiviproovides leiduva määramiseks. Ka hüpoteesid said tõestatud – jah, hambakivi analüüsimisega on võimalik tuvastada rohkem taimi ning jah, ma suutsin jõuda mikrojäänuste analüüsiga botaanilise hõimu tasandile.

Appendix

Appendix 1. Information on teeth.

Context	Grave goods summarised (Chat GPT 3.5 was used to summarise data). Info from Jonuks and Lõhmus (2010).	Type of tooth	Sex (Oras et al 2018)	Age (years, Oras et al 2018)	Weight of tooth before	Microfossils of plant origin (Oras et al 2018)	Weight of tooth after (dry)
Kukruse XII	1. Larger horseshoe-shaped brooch (*hoburaudsõlg*) found between the ribs on the right side of the chest. 2. Small (2 cm in diameter) sieve. 3. Small iron object, possibly a knife, on the outside of the left thigh. 4. Ceramic vessel broken into small pieces next to the left heel, most likely broken by the excavator 5. *Jalutsivõru* (leg bracelet) found between the two feet, possibly related to the right foot. 6. Sword on the right side of the burial, with the right palm resting on the upper part of the blade, poorly preserved. - Traces of a handle made of organic material around the iron swede of the handle. - Small square bronze stud near the handle, potentially related to the sheath decoration.	upper right first premolar	male	40-50	not weighed	no	0.8626 g
Kukruse burial XXX	1. Clay vessel.	lower right second incisor	male	22-26	not weighed	no	0.6129 g

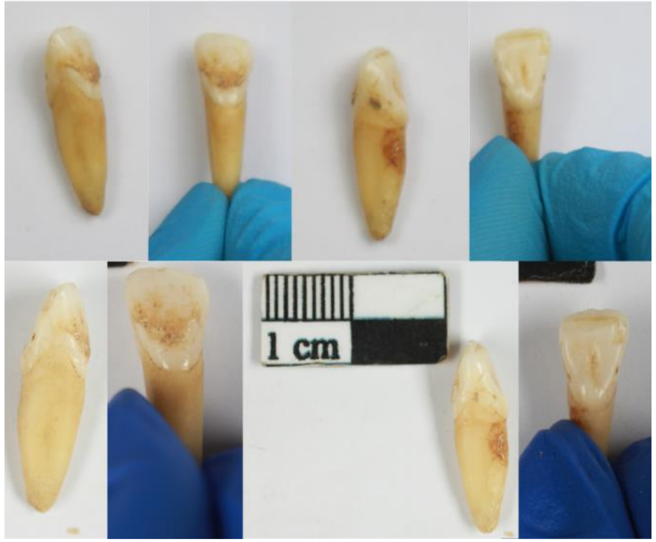
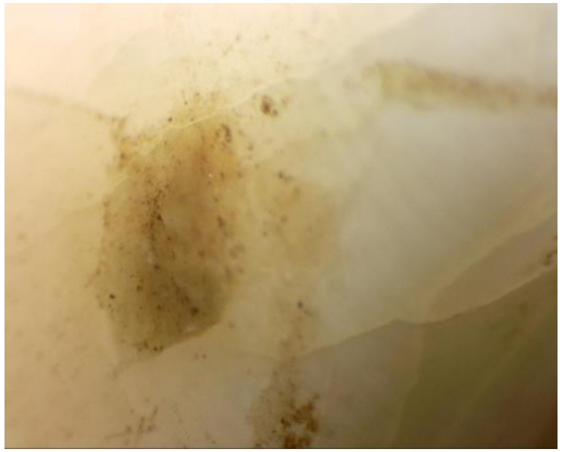
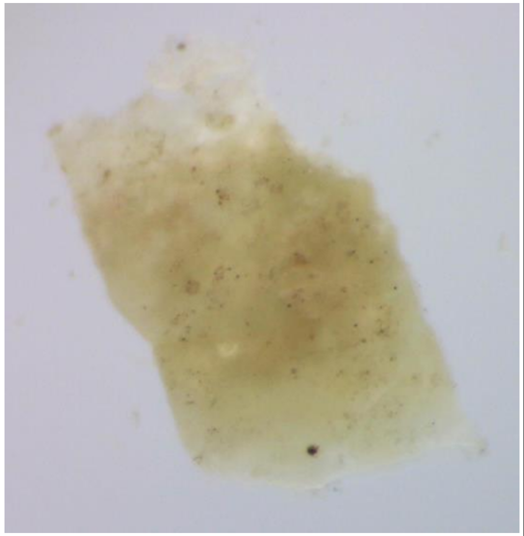
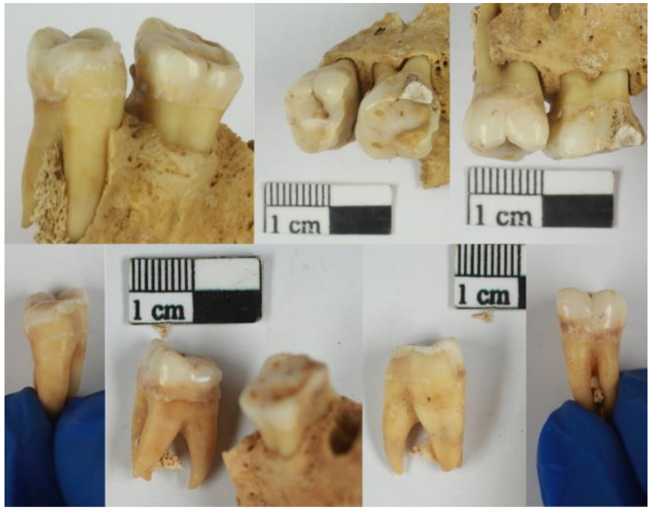
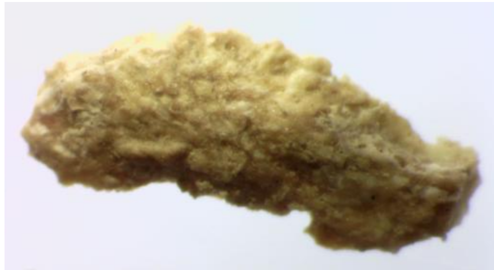
Context	Grave goods summarised (Chat GPT 3.5 was used to summarise data). Info from Jonuks and Lõhmus (2010).	Type of tooth	Sex (Oras et al 2018)	Age (years, Oras et al 2018)	Weight of tooth before	Microfossils of plant origin (Oras et al 2018)	Weight of tooth after (dry)
Kukruse burial IX	1.Complete clay vessel. 2.Scythe. 3.Spearhead. 4.Two bronze spirals between the legs. 5.Bronze wire sheath and a fire striker on the outside of the right pelvis. 6.Ring on the right hand. 7.Two bracelets made of twisted bronze wire on the left pelvis. 8.Bracelet of the same type around the left hand. 9.Bracelet on the left forearm. 10.Heavily oxidized iron knife with remnants of its sheath on the outside of the left thigh. 11.Horseshoe-shaped brooch (*huburaudsõlg*) on the right shoulder. 12.Two necklaces and a glass bead necklace around the neck. 13.Preserved organic material between the thighs (retrieved as a monolith).	upper right second molar	male	25-35	dry 11.2718 g	yes	2,1049 g (d
Kukruse burial I	1.Knife. 2.Scissors. 3.Bronze spirals. 4.Bronze chain. 5.Clay vessel (broken, in pieces). 6.Belt studs. 7.Bronze bracelets. 8.Glass beads. 9.Brooches. 10.Pendant coins.	upper right second incisor	female	25-40	dry 0.6034 g	yes	0,5990 g

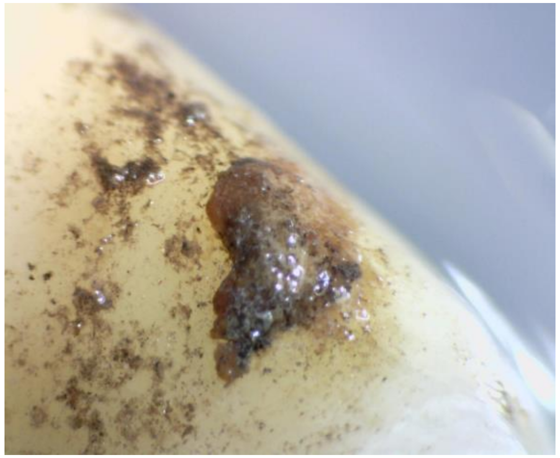
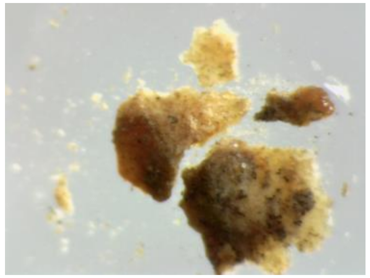
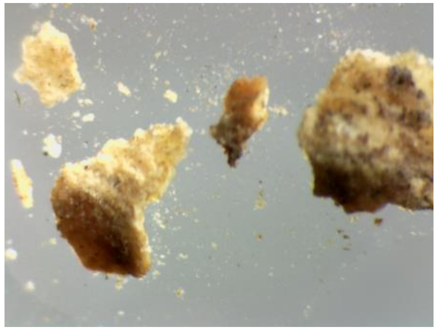
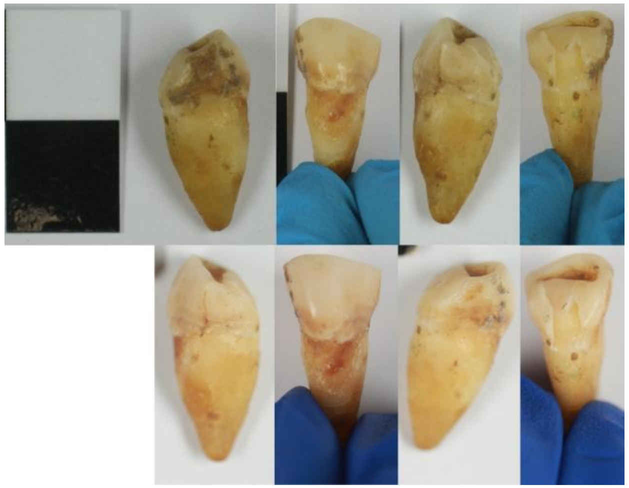
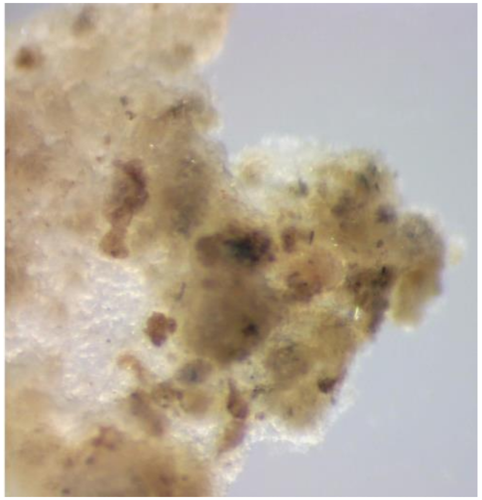
Context	Grave goods summarised (Chat GPT 3.5 was used to summarise data). Info from Jonuks and Lõhmus (2010).	Type of tooth	Sex (Oras et al 2018)	Age (years, Oras et al 2018)	Weight of tooth before	Microfossils of plant origin (Oras et al 2018)	Weight of tooth after (dry)
Kukruse burial XV	1. Cross-shaped brooch on the right shoulder. 2. Single necklace with an iron chain (*rauast varrasahelikuga ühekordne rinnakee*). 3. Glass bead necklace around the neck. 4. Chains on both shoulders. 5. Pendant on the left upper arm. 6. Pendant on the top of the right shoulder blade. 7. Bracelets made of twisted bronze wires on the arms. 8. Belt with a leather strap adorned with bronze studs. 9. Bronze-decorated knife sheath attached to the belt. 10. Bronze spiral-bordered apron. 11. Fabric with decorated lower edges. 12. Modest bronze spirals marking the dress or skirt edge. 13. Leather strips and pieces around the feet. 14. Half-broken clay vessel. 15. Fish bones and scales near the legs.	upper left canine	female	30-40	dry 0.8488 g	no	0.8531 g

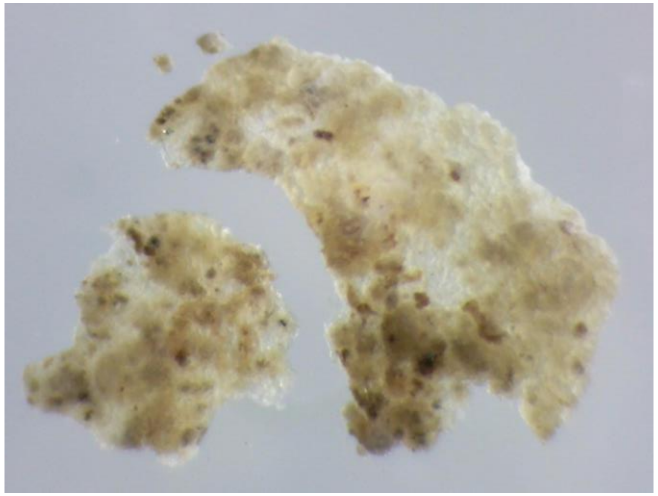
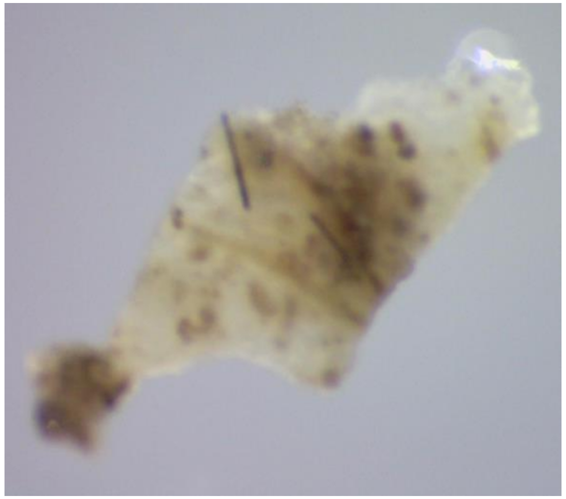
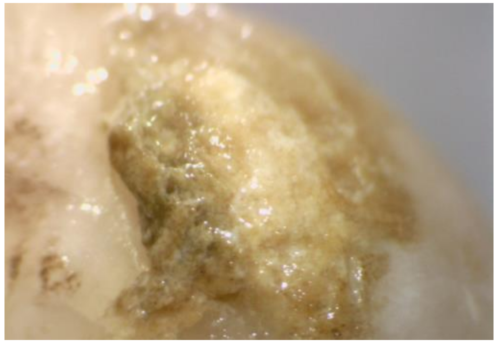
Context	Grave goods summarised (Chat GPT 3.5 was used to summarise data). Info from Jonuks and Lõhmus (2010).	Type of tooth	Sex (Oras et al 2018)	Age (years, Oras et al 2018)	Weight of tooth before	Microfossils of plant origin (Oras et al 2018)	Weight of tooth after (dry)
Kukruse burial VII	1. Entire set of funerary clothes. 2. Several necklaces made of glass beads, with *rinnalehed* and pendant coins (*ripatsmündid*). 3. Horse-shaped pendant on the left shoulder. 4. Preserved breast pins (*rinnanõelad*) and chains (*rinnakeed*) with chain carriers. 5. Six-row chain necklace extending over the whole body up to half the thigh. 6. Eight bronze bracelets on the right arm. 7. Seven bronze bracelets on the left arm. 8. Ring on the fourth finger of the left hand. 9. Small bronze spirals on the left side of the chest. 10. Bronze chain and textile under the right hand's bracelets. 11. Belt covered in round bronze studs. 12. Belt held together by two straps with trapezoidal extensions. 13. Knife and its sheath on the belt. 14. Bronze wire pipe (*toru*) on the pelvis. 15. Horseshoe-shaped brooch (*hoburaudsõlg*) with a hoop pierced through it on the left femur. 16. Preserved and partially traceable bronze spiral decorations on the outer sides of thighs, knees, and ankles. 17. Iron nail about 15 cm on the outside of the left knee. 18. Bronze spiral between the feet with loose ends pointing up. 19. Complete clay vessel between the feet.	upper right canine	female	50+	wet 0.9512 g	yes	0.8772 g

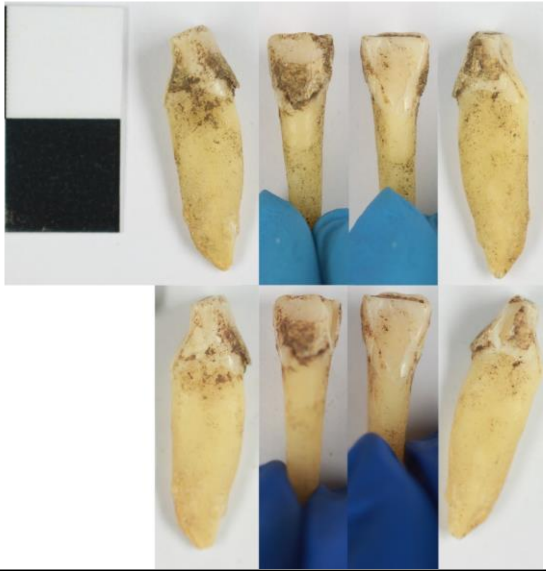
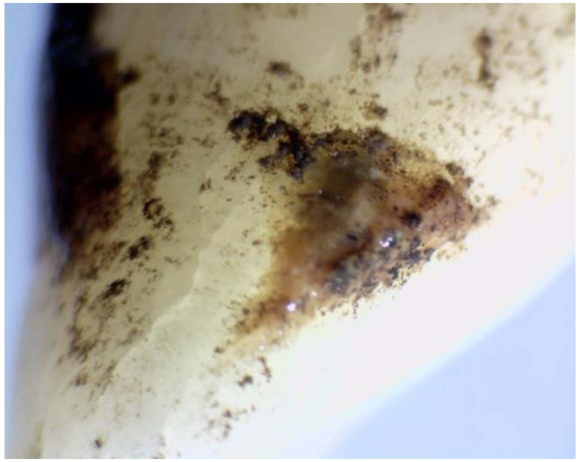
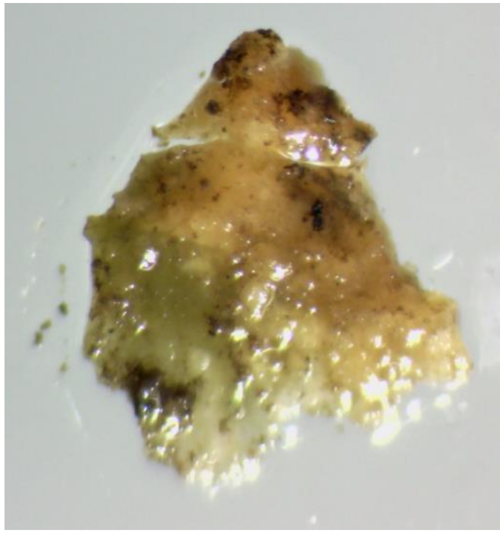
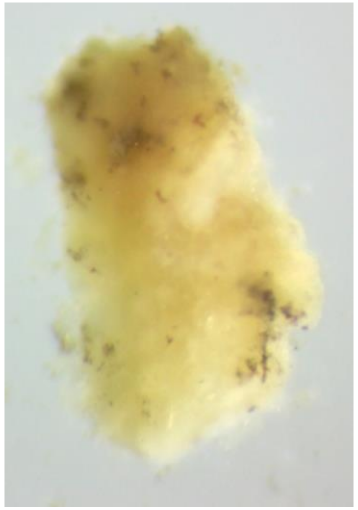
Context	Grave goods summarised (Chat GPT 3.5 was used to summarise data). Info from Jonuks and Lõhmus (2010).	Type of tooth	Sex (Oras et al 2018)	Age (years, Oras et al 2018)	Weight of tooth before	Microfossils of plant origin (Oras et al 2018)	Weight of tooth after (dry)
Kukruse burial VI	1. Bronze spirals. 2. Bronze bracelets around both hands. 3. Beaded necklace with silver plates (*hõbedast rinnalehed*) around the neck. 4. Breast pins (*rinnanõelad*) on both shoulders. 5. Necklace covering the entire body. 6. Other jewelry. 7. Rich selection of tools at the feet - Pot (likely broken during firing) - Scythe - Iron point (*raudteravik*) - Iron scissors.	upper right canine?	female	40-50	dry 0.8625 g	no	0.8431 g
Kukruse burial XLIII	1. Necklace near the right foot. 2. Intact and upright ceramic vessel on the outside of the left knee. 3. Bronze belt buckle. 4. Bronze belt pin . 5. Knife near the left femur, with the tip bent downwards. 6. Spearhead near the right shoulder. 7. Iron hoop under the chest. 8. Fish scales and fish backbones in the burial. 9. Larger collection of fish scales and backbones near the right hip.	lower left second incisor	male	30-45	wet 0,6952 g	no	0.6255 g

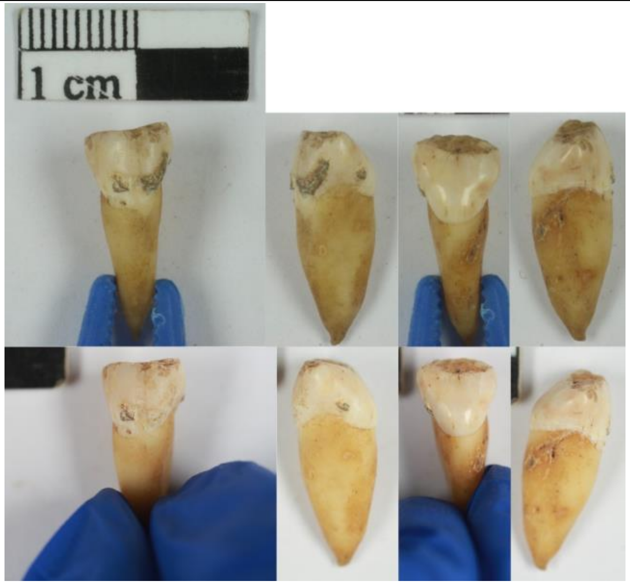
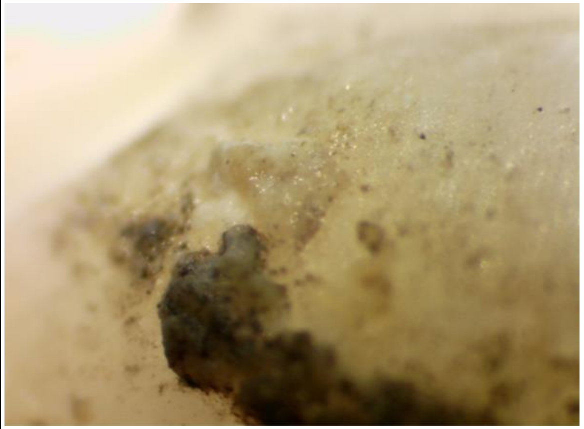
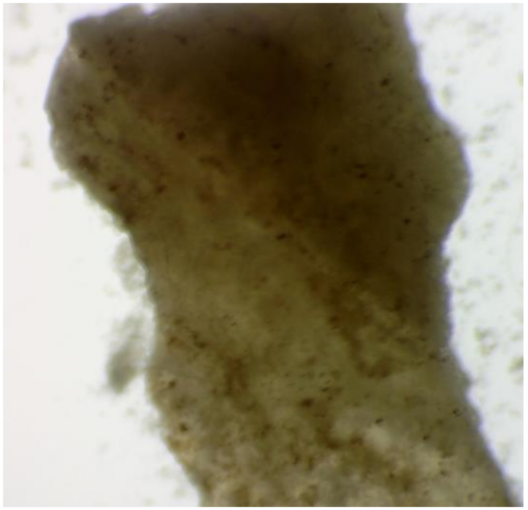
Context	Grave goods summarised (Chat GPT 3.5 was used to summarise data). Info from Jonuks and Lõhmus (2010).	Type of tooth	Sex (Oras et al 2018)	Age (years, Oras et al 2018)	Weight of tooth before	Microfossils of plant origin (Oras et al 2018)	Weight of tooth after (dry)
Kukruse burial XXXIII	1. Bronze chain beneath the chin and on the right side of the 1st and 2nd thoracic vertebrae. 2. Oval fire striker below the right pelvis. 3. Two flint fragments, likely part of a set carried in a pouch. 4. Heavily oxidized iron knife on the outer side of the left thigh. 5. Similarly heavily oxidized iron sheath related to the burial. 6. Iron ring distinguishable from the sheath. 7. Elongated iron object, possibly a chain link. 8. Posthole at the feet between both burials.	lower left second incisor	perhaps n	12-18	wet 0,5860 g	no	0.5241 g
Kukruse burial XXXIV	1. Iron ring (likely a belt ring) on the right pelvic bone. 2. Small pieces of wood near the head at the southern end of the burial pit. 3. Small piece of iron from the same level and area. - These might have been associated with a grave marker, as they were clearly deeper than the dark cultural layer; - No evidence of a posthole or similar marker found in connection with this burial.	upper left second incisor	male	40-50	wet 0,5789 g	no	0.5292 g

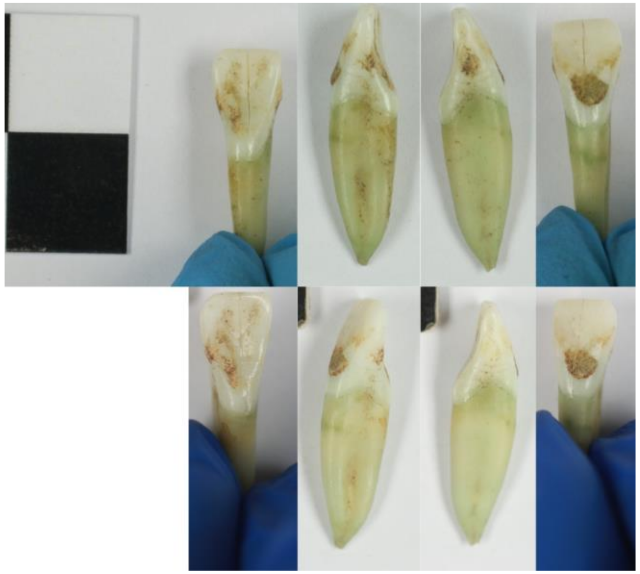
Burial	Teeth before (row above) and teeth after (row below)	Dental calculus	
		Before	After
I		 20x	 30x
IX		 13x	 20x

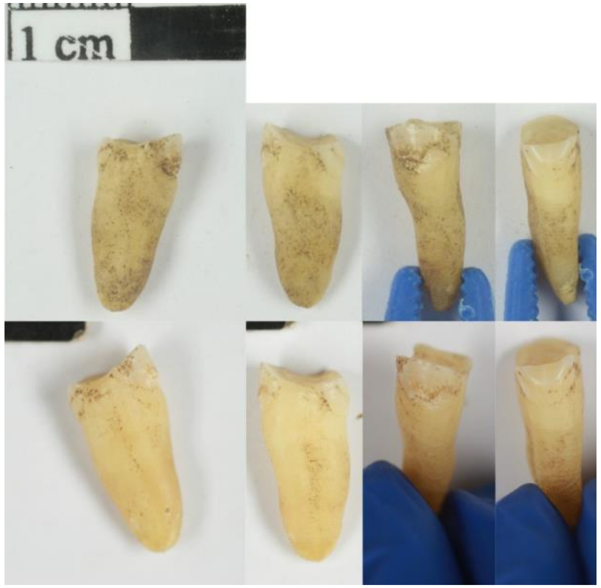
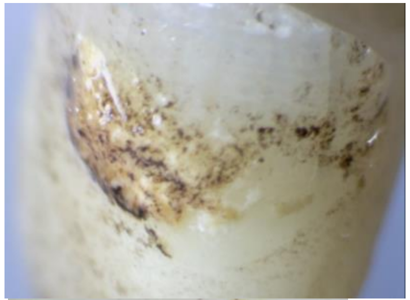
Burial	Teeth before (row above) and teeth after (row below)	Dental calculus	
		Before	After
VI		 13X	20X  
VII		 13X	 60 x

Burial	Teeth before (row above) and teeth after (row below)	Dental calculus	
		Before	After
VII more after images	 20x	 40x	 13x
XII		no before picture taken	 Magnification 13x

Burial	Teeth before (row above) and teeth after (row below)	Dental calculus	
		Before	After
XLIII			
XLIII more before images	 20x	 20x	 50x

Burial	Teeth before (row above) and teeth after (row below)	Dental calculus	
		Before	After
XV		 30x	 30x
XXX		 30x	 20x

Burial	Teeth before (row above) and teeth after (row below)	Dental calculus	
		Before	After
XXXIII		 13x	
XXXIII after removing the clean calculus	 13x		

Burial	Teeth before (row above) and teeth after (row below)	Dental calculus	
		Before	After
XXXIV		  13x	 13x
XXXIV additional after image	 13x		

Appendix 2. Protocol for dental calculus analysis

Protocol for dental calculus analysis was conducted by creating and carefully following this list:

1. Preparing the tooth

1. Make sure tooth will not be sampled for proteomics or aDNA as HCl may damage proteins.
2. Take a photo of the tooth before extraction. Weigh the tooth.
3. Soak the tooth in ultrapure water for anywhere from a few hours to a few days.

2. Preparing for cleaning

1. Put on appropriate laboratory clothes – no natural fibres, no makeup, hair covered, powder free gloves on.
2. Sample the room for contaminants, your clothes, hair. Wear inside shoes that can't bring contaminants from the outside.
    a. Put out a clean slide with a 50–50 glycerol-water mixture for some time openly into the room.
    b. For sampling your clothes and hair, use Sellotape. Stick it on a clean slide.
    c. Sample the bottom of the shoe – make sure no yeast/fungi come in with you.
3. Make sure you have enough HCl (0,06 M/0,1 M HCl), clean petri dishes, acupuncture needles, automatic pipette straws (Automatic straw pipette SP100), foil, ultrapure water, a separate mixture of 50–50 glycerine-water for each sample.

3. Cleaning the calculus

1. Put your photographed, weighed and soaked tooth on a clean Petri dish.

2. Take a picture of the dirty calculus before cleaning with your microscope DinoLite camera. Mark down the magnification.
3. Start to clean the tooth. Use an acupuncture needle, hold it from the tip so you maintain some bendiness, but just enough rigidity.
4. Consult supervisors if needed.
5. Once the tooth is clean, take a picture of the clean calculus.

4. Dealing with clean calculus before mounting

1. Weigh a 2 ml Eppendorf. Write it down/tare it on the scale.
2. Transport the clean calculus to the Eppendorf. NB! This step is different for each fleck as some need to be removed from the tooth, some have fallen off and some break. Carefully transport it, use a needle or whatever is clean and available.
3. Weigh the Eppendorf with the calculus. Write down the weight of the clean calculus.

5. Dissolving

1. Leave calculus in the Eppendorf with HCl for about 5 minutes. Sonicate (ultrasonic bath EMMI-D21) in bursts of 10 seconds to 30 seconds to remove the outermost layer. Hold the Eppendorf in the ultrasonic bath with tweezers.
2. Pipette the first out, mark it as the outermost layer.
3. Add another few drops of HCl. Leave it for some time (e.g. 2 hours, it depends on the speck!)
4. If it hasn't completely dissolved, sonicate it for up to 8 minutes.

5. Cleaning slides from debris:

1. Take a new box of slides.
2. Rinse the ones you want to use with ultrapure water in 001.
3. Leave to dry, covered in foil. If you still see specks of cardboard on it, sample the debris and use as normal, keeping in mind what kind of debris you can find.

7. Mounting

1. Make sure your work area is covered in foil.
2. Make sure your slides are dry.
3. Carefully and quickly pipette the first batch of HCl-dental calculus mixture out with a clean pipette – only a drop. Make sure no big chunks of calculus are in the mix.
4. Pipette it onto the clean slide with glycerine-water mixture.
5. Seal it with the cover slips from the plastic cases.
6. Put the slide into a small sealable container for easy transportation to the Olympus microscope.

8. Scanning the slides

1. Have a tally paper nearby, ready to record all microremains. This should reflect all possible debris you will find as well as some extra spaces for unexpected debris. See an example of the table below.
2. Make a folder for this specific tooth. Make a rule in the CellSens Entry programme to name the files according to the sample name.

3. I viewed the samples with an Olympus BX51 polararising microscope, with magnifications of 50×, 100×, 200×, ja 500×. I took pictures with application CellSens Entry, using an Olympus SC50 camera.
4. Whenever you see something, tally it on the piece of paper (see below).
5. Scan the slide in its entirety, keeping track of the direction (see below).
6. Rotate microremains if you are unsure of their nature.
7. If the slide needs to be paused, cover it and put it in the fridge (not freezer!) and leave it for when you have time to look at it again.

9. Finishing

1. Take a picture of the tooth after extraction.
2. Make a sample protocol in tara.ee.

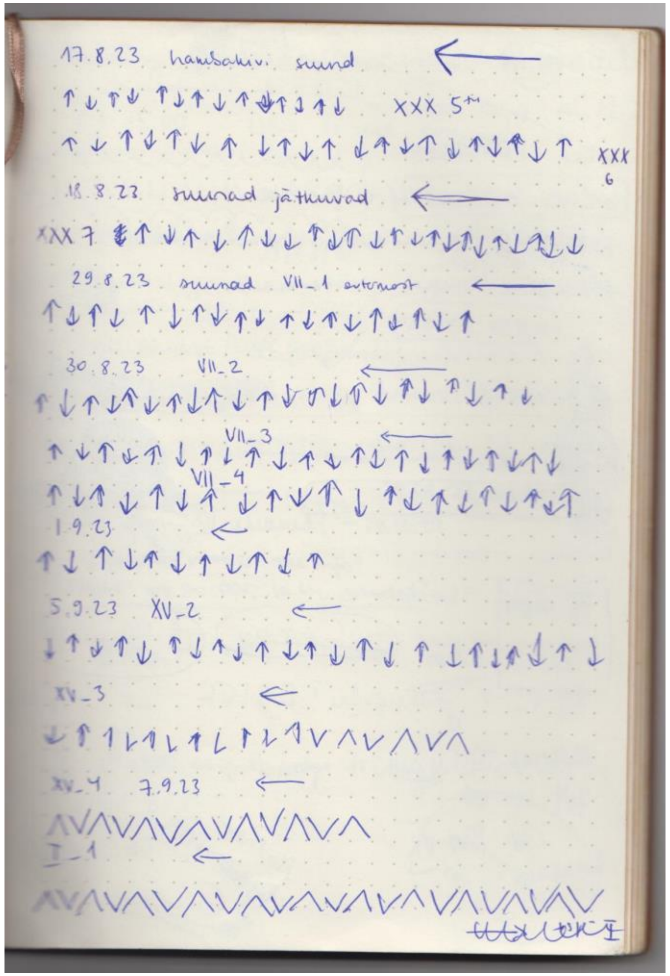
This table was printed out and used to tally each microfossil I encountered during the process. The information was then transferred into an Excel sheet and kept in my personal OneDrive folder.

burnt debris	
mineral	
fungi	

starch	
phytolith	
fibre	
plant cell	
unidentified plant debris	
hypha	
insect debris	
wood debris	
spore	
contamination	
fruit stone	
plant root	
bone	
root?	
problematic	
microcharcoal	
calclulus	
diatom?	

bacteria?	
flesh	
epithelial	
unidentified	

In addition, I kept track of the direction of movement when scrolling through a slide. Here is a scanned image of the directions.



Appendix 3. Reference collection

Protocol for reference collection sampling[20]

1. Prepare the workspace, put on gloves. Sample your clothes to identify potential debris. Set aside a slide of glycerol-water mixture to analyise airborne pollutants.
2. Use a clean scalpel to separate the part of the specimen.
3. If needed, cook, burn, boil, ferment the sample. Mark the procedures down in the laboratory diary.
4. Mount the specimen onto a clean slide, applying glycerol-water mixture onto the sample before sealing the slide with a clean cover slip.
5. Analyse the slide using light microscopy.
6. Record your procedures and observations in the laboratory diary. Make sure the images are incorporated well into your reference collection system to avoid future errors.

Protocol for dry-ashing of reference collection sampling

No clear one method was used to dry ash reference collection material, so trial and error did occur. For example, when sampling fish, we found that separating different parts of the fish, putting them into separate crucibles and firing them in the muffle oven at 300 degrees Celsius for 3 hours was far too long and too hot to render the samples useful. Woods were dry-ashed successfully at 500 degrees Celsius for 2 hours in the muffle oven.

[20] Chat GPT 3.5 was used to help with wording in this protocol.

The following plants were dry ashed at 150 degrees Celsius for 1 hour and 15 minutes. It was then clear this was not enough time, so they went back in the muffle oven for 1 hour and 15 minutes at 200 degrees Celsius. The plant samples contain easily discernible phytolith.

No	Species	Estonian	Processed	Part
1	*Leuciscus idus*	Säinas	boiled	meat and bone
2	*Abramis brama*	latikas	boiled	meat and bone
3	*Tenca tenca*	linask	boiled	meat, bone, skin
4	*Tenca tenca*	linask	raw	meat, bone, skin
5	*Abramis brama*	latikas	raw	meat, bone, skin
6	*Leuciscus idus*	säinas	raw	meat, skin
7	*Sus domestica*	sealiha	boiled	meat, bone
8	*Brassica rapa rapa*	naeris	boiled ca 10 min	
9	*Brassica napus*	kaalikas	boiled ca 15 min	
10	*Allium sativum*	küüslauk	boiled ca 10 min	
11	*Pisum sativum*	hernes	boiled ca 15 min	
12	*Vicia faba*	põlduba	boiled ca 15 min	
13	*Triticum*	nisuterad	boiled ca 30 min	
14	*Secale cereale*	rukkiterad	boiled ca 30 min	
15	*Hordeum vulgare*	odraterad	boiled ca 30 min	

The reference collection

No	Class	Latin	Estonian	English	Part sampled	Reason for inclusion
1	Animalia	-	-	human bone	bone debris	Other microdebris - environment
2	Animalia	-	taruvaik	propolis	propolis	Other microdebris - gathered
3	Animalia	*Abramis brama*	Latikas	common bream	raw meat, boiled meat, bone, scale	Fishing
4	Animalia	*clade Anthophila*	mesilane	bee	wing, leg	Other microdebris - environment
6	Animalia	*Gallus domesticus*	kana	chicken	meat, skin	Animal husbandry
7	Animalia	*Sus domestica*	siga	pig	meat, skin	Animal husbandry
8	Animalia	*Araneae*	ämblik	spider	whole spider	Other microdebris - environment
9	Fungi	-	pärm	yeast	fungal mater	Yeast. Used for malting and baking. Can leave marks on starch when used for dough.
10	Fungi	-	hallitus	mold	fungal matter	Other microdebris - environment

11	Plantae	-	õietolm	pollen	pollen granules	Other microdebris - environment
12	Plantae	*Alliaria petiolata*	salukõdrik	garlic mustard	leaves	Vegetables and herbs
13	Plantae	*Allium cepa*	sibul	onion	flesh, peel	Vegetables and herbs
14	Plantae	*Allium sativum*	küüslauk	garlic	flesh, peel	Vegetables and herbs
15	Plantae	*Alnus glutinosa*	sanglepp	black alder	bark, leaf, wood	Trees - used for many purposes such as building, making everyday objects, firemaking. Food vessels were made from this tree (Viires and Vunder, 1998).
16	Plantae	*Alnus incana*	hall lepp	grey alder	bark, leaf, wood	Trees - used for many purposes such as building, making everyday objects, firemaking. Food vessels were made from this tree (Viires and Vunder, 1998).
17	Plantae	*Avena fatua*	tuulekaer	common wild oat	dry-ashed seed	Weed
18	Plantae	*Avena sativa*	kaer	oat	starch, stem, chaff	Cultivated plants, likely for animals

19	Plantae	*Brassica rapa*	naeris	turnip	root	Vegetables and herbs. Comes in many forms
20	Plantae	*Butomus umbellatus*	luigelill	Butomus	rhizome	Gathered plant - rhyzome is edible
21	Plantae	*Camelina sativa*	põldtuder	gold of pleasure	seed	Cultivated plants for oil
22	Plantae	*Cannabis sativa*	harilik kanep	Cannabis sativa	leaf, stem, seed	Cultivated plants for fibres, to make rope. Seeds are edible.
23	Plantae	*Centaurea cyanus*	rukkilill	cornflower	flower bud, stem	Weeds. Grow in cultivated plants
24	Plantae	*Cerasus vulgaris*	hapu kirss	sour cherry	fruit	Fruit trees
25	Plantae	*Chenopodium album*	valge hanemalts	lamb's quarters	seed	Weeds
26	Plantae	*Corylus avellana*	sarapuupähkel	hazelnut	wood, burnt wood, nut	Gathered plants. Trees - used for many purposes such as building, making everyday objects, firemaking
27	Plantae	*Ficus carica*	viigimari	fig	seed, skin	Trade-related
28	Plantae	*Fragaria*	maasikas	strawberry	berry	Berry bushes
29	Plantae	*Galium aparine*	roomav madar	cleavers	seed	Weed
30	Plantae	*Hordeum vulgare*	oder	barley	seed	Cultivated plants
31	Plantae	*Larix*	lehis	larch	wood, burnt wood	Trees - used for many purposes such as building, making everyday objects, firemaking
32	Plantae	*Lens culinaris*	läätsed	lentil	seed	Cultivated plants
33	Plantae	*Linum usitatissimum*	harilik lina	linseed	seed, stem	Cultivated plants for fibres to make clothes. Seeds are edible

34	Plantae	*Malus*	õun	apple	flesh, peel	Fruit trees
35	Plantae	*Nuphar*	vesikupp	pond-lily	edible root	Gathered plant - roots are edible
36	Plantae	*Oxycoccus palustris*	jõhvikas	cranberry	berry	Berry bushes
37	Plantae	*Panicum miliaceum*	hirss	millet	seed, seed coat	Trade-related
38	Plantae	*Papaver somniferum*	unimagun	opium poppy	seed	Cultivated plants
39	Plantae	*Phragmites australis*	harilik pilliroog	common reed	wood, dry-ashed	Reed - used for thatching, firemaking, picking teeth etc.
40	Plantae	*Picea abies*	harilik kuusk	Norway spruce	wood, needle, dry-ashed	Trees - used for many purposes such as building, making everyday objects, firemaking
41	Plantae	*Pinus sylvestris*	harilik mänd	Scots pine	burnt wood, pollen, dry-ashed	Trees - used for many purposes such as building, making everyday objects, firemaking
42	Plantae	*Pisum sativum*	harilik hernes	(garden?) pea	seed	Cultivated plants
43	Plantae	*Populus tremula*	harilik haab	European aspen	wood, bunt wood, dry-ashed	Trees - used for many purposes such as building, making everyday objects, firemaking.
44	Plantae	*Prunus domestica*	harilik ploomipuu	-	dried fruit	Fruit trees

45	Plantae	*Quercus*	perekond tamm	oak	seed, wood, burnt wood	Trees, fibres, gathered plants - used for many purposes such as building, making everyday objects, firemaking. Gathered plants - the acorn of Quercus is edible.
46	Plantae	*Ribes nigrum*	mustsõstar	blackcurrant	berry	Berry bushes
47	Plantae	*Ribes rubrum*	punane sõstar	redcurrant	berry	Berry bushes
48	Plantae	*Rubus idaeus*	vaarikas	raspberry	berry	Berry bushes
49	Plantae	*Rumex acetosella*	väike oblikas	red sorrel	leaf, stem, seed	Weeds
50	Plantae	*Secale cereale*	rukis	rye	seed, dry-ashed	Cultivated plants
51	Plantae	*Sorbus aucuparia*	pihlakas	rowan	berry	Fruit trees
52	Plantae	*Spergula arvensis*	harilik nälghein	corn spurry	leaf, stem, seed	Weeds
53	Plantae	*Stellaria media*	vesihein	chickweed	leaf, stem, seed	Weeds
54	Plantae	*Tilia cordata*	pärn	small-leaved lime/linden	bark, wood	Trees - used for many purposes such as building, making everyday objects, firemaking. Food vessels were made from this tree (Viires and Vunder, 1998).
55	Plantae	*Trapa natans*	harilik vesipähkel	water chestnut	seed	Gathered plants

56	Plantae	*Tripleurospermum inodorum*	harilik kesalill	scentless false mayweed	flower, stem	Gathered plant?
57	Plantae	*Triticum aestivum*	harilik nisu	common wheat	seed	Cultivated plants
58	Plantae	*Triticum compactum*	kääbusnisu	club wheat	seed	Cultivated plants for oil
59	Plantae	*Triticum dicoccon*	emmernisu	emmer wheat	seed	Cultivated plants
60	Plantae	*Triticum monococcum*	kultuur-üheteranisu	einkorn wheat	seed	Cultivated plants
61	Plantae	*Triticum spelta*	speltanisu	spelt	seed	Cultivated plants
62	Plantae	*Urtica dioica*	kõrvenõges	common nettle	leaves, stem	Weed, gathered plant
63	Plantae	*Vaccinium myrtillus*	mustikas	blueberry	berry	Berry bushes
64	Plantae	*Vaccinium vitis-idaea*	pohl	lingonberry	berry, seed	Berry bushes
65	Plantae	*Vicia faba*	põlduba	broad bean	bean	Cultivated plants, quite rare in the Estonian material
66	Plantae	-	okaspuu	conifer	pollen	Pollen
67	Possible contaminant	-	klaas	glass	glass	Other microdebris - possible contamination
68	Possible contaminant	-	tolm	dust	dust particles	Other microdebris - environment
69	Possible contaminant	-	-	"clean" slide	slide effects	Other microdebris - possible contamination

Appendix 4. The results table

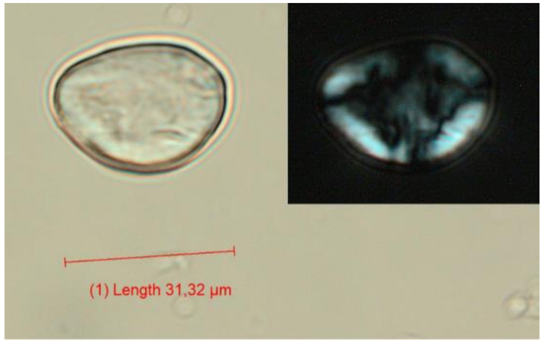
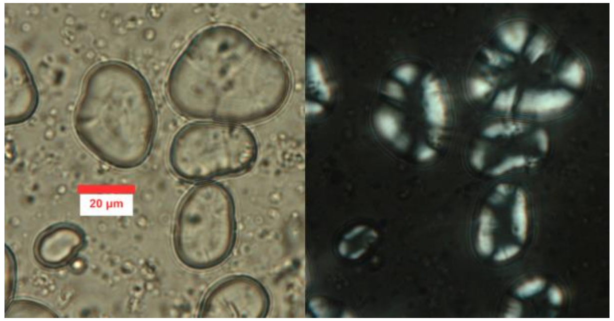
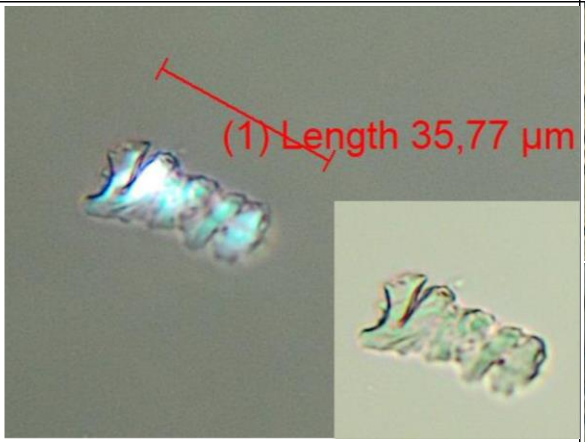
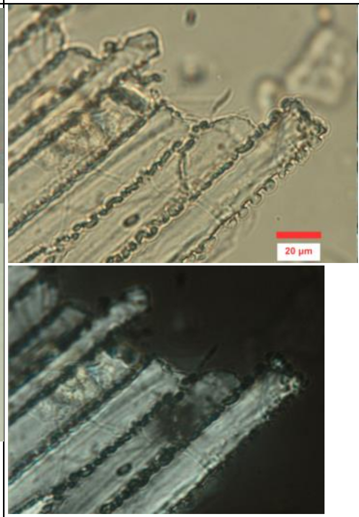
Kingdom	Debris	XII	XXX	VII	IX	XV	I	XLIII	XXXIII	XXXIV	VI	Sum
Problematic debris	burnt debris	40	12	50	11	7	13	29	3	12	43	220
Problematic debris	cf burnt debris	1	0	1	0	0	0	0	0	0	0	2
Non-living nature	mineral	0	9	40	present	7	11	38	7	5	14	131
Fungi	Glomeromycota-type	3	0	0	0	0	0	0	0	0	0	3
Fungi	cf Glomeromycota-type	2	0	0	0	0	0	0	0	0	0	2
Fungi	*Alternaria*-type	1	1	0	0	0	0	0	0	0	0	2
Fungi	cf *Alternaria*-type	0	1	0	0	0	0	0	0	0	0	1
Fungi	fungi	23	3	13	1	0	1	1	0	0	2	44
Fungi	cf fungi	1	0	2	0	0	0	4	0	0	2	9
Plantae	starch	46	1	5	1	2	4	1	1	0	2	63
Plantae	legume starch	3	0	0	0	1	0	0	0	0	0	4
Plantae	cf legume starch	4	0	0	0	0	0	1	0	0	1	6
Plantae	Triticeae	2	0	0	0	0	1	0	0	0	0	3

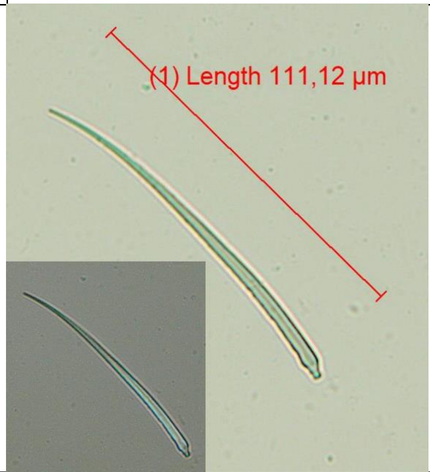
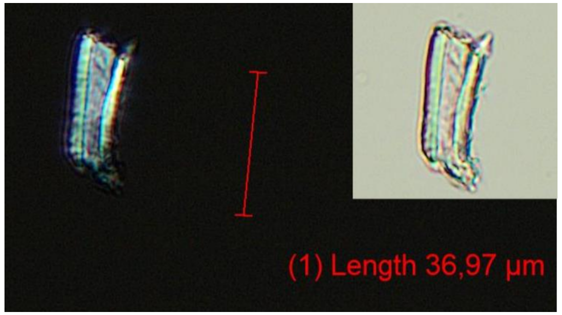
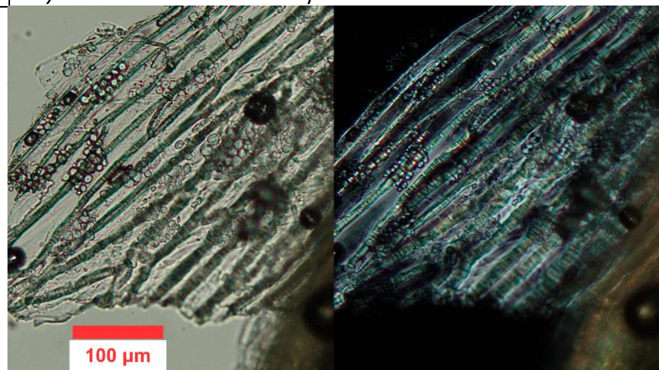
Plantae	cf Triticeae	6	1	0	0	0	0	0	0	0	0	7
Plantae	cf Avena	3	0	0	0	0	0	0	0	1	0	4
Plantae	compound starch	4	0	0	0	0	0	0	0	0	0	4
Plantae	cf compound starch	0	0	0	0	0	1	0	1	0	0	2
Plantae	cf starch	1	2	4	0	0	0	0	0	0	3	10
Plantae	phytolith	1	0	0	2	0	0	0	0	0	0	3
Plantae	cf phytolith	1	2	0	0	0	1	0	0	0	1	5
Plantae	fibre	9	5	5	0	7	7	2	3	1	12	51
Plantae	cf fibre	0	2	4	0	0	0	0	0	0	0	6
Plantae	cf plant cell	1	2	0	0	0	2	9	1	0	0	15
Plantae	unidentified plant debris	15	22	10	7	9	2	2	4	0	4	75
Plantae	cf unidentified plant debris	0	0	1	0	0	1	0	0	0	0	2
Fungi	hypha	7	0	0	1	0	0	0	0	0	1	9
Fungi	cf hypha	0	1	0	0	0	0	0	0	0	0	1
Animalia	insect debris	1	1	15	0	2	1	0	0	0	1	21
Animalia	cf insect debris	1	2	2	0	0	0	0	0	0	0	5
Plantae	wood debris	5	2	9	1	5	1	0	2	1	0	26
Plantae	cf wood debris	2	4	2	0	1	2	1	2	2	0	16
Fungi	spore	0	3	1	0	1	2	2	0	0	10	19
Fungi	cf spore	0	0	0	0	0	1	0	0	0	0	1
Problematic debris	contamination	8	10	6	0	3	2	3	5	1	5	43

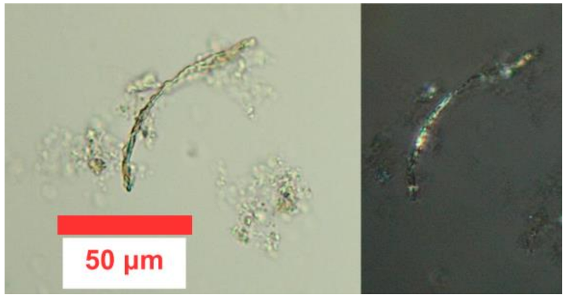
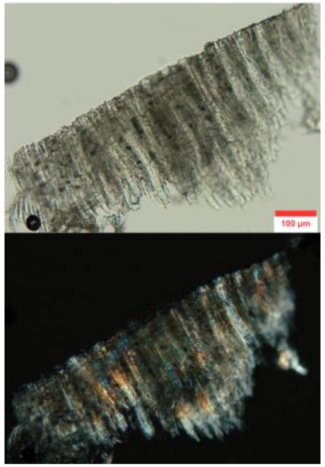
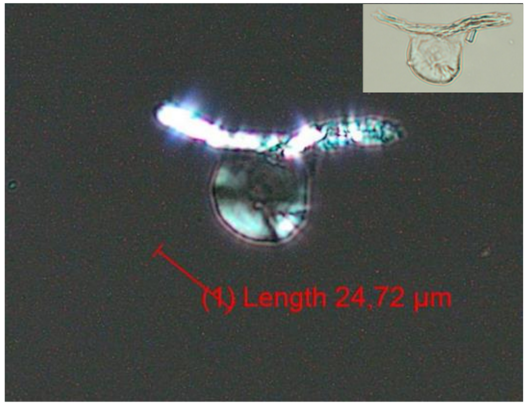
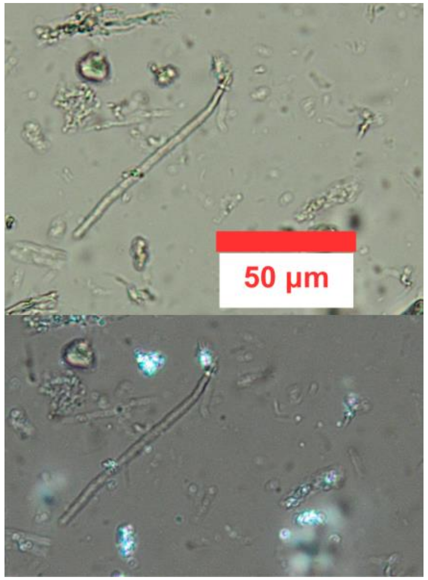
Problematic debris	cf contamination	1	0	0	0	1	1	0	0	0	1	4
Plantae	fruit stone	0	0	0	13	0	0	0	0	0	0	13
Plantae	cf fruit stone	0	1	0	1	0	0	0	0	0	0	2
Animalia	bone	1	0	1	0	0	0	0	0	0	0	2
Animalia	cf bone	0	1	1	0	0	0	0	0	0	0	2
Plantae	cf root	1	0	0	0	0	0	0	0	0	0	1
Problematic debris	problematic	5	2	3	1	0	0	1	0	0	0	12
Plantae	microcharcoal	1	0	4	0	0	0	0	0	0	2	7
Plantae	cf microcharcoal	0	0	1	0	0	0	0	0	0	0	1
Non-living nature	calclulus	present	present	present	present	present	present	present	present	present	present	present
Non-living nature	cf calculus	1	1	0	0	1	0	0	0	0	0	3
Bacteria	cf bacteria	0	0	1	0	0	0	0	0	0	0	1
Animalia	cf flesh	1	2	0	0	0	0	2	1	0	2	8
Plantae	plant hair	1	2	1	1	0	0	0	0	0	0	5
Problematic debris	epithelial	2	4	18	1	5	6	14	21	0	4	75
Problematic debris	cf epithelial	6	0	1	0	0	0	1	0	0	0	8
Problematic debris	unidentified	24	39	15	0	11	4	21	8	2	19	143
Glass effect	glass	0	present	present	0	0	0	0	1	0	2	3

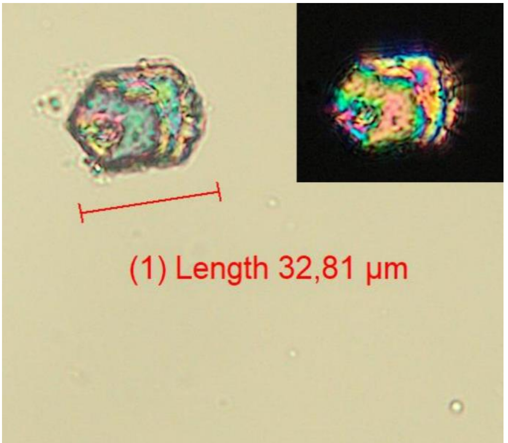
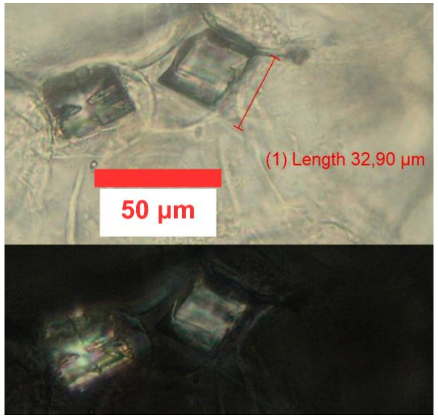
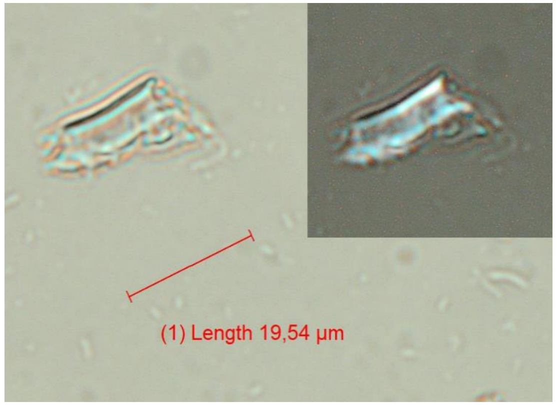
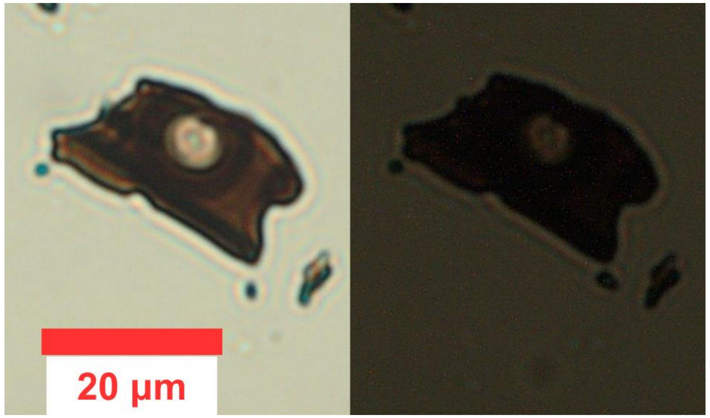
Problematic debris	cf food	0	0	0	1	0	0	0	0	0	0	1
Glass effect	dried slide	0	0	0	1	0	0	0	0	0	0	1
Plantae	pollen	0	0	0	0	1	0	0	0	0	0	1
Plantae	cf pollen	0	0	0	0	0	1	0	0	0	0	1
Animalia	hyaline	7	4	4	0	1	6	5	0	3	12	42
Animalia	cf hyaline	0	0	0	0	0	0	0	0	0	1	1
Non-living nature	crystal	0	0	1	0	0	0	1	0	0	4	6
Problematic debris	hair	0	0	0	0	1	0	0	0	0	0	1
Problematic debris	cf hair	0	0	1	0	0	0	0	0	0	0	1
Other	oil	0	0	0	0	0	1	0	0	0	0	1
Non-living nature	phosphate	0	0	0	0	1	1	0	0	0	0	2
Problematic debris	ink	0	1	0	0	0	0	0	0	0	0	1
Sum		242	143	222	43	67	73	138	60	28	148	**1164**

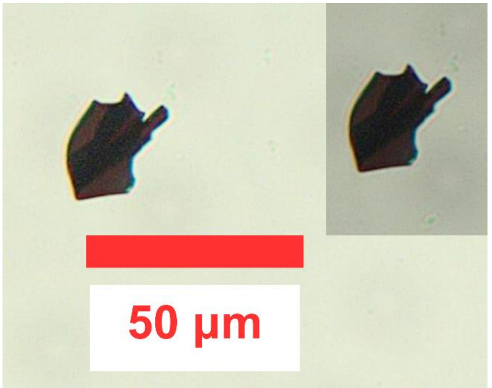
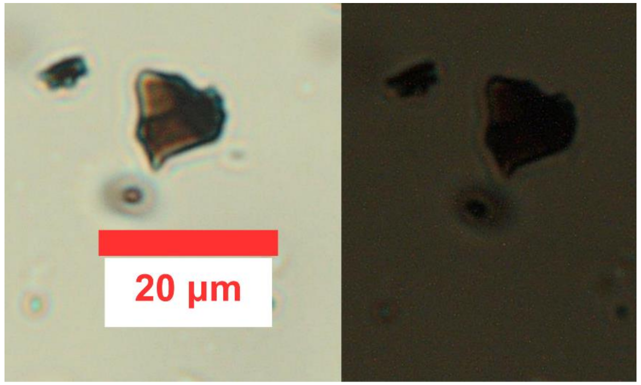
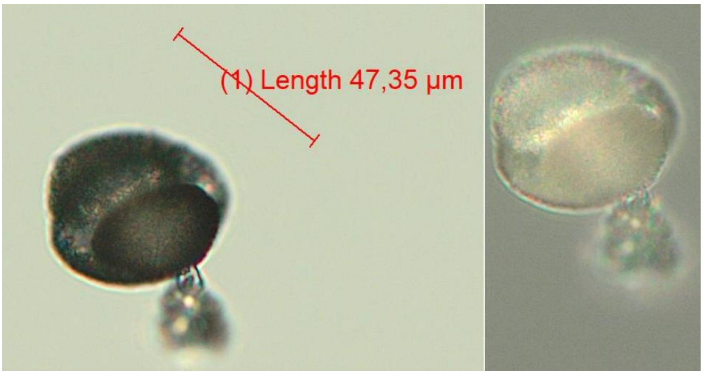
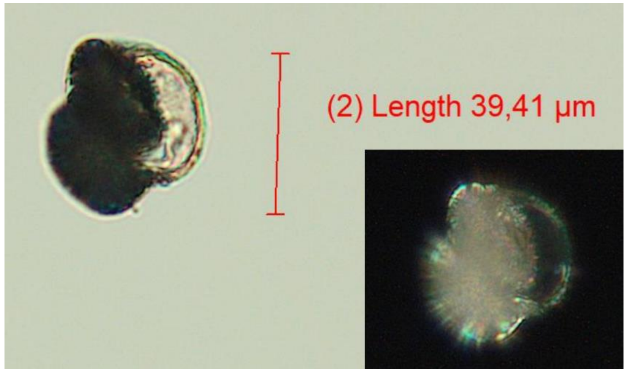
Results with reference collection images

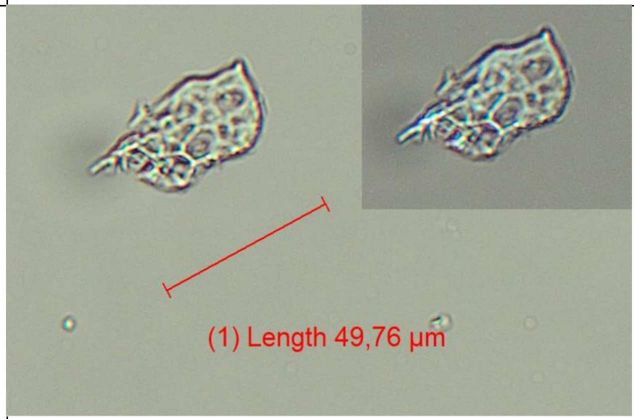
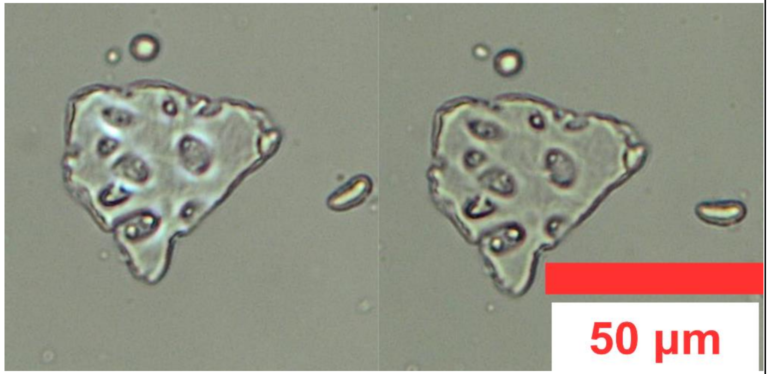
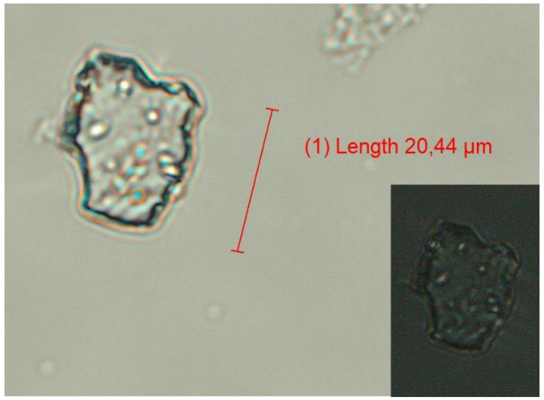
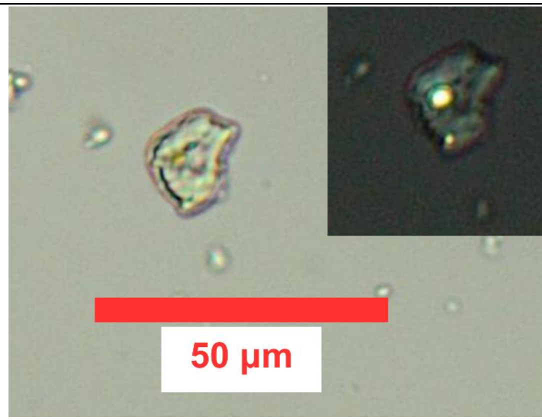
Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Plantae	Starch	106	 Fabaceae starch, XII_3_4_045	 *Pisum sativum* raw seed starch
Plantae	Phytolith	8	 cf phytolith. I_2_20-21	 Phytoliths seen inside *Avena sativa* chaff

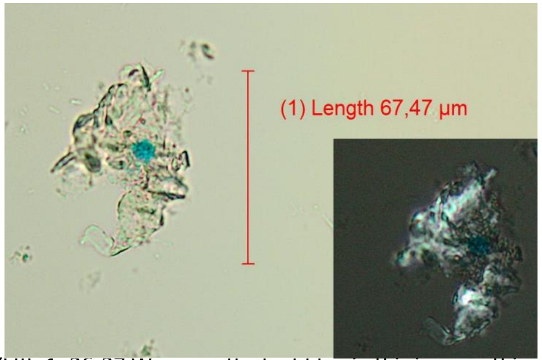
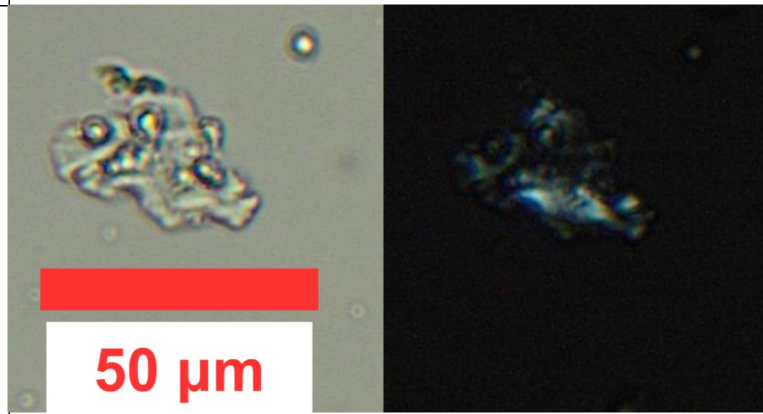
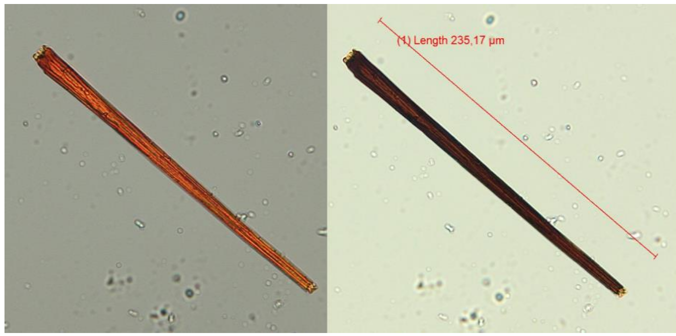
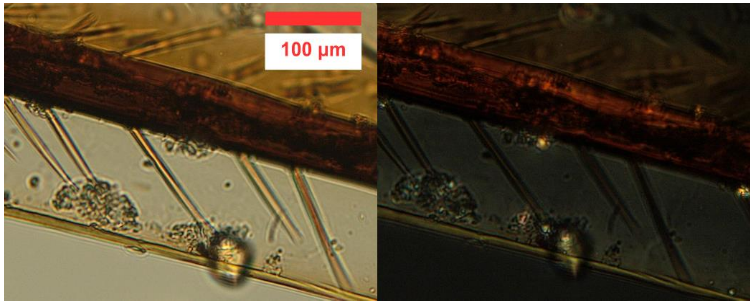
Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Plantae	Plant Hair	5		 *Corylus avellana* seed's velvety outer shell
Plantae	Cf Plant Cell	15	 I_1_9-10	 *Linum usitatissimum* cells

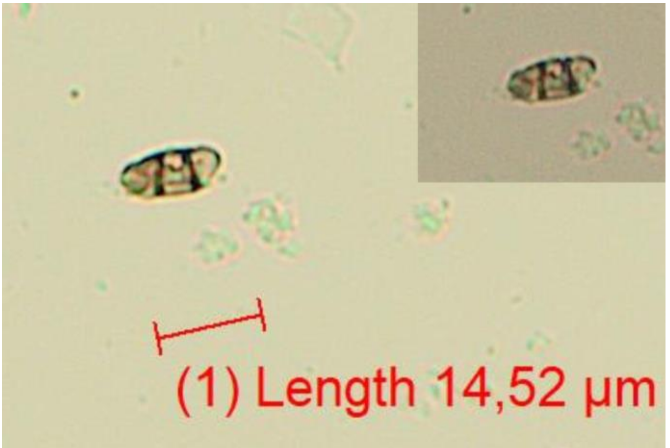
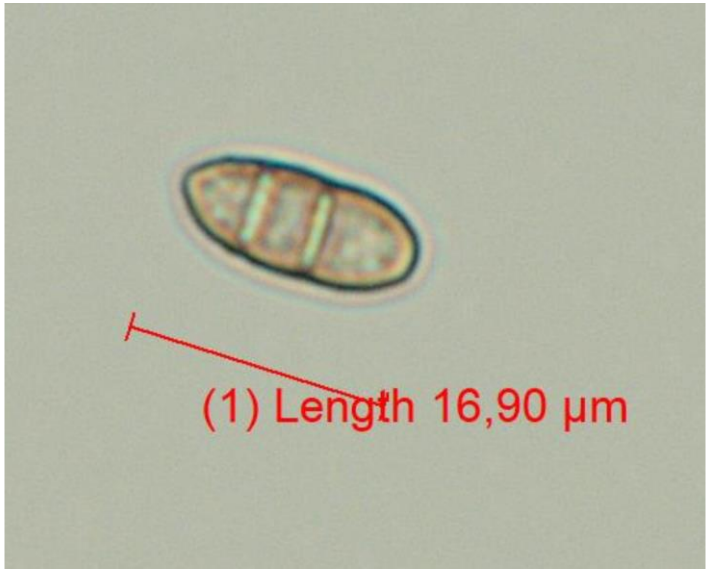
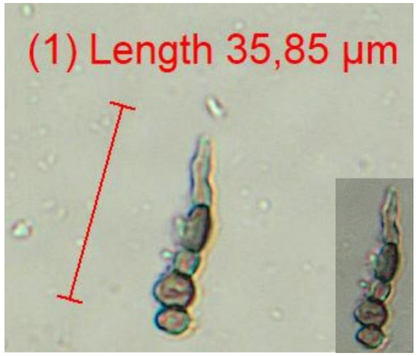
Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Plantae	Fibre	57	 VI_2_039	 *Linum usitatissimum* fibres
Plantae	Unidentified Plant Debris	77	 XV_4th_20 Starch grain with unidentified plant debris attached - this could be a separate fibre or part of the amyloplast the starch originated from. It is not possible to tell what plant this is from.	 Dry-ashed *Secale cereale* - this specific part looks unidentifiable.

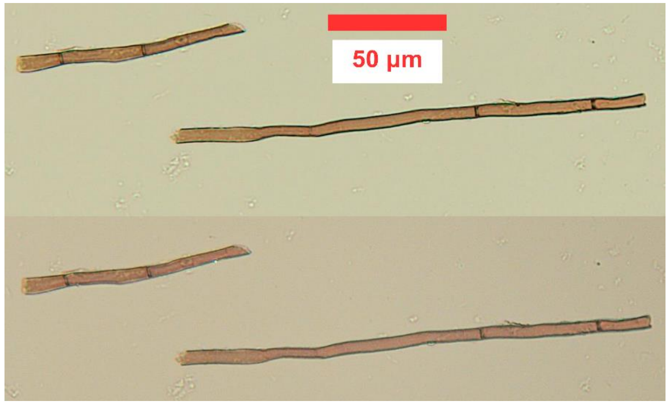
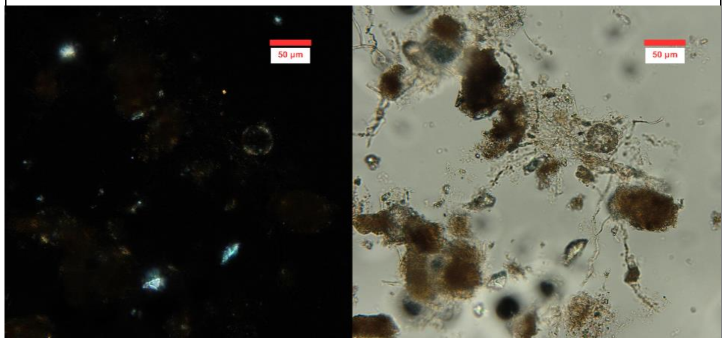
Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Plantae	Fruit Stone	15	 IX_2_5-6 Potentially fruit stones	 Stone-like structures inside a *Pyrus communis*
Plantae	Wood Debris	42	 XII_5_56-57 This particular one could be conifer due to the wood pits in the speck. However, the piece should be bigger to be able to tell for sure whether it's conifer wood.	 *Pinus sylvestris,<* burnt

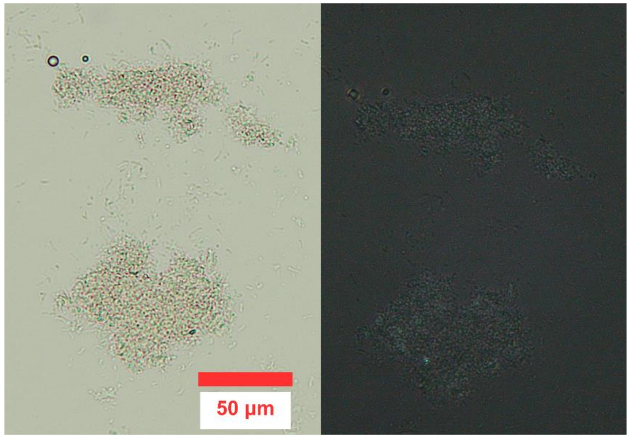
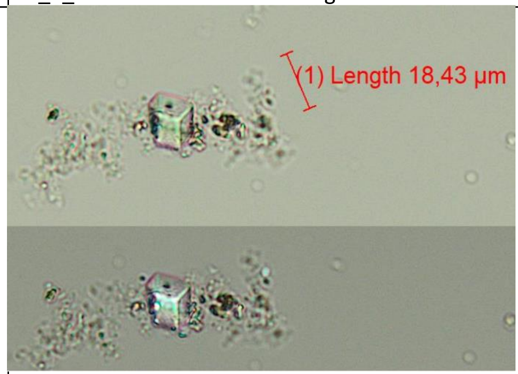
Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Plantae	Microcharcoal	8	 VII_3_29-30 Microcharcoal from an unknown source.	 *Pinus sylvestris* , burnt
Plantae	Pollen	2	 XV_4_001	 *Pinus sylvestris* pollen

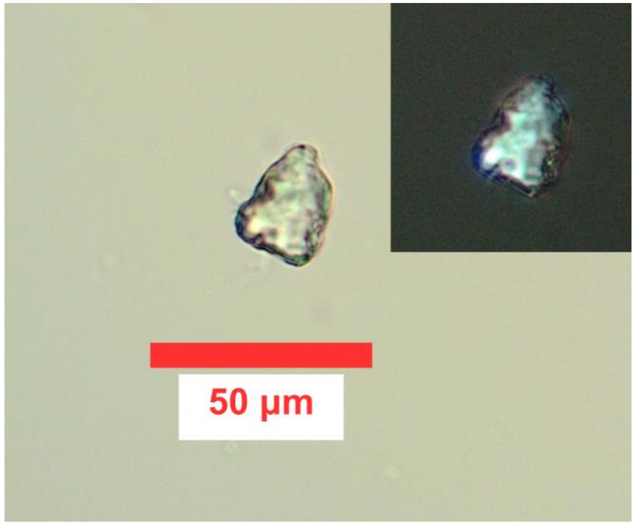
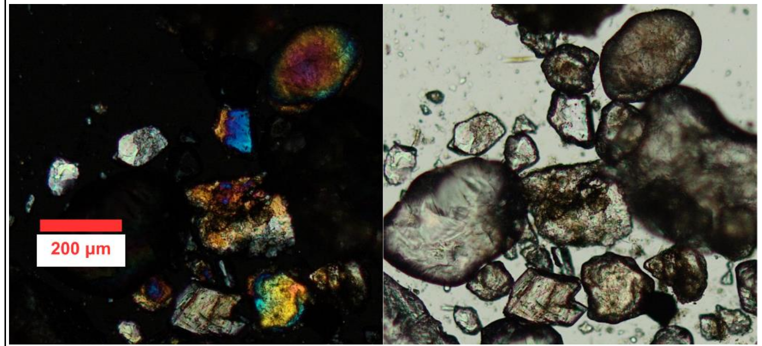
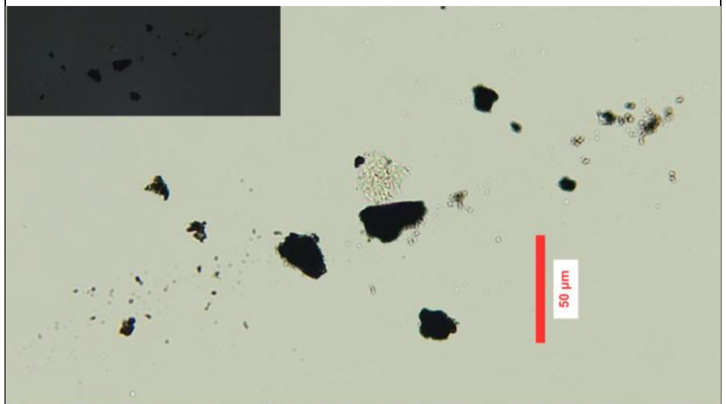
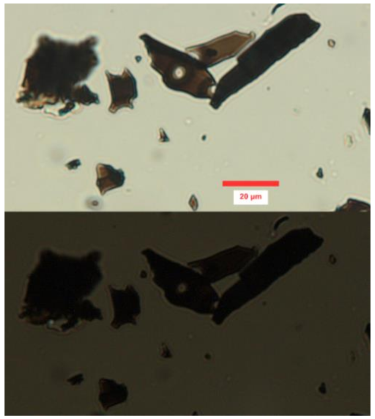
Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Animalia	Hyaline	43	 XV_2_053	 Chicken meat.
Animalia	Bone	4	 VII_4_39-40 Possible bone debris.	 Human bone debris

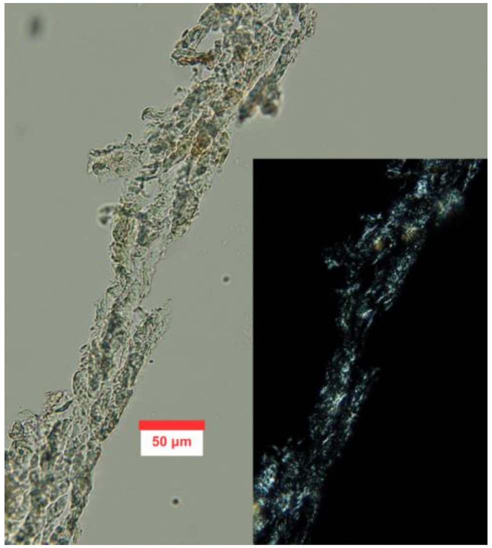
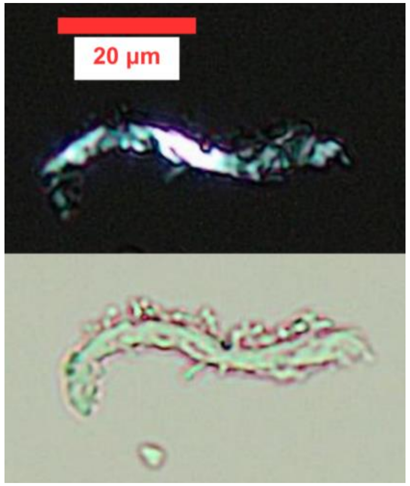
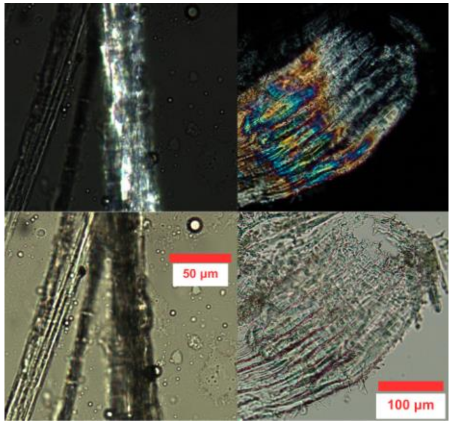
Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Animalia	Cf Flesh	8	 XLIII_1_26-27 We see a fleck of blue in this image - this could be phosphate, very often found in living organisms. It is surrounded by potential animal flesh.	 Chicken meat.
Animalia	Insect Debris	26	 VII_1_55-56 VII sample had the most insect debris, most notably in the outermost layers of the dental calculus. Reasons for this are outlined in the 4th and 5th chapters.	 Hairs from a bee

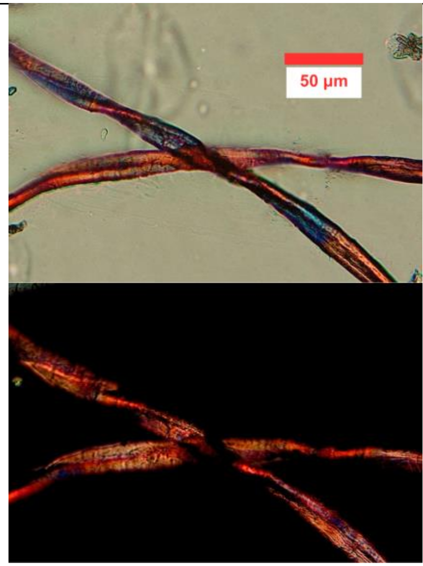
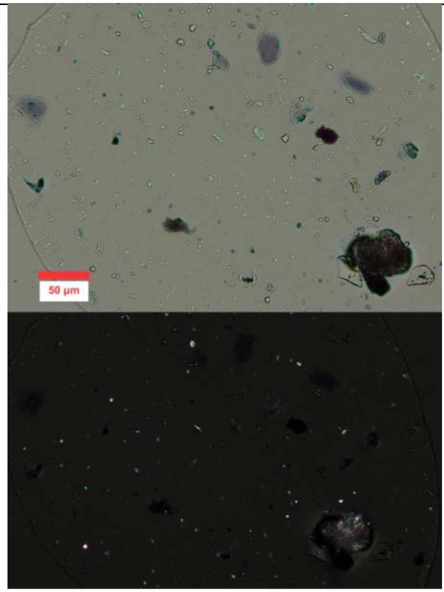
Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Fungi	Fungi	53	 XII_3_054-055 alternaria type fungal matter	 Picture by Kristiina Johanson. Fungal matter from the inflorescence of wheat.
Fungi	Spore	20	 XXX_3_5-6 Some spores attached to a hypha.	 Sordaria fimicola spores. By CarmelitaLevin - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=41198837

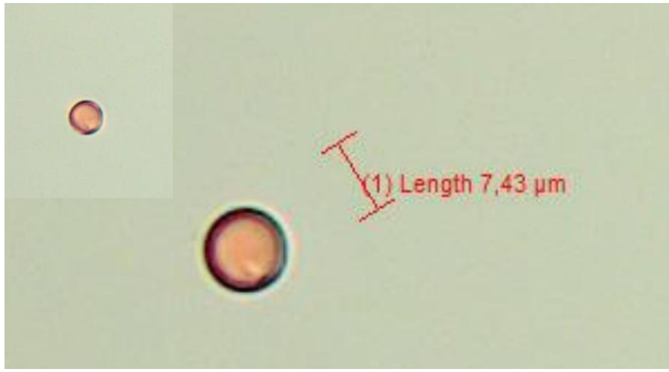
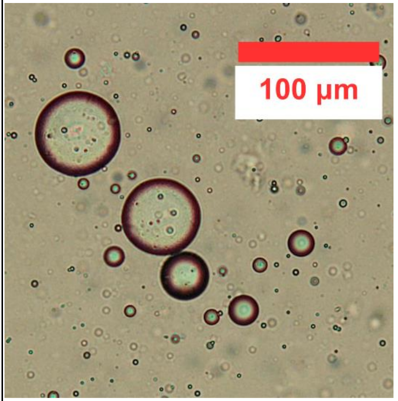
Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Fungi	Hypha	10	 XII_3_102-103	 Found from a sample of *Panicum miliaceum*
Other	Cf Bacteria	1	 VII_4_5-6 Potential strands of bacteria can be seen inside undissolved calculus. Note also some minerals.	no reference picture available.

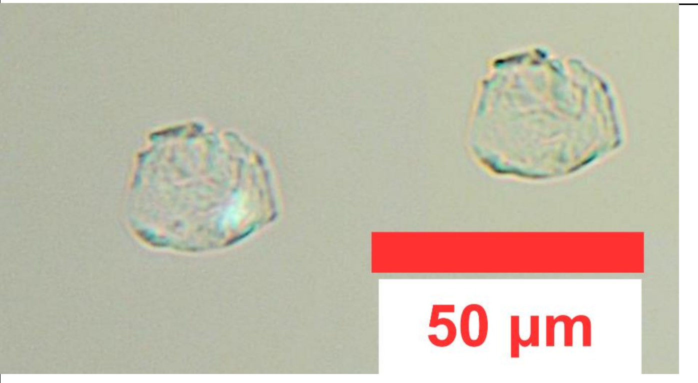
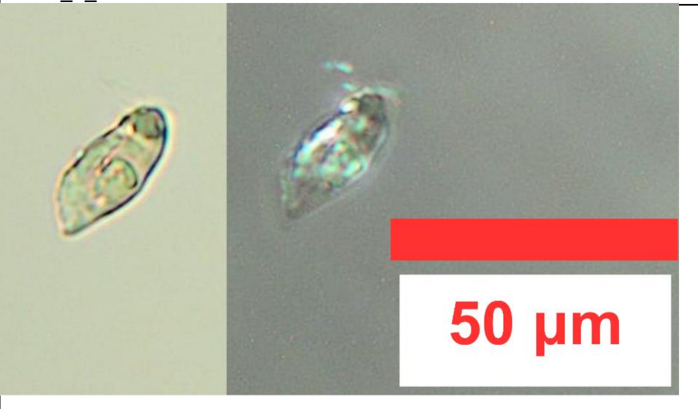
Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Non-living nature	Calculus	present in many samples	 XV_2_3 Undissolved or dissolving calculus is often found in samples.	no reference picture available.
Non-living nature	Crystal	6	 VI_1_089	no reference picture available.

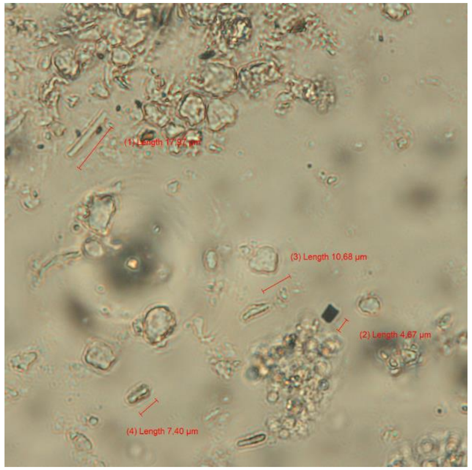
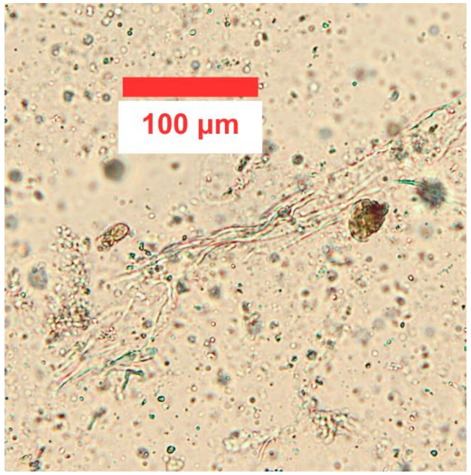
Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Non-living nature	Mineral	131	 XLIII_3_11-12	 Sandy soil from river Emajõgi, collected in August 2023
Problematic debris	Burnt Debris	220	 XV_2_16-17	 *Pinus sylvestris* , burnt

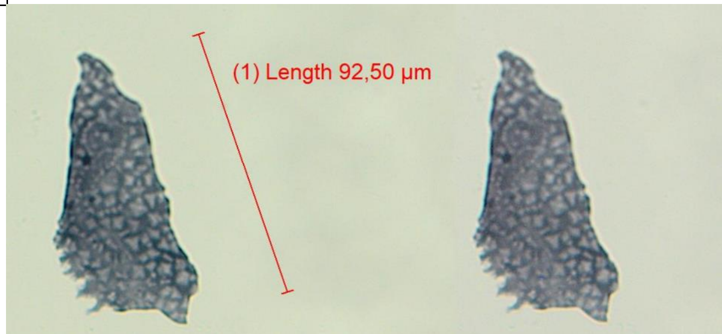
Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Problematic debris	Problematic	12	 VII_1_45-46 This looks quite ancient due to the deterioration and the calculus around the part, however, it is such a large find that I am not sure whether it's ancient or contamination. If it is ancient - is it ingested with some food or inhaled? It could also be a part of wood.	 Many processed plants look like this. Here is an example of *Alnus incana* wood.
Problematic debris	Hair	2	 XV_1_002	 Seeing as in the case of this particular hair I cannot tell whether it is plant or animal based, I have added here choices of both kingdoms. *Gallus domesticus* feather (left) and *Cannabis sativa* stem (right)

Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Problematic debris	Contamination	47	 VII_3_11 Large fibres were noted in some samples. As these were for example cotton, it could not have been a part of the Iron Age environment, and is therefore considered contamination. Their large size points to it being contamination as well, as is commonly known in the dental calculus analysists' community that debris larger than 200 microns is usually picked off the teeth by the individual during their lifetime. On the picture we see a strand of cotton that has its charactersitc twist.	 Fibres from clothes - twist appears cotton-like.
Non-living nature	Phosphate	2	 XV_4_005	no reference picture available.

Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Other	Glass	3	 IX_1_003	no reference picture available.
Other	Oil	1	 I_2_016	 *Abramis brama* oil from raw fish

Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Problematic debris	Epithelial	83	 XXXIII_1_033	no reference picture available.
Problematic debris	Unidentified Debris	143	 XXXIII_1_016	no reference picture available.

Kingdom	**Debris**	**Sum (numbers include the cf-s)**	**Archaeological example**	**Reference collection example**
Problematic debris	Cf Food	1	 IX_1_III_10	 Some soup broth. The example shows how ambiguous food can look.
Other	Dried Slide	1	 IX_1_010	no reference picture available.

Kingdom	Debris	Sum (numbers include the cf-s)	Archaeological example	Reference collection example
Problematic debris	Ink	1	 XXX_7_003	no reference picture available.

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Agnes Unt

08.01.2024