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The Neolithic settlement of Kreiči revisited: New archaeological and environmental evidence

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Keywords

Kreiči settlement, Neolithic, radiocarbon dates, prehistoric landscape, ceramics, eastern Latvia, paleoenvironmental analysis

Abstract

The Kreiči settlement is one of the most extensively investigated Stone Age sites in eastern Latvia, yet until recently, it lacked a precise chronological framework. This article presents the results of test excavations conducted in 2022, aimed at refining the site's chronology and reconstructing the paleoenvironment. One of two excavated test pits in a marshy lowland area of the site revealed layers similar to those discovered in excavations in 1956–1959 by Lūcija Vankina and Francis Zagorskis. Radiocarbon dates from plant macro-remains from a soil monolith extracted from this trench and hazelnut shell from the deepest recorded artefact-bearing layer (layer 5), which contained finds of Piestiņa (Post-Narva) Ware, can be attributed to the second half of the 4th millennium BC (3330–2924 cal BC). Conversely, the upper artefact-bearing layer 3 yielded Late Neolithic dates (2869–1696 cal BC), despite containing Middle Neolithic pottery, suggesting significant redeposition processes likely driven by slope erosion. Paleoenvironmental analysis indicates a transition from a Middle Neolithic fen environment to a fluctuating lakeshore ecotone. High concentrations of microscopic charcoal in the basal layers of analysed samples from the monolith suggest that habitation predates the excavated archaeological material. Zooarchaeological analysis demonstrates that wild boar and elk were the main species in subsistence practices and points to Kreiči as a multifunctional habitation site encompassing hunting, fishing, food processing and bone working. Petrographic and chemical analyses of the ceramics confirm local production of Piestiņa (Post-Narva) Ware utilising shell temper and coarse clays. These findings and new absolute dates, not only begin to clarify the site formation processes and human adaptation in the Lake Lielais Ludzas basin but can be used as a basis for re-evaluation of 1950s excavation collections.

Introduction

Kreiči settlement, in terms of the proportion of excavated area, stands as one of the most extensively investigated Stone Age sites in Latvia. It is situated at the foot of a small hillock known as 'Zaļais kalniņš' (the Green Hill). Currently, the site lies on the right bank of the Pilda (Isnauda) River, approximately 150 m from the river channel and 400 m from where it flows into Lake Lielais Ludzas (Fig. 1 and Fig. 2).

Lake Ludza was formed by the melting of a glacier, located on the edge of the Latgale Upland at 132.8 m above sea

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Figure 1. Aerial photograph of Kreiči site area (photograph by M. Kalniņš).

level. Today, it is a eutrophic, run-off lake basin, but at the end of the Ice Age and in the Holocene, it was a large basin of glacial meltwater, the level of which was at least a metre higher than now. As the lake level decreased, the shallow bays became overgrown and the coast became swampy, including the area around the Kreiči settlement.

The site – settlement and the associated burial ground (comprising 17 graves with at least 23 individuals (Macāne and Nordqvist 2021)) – was discovered in 1955 (Zgorskis 1961; 1963). The discovery was made during gravel extraction for the construction of a new road connecting Ludza and Kreiči, which revealed two skeletons on the western slope of the hillock (Zagorskis and Vankina 1957).

Extensive archaeological excavations were conducted at the Kreiči settlement from 1956 to 1959, directed by Lūcija Vankina (1956–1957) and Francis Zagorskis (1958–1959) (Zagorskis 1963). Over four field seasons, 28 excavation areas covering a total of 670 m² were investigated (Fig. 2). According to Zagorskis's estimates, this represents approximately two-thirds of the total settlement area (Zagorskis 1963). The excavations yielded a rich assemblage, including over 10,000 pottery sherds, approximately 4,000 animal bones, and more than 300 artefacts made of bone, flint, stone and amber. While the material primarily indicates a Middle Neolithic habitation, a small number of finds are attributed to the Bronze and Iron Ages as well (Zagorskis 1963; Zagorska 2025).

During excavations in the 1950s, an intensive, dark cultural layer averaging 0.30–0.40 m in thickness and extending across a 10–12 m wide strip on the gentle slope of the hillock was recorded and completely excavated (Zagorskis 1963). However, a large number of finds – particularly pottery and animal bones – were also recovered from the marshy lowland zone at the foot of the hill. Here, the cultural sequence consisted of loose peat and sand interlayers, sealed by a 0.30–0.80 m thick peat overburden (Zagorskis 1963).

Despite the extensive fieldwork and the substantial amount of material recovered, the comprehensive results have essentially been published in only one article by Zagorskis (1963) and discussed in his doctoral dissertation (1967). Furthermore, no additional archaeological investigations had been conducted at the site since 1959. Although the 1950s excavations produced a significant number of artefacts, very few organic samples suitable for reliable radiocarbon dating have survived in the collection of the Latvian National Museum of History. The only radiocarbon date available for the Kreiči settlement until the 2022 research was a conventional ^{14}C date of 4020±340 (Table 3; Fig. 9) from an ash (*Fraxinus*) wood sample recovered from the lower horizon of the cultural layer in the lowland zone dated in 1961 (Zagorskis 1963). However, when calibrated, this date yields an exceptionally broad range – 3514–1687 cal BC (Table 3; Fig. 9), encompassing the majority of the Middle Neolithic, the entire Late Neolithic, and extending into the Early Bronze Age, and is therefore insufficient for precise chronological reconstruction of the settlement layers.

Because of the site's significance and the paucity of reliable chronological data, a small-scale test excavation was

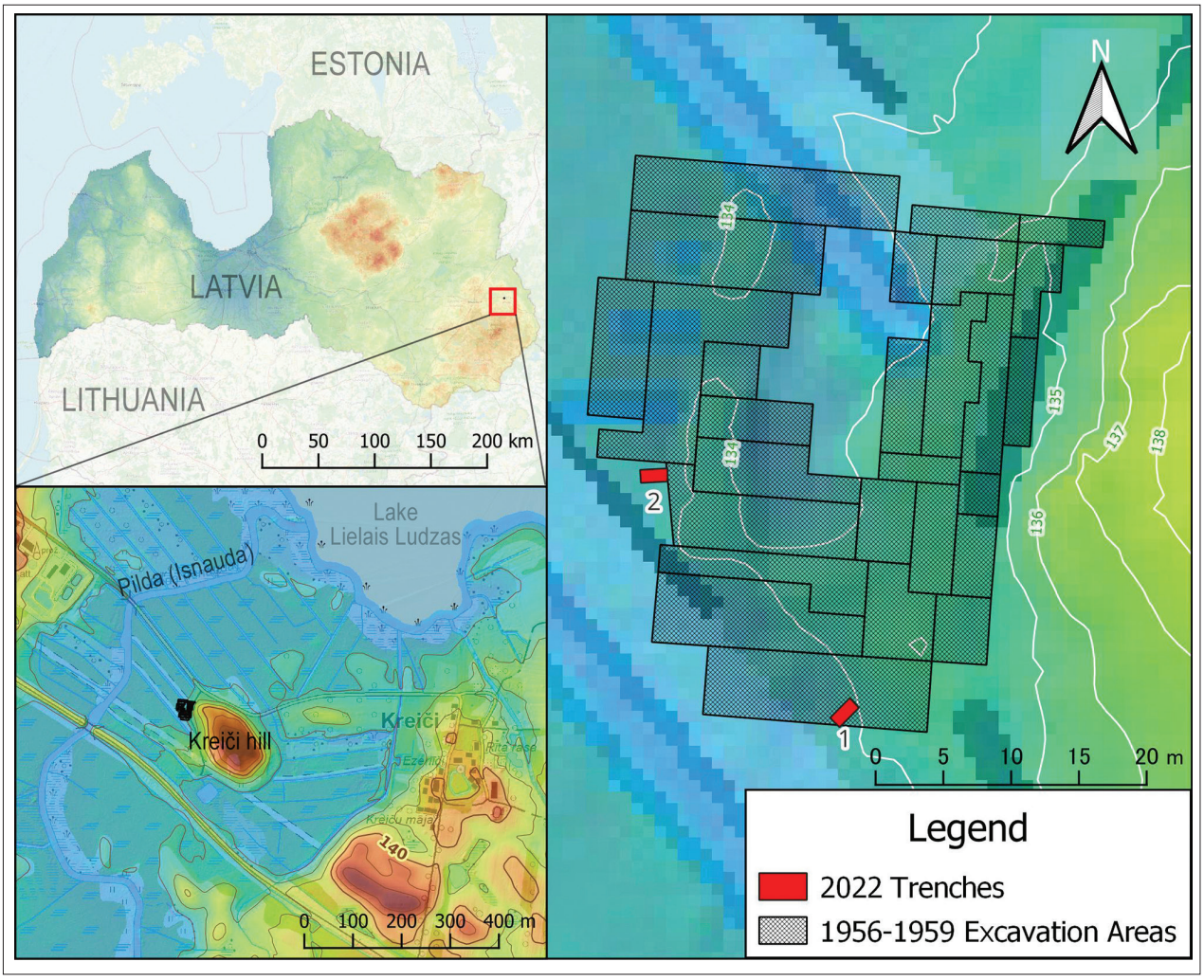


Figure 2. Map of Krieči site with 1950s and 2022 excavation areas (map by M. Kalniņš).

carried out in 2022 (Kalniņš and Macāne 2024). The primary objectives of the research were to obtain organic material suitable for AMS radiocarbon dating to refine the chronology of the Stone Age habitation and to clarify the formation processes and significance of the artefact-rich peat and sand layers previously identified by Zagorskis (1963) in the marshy lowland part of the site. Additionally, the fieldwork aimed to recover artefacts for in-depth analysis, particularly pottery and organic artefacts, from a secure and dated context, and, if possible, to clarify the precise location of the 1950s excavation areas in the field, as many of the original reference points used by Zagorskis and Vankina have been lost or altered.

1. Field research and methods

1.1. Archaeological excavations

During the 2022 fieldwork at the Kreiči settlement, two test pits (2×1 m) were excavated, strategically positioned to intersect with areas previously excavated by Zagorskis (Kalniņš and Macāne 2024) (Fig. 2). Test pit 1 was situated in the southern part of the settlement at the base of Kreiči hillock, intended to abut the northern profile of the 1959 excavation area 5. Test pit 2 was located on a slight slope within the marshy lowlands in the western part of site; it was oriented such that its eastern profile abutted the western profile of the 1957 excavation area 3.

Excavation was conducted mainly using small hand tools, and all sediment from archaeologically significant layers was wet-sieved through a 2 mm mesh. At the end of the excavation, a 1 m sediment monolith was sampled from the western profile of test pit 2 (Fig. 3) extending from the surface downwards using a 5 cm diameter tube. The monolith was sealed with polyethylene film to preserve the naturally occurring moisture and transported to the Laboratory of Quaternary Environment, Faculty of Science and Technology, University of Latvia for analysis of plant micro- and macro-remains, and sampling for radiocarbon (^{14}C) dating. Furthermore, several bulk soil samples were also collected from the cultural layer horizons (layers 3 and 5) in test pit 2 for the same purpose.

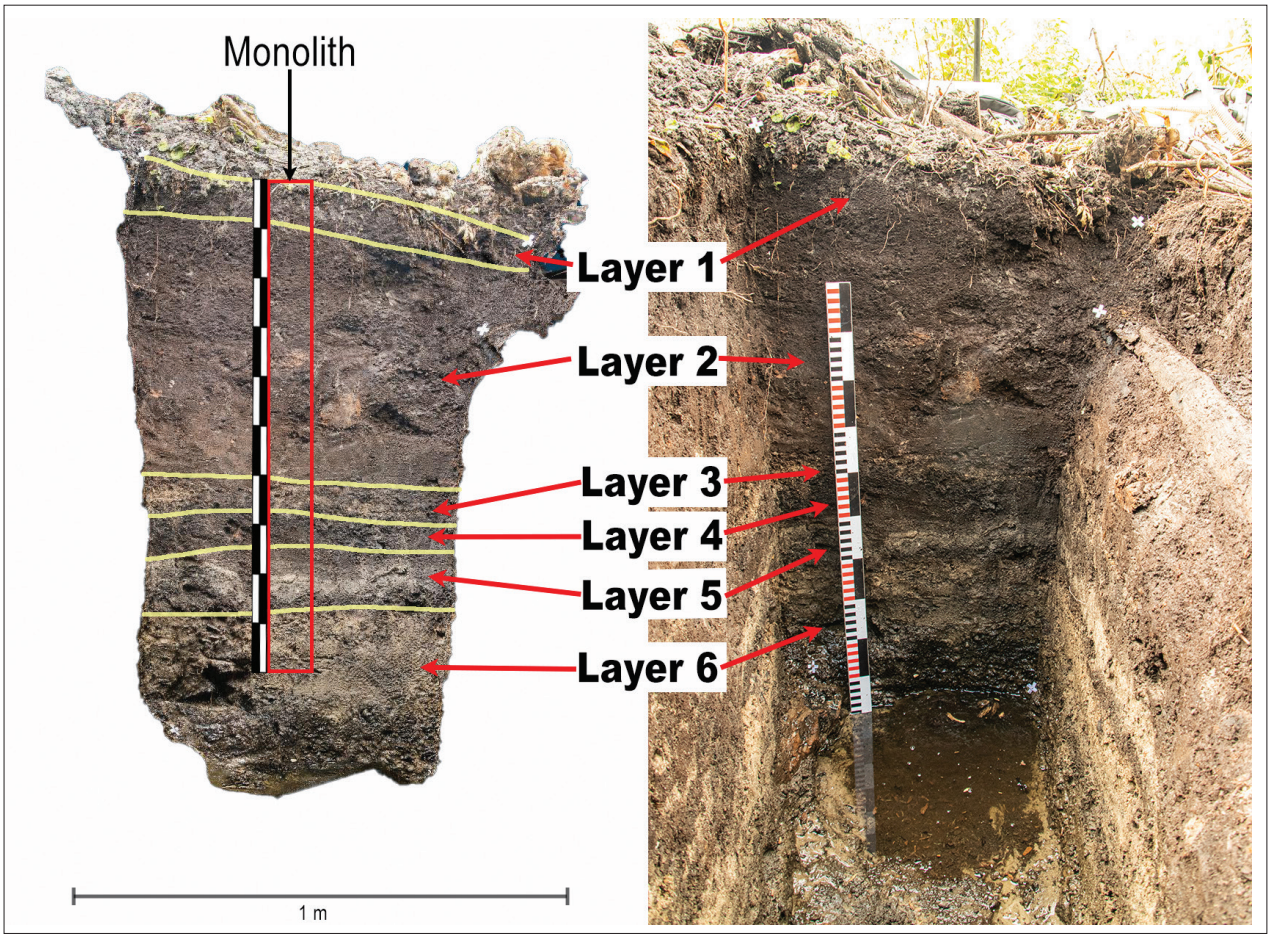


Figure 3. On left: 3D model of western profile of test pit 2 from 2022. On right: photograph of western profile of test pit 2 from 2022 (created by M. Kalniņš).

1.2. Zooarchaeological analysis

All faunal remains from test pit 2 were analysed and identified to specific taxa and anatomical elements. In cases where it was not possible to determine the animal species, the specimen was identified to family or group level (e.g. carnivores or ungulates). Skeletal elements were identified for bones, while teeth were classified by anatomical category (incisor, canine, premolar or molar) and cranial origin (skull or mandible). When possible, the side (left or right) from which the bone or tooth originates was determined, and data on the animals' age, sex, tooth wear or other specific properties was documented.

Identifications were conducted following principles of comparative anatomy, using reference collections and standard identification manuals (e.g. Hillson 1992; Schmid 1972). Age estimation was primarily based on dental development, including deciduous versus permanent dentition and stages of root formation. Quantification of the assemblage employed the total Number of Fragments, Number of Identified Specimens (NISP), and the Minimum Number of Individuals (MNI) methods (Grayson 1984; Lyman 1994).

1.3. Ceramic petrography

Petrographic analysis was used to determine the microstructure and technological aspects of the pottery production in the Kreiči settlement. Thin sections of six selected sherds were prepared and further analysed according to the following protocol (Quinn 2013; Visocka 2022):

1) Samples were cut manually with a motorised hand saw (4000 Dremel) from a position vertical or potentially vertical to the vessel's rim.

2) The chosen side of the sample was polished with a silicon carbide powder (grit size: 400–800) and, once dry, the surface was impregnated with epoxy resin, which had been heated for 15 minutes at 50°C on a hotplate.

3) When hardened, the sample was polished with a silicon carbide powder. After drying, the sample was glued to a microscope slide.

4) The excess was cut, leaving a 1–2 mm thick sample, which was then manually ground and polished with a silicon carbide powder until it was ca. 30 micrometres thin.

Thin sections were analysed using a polarised light microscope (Bresser Science MPO 401) in both plain and

crossed polarised light (PPL and XPL). Micrographs were taken with a smartphone camera using an adapter in both regular and panorama settings. The size of the temper and inclusions was measured using a ruler on the ocular micrometer, and the volume was measured by placing a grid over a micrograph.

1.4. Wavelength dispersive X-ray fluorescence spectroscopy (WD-XRF)

WD-XRF was used in order to determine the chemical composition of the pottery and clay samples to establish interpretations regarding the provenance (Hall 2016). A total of seven samples – six pottery and one clay sample from Kreiči surroundings – were analysed with WD-XRF. All samples were analysed using a Bruker S8 Tiger spectrometer. One measurement was conducted for each sample and the obtained concentration values (heavy elements in oxide form) were evaluated and normalised after the exclusion process.

The pottery sherds were analysed in a non-destructive approach, i.e. the samples were analysed in a solid form. Full analysis in a vacuum atmosphere was conducted. The radiation size of the sample holder was 8 mm. The clay sample was previously prepared for the analysis. The clay was air-dried and ground into a powder using a pestle. The powdered sample was pressed into a pellet and then placed on a 5 µm thick polypropylene film. Full analysis in a helium atmosphere was conducted. The radiation size of the sample holder was 34 mm.

Normalised WD-XRF data was converted to Centered Log-Ratio (CLR) values (Aitchison 1986) for hierarchical clustering. CLR values are effective for predicting geochemical anomalies and chemical traits (Rollinson 1993). To avoid errors from '0' values, elements were filtered based on detection limits and stability (detailed in 'WD-XRF measurements').

1.5. Analysis of plant micro- and macro-remains

In order to reconstruct the paleoenvironment and depositional conditions during the excavation process, a 1 m long soil monolith from test pit 2 was analysed in detail (at 2 cm intervals). To trace environmental changes during the formation of specific sediment layers and to assess the formation character of the cultural layer, loss on ignition (LOI) analysis was performed on all 50 samples from the monolith. Analyses were conducted to determine the content of organic matter, carbonates and mineral matter in the sediments. Samples were sequentially dried at 105°C in a drying oven, followed by combustion at 550°C and 900°C in a muffle furnace (Heiri et al. 2001). The data obtained from the LOI analysis was plotted and interpreted using TILIA software (version 2.6.1).

On all 50 samples, spore-pollen analysis was performed as well. The preparation of sediment samples for pollen analysis was conducted in accordance with the methodology outlined by Bennett and Willis (2001). During the analysis, 400–700 pollen grains were identified from the pollen concentrate obtained from each sample, classifying them into ecological groups. Aquatic plant pollen and spores were recorded separately. For the construction of the percentage pollen diagram, the total pollen sum (100%) was calculated based on the sum of all terrestrial pollen grains, excluding aquatics, spores, microscopic charcoal particles (<25 µm) and algae (Berglund and Ralska-Jasiewiczowa 1986).

To recover plant macro-remains, 50 samples (approx. 20 ml in volume each) from the monolith and two 1 litre bulk samples from test pit 2 layers 3 and 5 were processed subsequently through sieves with mesh sizes of 3, 2 and 1 mm to recover coarse fractions containing larger seeds and plant parts, and a 0.25 mm sieve to recover smaller plant macro-remains. The identification of plant and other remains was carried out using a ZEISS Stemi 508 stereomicroscope, utilising available reference materials such as Cappers et al. (2006) and Rasiņš (1954). The sediment accumulation rate model was made using the CLAM package in R (Blaauw 2010).

1.6. Sampling strategy for ^{14}C dating

In order to date the stratigraphy of test pit 2, a total of six samples of plant macro-remains were selected from specific intervals from the monolith extracted from the pit's western profile. The plant remains were sampled from the bottom of the monolith (depth from ground level 0.98–1.00 m), top and bottom of layer 3 (depth from ground level 0.62–0.64 m and 0.68–0.70 m) and layer 5 (depth from ground level 0.82–0.84 m), which contained archaeological finds, and from the bottom of the peat layer (layer 2) at a depth of 0.58–0.60 m covering the archaeological layers, and from peat (layer 4) at a depth of 0.72–0.74 m from ground level separating the find layers (Table 3). In order to prepare the samples, they were treated with 10% HCl, rinsed several times in distilled water and dried at a temperature of 70°C. The preparation samples were then placed in foil bags and stored in a refrigerator, where they remained until shipment to the Vilnius Radiocarbon Laboratory.

To complement the sediment monolith analysis, six additional samples were submitted to the Poznań Radiocarbon Laboratory for AMS dating. The selection included two botanical samples (hazelnut shells) and four osseous samples (bone and antler). Two botanical and two osseous

samples were recovered from the recently excavated test pit 2 (layers 3 and 5), while the remaining two osseous samples were selected from the collections of the 1958 and 1959 excavations (areas 3 and 4). Selected from the 2022 excavations were a roe deer (*Capreolus capreolus*) bone and a harpoon. A worked red deer (*Cervus elaphus*) antler fragment from 1958 trench 4 (square 1, recovery depth 0.30 m) and a fragment of a Eurasian elk (*Alces alces*) ulna dagger/knife from 1959 trench 3 level 3 (first sand layer under the turf, Square 42l, recovery depth 0.62 m) were selected for dating.

This sampling strategy was designed to cross-validate the sedimentary chronology with the archaeological horizons, which could in the future facilitate the integration of the results from Zagorskis's excavations into the newly established chronological framework. Furthermore, three samples were selected from burials at Kreiči (burials 13, 14 and 23) to produce the first radiocarbon dates for the cemetery and to improve our understanding of the chronology and use of both the settlement and the associated burial ground.

2. Excavation results and artefact analysis

2.1. Test pits and stratigraphy

Archaeologically significant layers comparable to those identified by Zagorskis (1963) were discovered only in one of the two test pits – test pit 2. The upper part (0.20–0.25 m) of test pit 1 contained modern waste materials, including a brush head, resembling the instruments used in excavations during the 1950s fieldwork, indicating that this test pit completely overlapped with area 5 excavated by Zagorskis.

In contrast to the disturbed context of test pit 1, test pit 2 yielded intact archaeological deposits. Its upper stratigraphy, extending to a depth of 0.55 m, consisted primarily of peat (layer 1 – topsoil – and layer 2) (Fig. 3). An exception was noted in the northeast corner, where a layer mixed with light yellow gravel was observed from the surface, with the peat layer resuming at a depth of 0.40 m. Excavation was significantly obstructed by a large, horizontally lying tree trunk, which appeared diagonally across the test pit at depths of 0.53 m (E profile) and 0.20 m (W profile)



Figure 4. Test pit 2, 2022 (photograph by M. Kalniņš).

(Fig. 4). This trunk extended into the northern profile, reducing the excavation area by more than one-third.

At the level of the trunk on the northern side, sandy lenticular inclusions mixed with peat were observed. Below the peat sequence (layer 2), stratigraphy alternated between sand and peat layers and was recorded as such:

- Layer 3 – a coarse sand layer reached at 0.59 m (W profile) and 0.50 m (E profile). At the W profile, this layer was 0.06 m thick, while in the second metre and at the E profile, it merged with lenticular inclusions.
- Layer 4 – in the first metre of the test pit at a depth of 0.65 m, beneath layer 3, a sterile peat layer up to 0.08 m thick was recorded.
- Layer 5 – approx. 0.15–0.20 cm thick sand layer containing organic remains, identified at a depth of 0.74 m next to the W profile and a depth of 0.80 m at the E profile.
- Layer 6 – at approx. 0.9 m depth, a sandy peat layer with alternating bands of sand and peat which yielded no archaeological finds.

At a depth of approximately 0.70–0.75 m, a groundwater ingress was first encountered, emanating from the permeable sand layers. This necessitated regular pumping to facilitate further excavation. Research in test pit 2 was ultimately terminated at a depth of 1.20 m due to the rapid and unmanageable influx of water through the sand and sandy peat layers, including layers 3 and 5.

2.2. Archaeological assemblage

Archaeological assemblages were discovered only in test pit 2. The first artefacts in test pit 2 were recovered from sandy-peaty inclusions (layer 2) at a depth of 0.25 m. This horizon yielded a modest assemblage consisting of small, highly fragmented animal bones, isolated teeth and charcoal. The faunal material (n=13) is characterised by a light brown colour and generally poor condition. Taphonomic observations indicate that the bone surfaces are heavily weathered and porous, likely due to their proximity to the surface and fluctuations in the water. Most fragments are indeterminate, though long bone fragments of larger ungulates and small-to-medium-sized mammals were recorded.

The density and diversity of the finds increased substantially within the coarse sand of layer 3 at a depth of 0.50–0.66 m from ground level. The faunal remains included both worked and unworked animal bones (n=46) (Fig. 5.1–9), with a significant increase in both frequency and species variety. Burnt or calcined bone fragments (white and grey in colour) found in layer 3 indicate domestic activity such as cooking or waste disposal. While many bones show weathered surfaces, the preservation of smaller elements like fish vertebrae and mammalian teeth can be considered to be relatively good. The lithic industry was represented in layer 3 by a fragment of a flint biface tool (Fig. 5.18), alongside quartz (n=1) and flint (n=3) debitage – flake fragments (Fig. 5.16–17) and shatter. In terms of ceramics, Piestiņa Ware pottery sherds (n=17) (Fig. 5.10–14) and a single Comb Ware sherd (n=1) (Fig. 5.15) were found. Piestiņa Ware is considered by Latvian archaeologists to represent a subtype of the more widely known Post-Narva Ware, also referred to as Middle Neolithic porous ware. This pottery is characterised by a porous clay fabric resulting from organic tempering, which included mussel shells and plant remains. It typically exhibits sparse ornamentation, with surfaces that are either smooth or striated, and vessels are generally oval in shape (Dumpe 2024; 2025). During the Middle Neolithic, this type of pottery coexisted with Comb Ware, which was also identified at the Kreiči settlement during excavations carried out in the 1950s (Zagorskis 1963).

Similar archaeological finds to those in layer 3 were recorded in the lower sand layer – layer 5, at a depth of 0.74–0.90 m from ground level. This layer contained various organic remains, worked and unworked animal bones (n=13) (Fig. 5.19–24) and 12 Piestiņa Ware (Post-Narva Ware) pottery sherds (Fig. 5.25–27). Despite the lower quantity of finds, the preservation state in layer 5 is markedly superior to the upper layers. The bones exhibit a darker coloration and smoother surfaces, characteristic of rapid burial in stable, anaerobic (waterlogged) conditions. The most significant find from this horizon is a fragment of a bone harpoon (Fig. 5.19), which, combined with the presence of larger, better-preserved bone fragments, suggests this layer represents a well-preserved primary depositional context.

2.3. Results of zooarchaeological analysis

The bone assemblage recovered from the Kreiči settlement includes a diverse array of osteological remains of animal origin. A total of 124 bone and tooth fragments were recovered from test pit 2. The analysed faunal assemblage from the Kreiči excavations consists of a highly fragmented and generally poorly preserved collection of animal remains, and therefore the majority of fragments are classified as indeterminate (ca. 72%). Bone colour ranges from dark brown and black to light brown and grey, reflecting variable depositional conditions and possible post-depositional displacement within the trench. Several specimens exhibit advanced cortical exfoliation, and a number of fragments are fully calcined (white), indicating exposure to high temperatures.

In total, only 35 fragments could be assigned to specific taxa or to a family or group level. The identified material consists predominantly of long bone fragments, distal limb bones and teeth. Dental remains provided the



Figure 5. Finds from layers 3 and 5 in test pit 2. 1–4 worked bones; 5–9 unworked bones and teeth; 10–14, 25–27 Piestiņa Ware pottery; 15 Comb Ware pottery; 16–18 flint artefacts; 19 harpoon; 20–24 animal bones. 1–18 layer 3; 19–27 layer 5 (photograph by M. Kalniņš).

most reliable taxonomic identifications, whereas the high degree of fragmentation limited more precise identification of other skeletal elements.

Identified taxa include a mix of terrestrial and aquatic species: wild boar (*Sus scrofa*), Eurasian elk (*Alces alces*), red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), pine marten (*Mates martes*), pike (*Esox lucius)*, zander (*Sander lucioperca*) and perch (*Perca fluviatilis*). The majority of the identified remains belong to pig (most likely wild boar, although some specimens fall within the size range of the domestic pig) – 14 identified fragments – followed by elk (7) and other cervids (5), and a possible bovid. Carnivores are represented by remains of pine marten or similarly sized taxa (Fig. 5).

Several juvenile individuals were identified on the basis of deciduous teeth, including elk, cervids and pig. Cut marks were observed on three fragments, most clearly on a pig humerus, where they are consistent with butchery activity. In addition, some bone fragments display traces of

working, including polishing, shaping and splintering, and a fragment of a bone harpoon was also recovered.

The faunal assemblage from Kreiči is consistent with Stone Age hunter-fisher-gatherer settlements in the eastern Baltic, characterised by broad-spectrum subsistence practices and intensive on-site processing of animal resources (e.g. Lõugas 2017). The poor preservation and high degree of fragmentation are best explained by intensive site use, trampling, repeated burning and post-depositional processes. Wild boar/pig and large ungulates, particularly elk and other cervids, most likely constituted the most important terrestrial resources and are in accordance with faunal data from excavations in the 1950s (Zagorskis 1963, p. 33; Paaver 1965). The presence of different bone elements indicates local hunting and primary carcass processing at the site. Cut marks and extensively fragmented limb bones point to systematic butchery, marrow extraction and food preparation.

The identification of juvenile individuals suggests non-selective hunting and/or seasonal use of animal resources. Small carnivores, represented by marten-sized animals, are best interpreted as evidence for fur exploitation, a well-attested practice in Stone Age northern and north-eastern Europe (see, e.g., Vang Petersen 2013). The skeletal representation, including mandibles and limb bones, is consistent with skinning rather than meat-oriented processing. Fish remains demonstrate the exploitation of freshwater resources, complementing terrestrial hunting activities. The identified taxa indicate fishing in lakes and riverine environments, consistent with the site's location.

In addition, several worked or modified bones, including a barbed harpoon, provide direct evidence for osseous technology. These finds indicate on-site manufacture of bone tools and highlight the integration of subsistence, craft production and the use of animal materials beyond dietary purposes. The harpoon fragment (Fig. 5.19), in particular, strongly supports fishing and aquatic resource exploitation. The faunal evidence suggests that Kreiči functioned as a multifunctional habitation site where hunting, fishing, food processing, bone-working and refuse disposal were carried out.

2.4.Chemical composition of pottery and clay

2.4.1.WD-XRF measurements

The WD-XRF spectrometer, depending on the sample, has measured up to 21 elements (Appendix 1). Nine of these elements did not exceed 0.1 wt% and were not detected in all the samples, such as barium, chlorine, manganese, sulphur etc., whereas 12 elements were detected in all the samples analysed. Most of the elements are common for clay chemical composition – silica, aluminium, iron, calcium, potassium, magnesium, sodium and titanium.

Bearing in mind mobility (leaching) due to post-depositional processes, as well as possible impact from temper and firing, the following elements cannot be viewed as reliable and will not be considered in the analysis – calcium, barium, phosphorus and sulphur (Schwedt et al. 2004; Hall 2016). The low amount of sodium in samples (up to 0.7 wt%) does not indicate soil contamination for this element, thus it will be considered in the analysis. The remaining elements which do not reach a concentration of 0.1 wt% and are not detected in all samples will not be considered due to limited diagnostic value.

Based on the criteria above, the following major elements were selected for further compositional data analysis: silica, aluminium, iron, potassium, magnesium, titanium and sodium. These element concentrations were normalised and converted to CLR values to identify the final chemical signatures (Table 1; Appendix 2).

2.4.2.Compositional data analysis

Based on the dendrogram structure, a cut-off distance was chosen at 0.6. Hierarchical clustering analysis indicates the presence of two distinct groups and one loner (Fig. 6). Group 1 contains four samples (KR1, KR2, KR4, and the Kreici-M – clay sample), while group 2 comprises two samples (KR3 and KR5). Sample KR6 was identified as a separate outlier.

Cluster group 1 is characterised by relatively higher silica (2.458), iron (0.394) and magnesium (-0.925) values. In contrast, group 2 shows higher values for aluminium (1.370) and titanium (-0.953). These compositional differences define the distinct chemical signatures of the two groups.

Loner KR6 appears particularly distinct due to its higher potassium (0.254), enriched titanium (-0.604), and significantly lower magnesium (-1.580) and sodium (-2.079) values (Table 1).

Table 1. Converted CLR values from normalised WD-XRF measurements (created by V. Haferberga).

Sample	SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO	TiO_2	Na_2O
KR1	2.532	1.342	0.344	-0.017	-0.905	-1.367	-1.93
KR2	2.371	1.051	0.479	0.113	-0.943	-1.399	-1.669
KR3	2.323	1.434	0.215	0.056	-1.186	-0.889	-1.951
KR4	2.308	1.233	0.243	0.246	-0.904	-1.303	-1.82
KR5	2.374	1.306	0.16	0.183	-1.169	-1.017	-1.84
KR6	2.506	1.271	0.235	0.254	-1.58	-0.604	-2.079
Kreici-M	2.621	1.259	0.509	0.158	-0.948	-1.538	-2.063

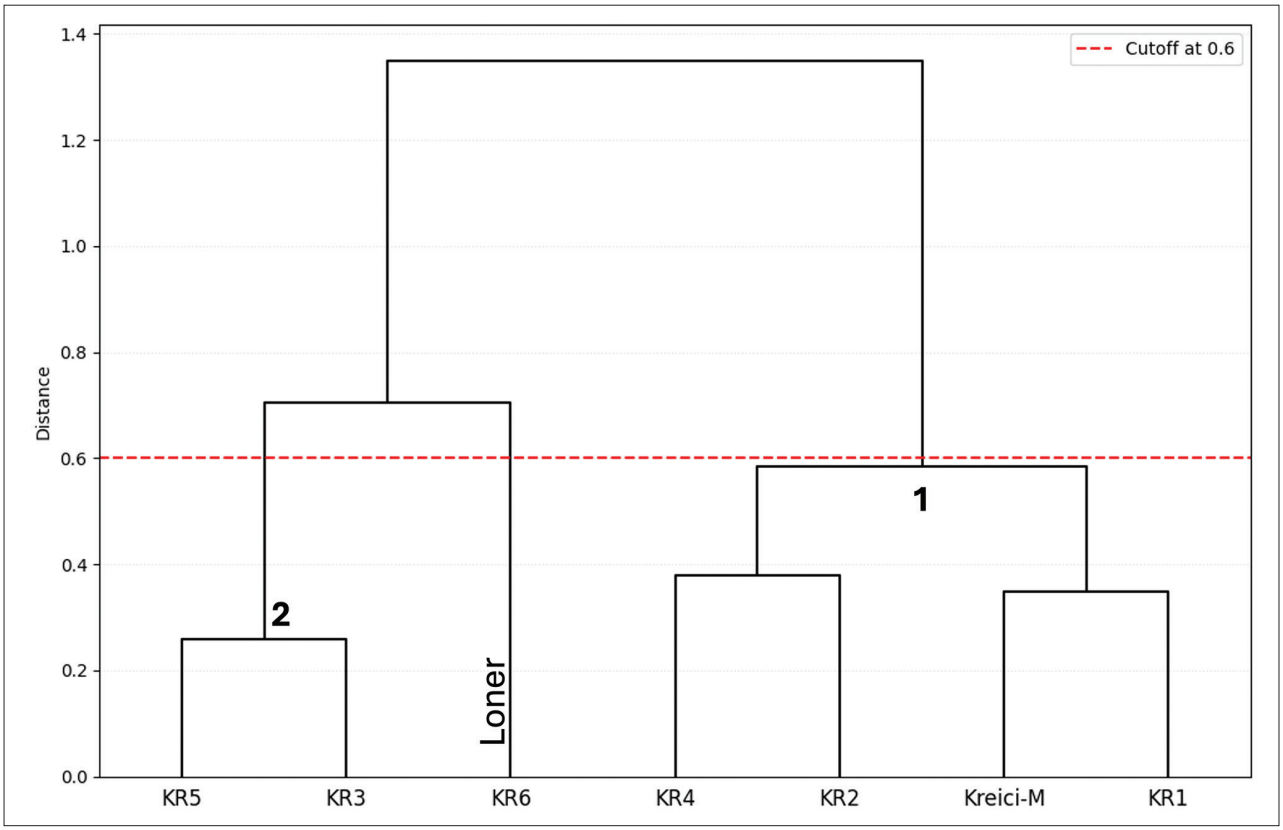


Figure 6. Dendrogram made from CLR values. Made by using AI Gemini in colab.google (compiled by V. Haferberga).

2.5. Microstructure of pottery

2.5.1. Clay, temper and inclusions

All of the vessels analysed were made from similar coarse clays – rich in silt and fine –coarse sized sand (Table 2). In one instance (KR1), the clay contained a few ferric concretions, indicating possible multiple clay sources.

The tempering material used in all of the pottery samples was crushed mussel shells. Often, reddish and yellowish hues of shell fragments under plain polarised light (PPL) were detected (Fig. 7A), indicating a possible iron-rich environment. In all cases, mussel shells were poorly preserved; only in isolated cases shell fragments were almost fully present, while in the majority of cases only empty pores/voids were visible. The microstructure of these mussel shells was not identifiable.

Regarding inclusions, all of the samples contained fragments of plant matter. These were preserved as small oval or oval-elongated pores, often with charred plant fragments inside, sometimes just charred pieces (Fig. 7B). Only a few pieces were usually present in the clay paste, not exceeding ca. 2% of the total volume, thus it is not considered a tempering material, but rather a natural inclusion. In none of the plant samples was it possible to determine any identificatory traces of specific species.

The majority of the samples (KR1,3,4,5,6) contain clay pellets (Fig. 7C). These clay pellets were quite large, reaching up to 1.5 mm in size. By nature, clay pellets in the majority of cases are finer than the matrix. These are either formed naturally in the clay, a result of mixing various raw materials or due to poor homogenisation of clay paste during the production (Quinn 2013; Stilborg 1997).

2.5.2. Pottery fabrics

Based on the data observed, pottery fabrics are overall quite similar. All were made with medium to coarse clay, contain charred plant matter and were tempered with crushed mussel shells. However, due to a few nuances, it was possible to distinguish four fabric groups (Fig. 7D).

Fabric '1' consists of two samples (KR1 and KR6) and is generally characterised by coarse clay rich in silt and various sized sand and few inclusions of charred plant matter. In the case of KR1, ferric concretions were distinguished in the clay. Fabric was tempered with various sized mussel shells in a volume of 10%–14%.

Fabric '2' also consists of two samples (KR4 and KR5). This group can be characterised as made from medium coarse clay rich in silt and fine sand and tempered with various sized crushed mussel shells in a volume of 17%–19%.

Loners '1' and '2' are outliers as each consists of only one sample. Loner '1' (sample KR2) is characterised as a vessel

Table 2. The results of the petrographic analysis (created by V. Haferberga).

No.	Sample	MACROSCOPIC DATA					PETROGRAPHIC DATA										Notes
		Type	Wall thickness, cm	Temper, mm	Coarseness	Sortness	Silt	F. sand	C. sand	Mica	Fe concr.	Temper	Volume, %	Max. size, mm	Max avg. s., mm	Homogeneity	
1	KR1	Post- Narva (Piestiņa type)	0.91	5.4	Coarse	N	++	++	+	-	+	Mussel shells	13.5	3.1	1.74	W	Mussel shells are not well preserved, majority are simply pores, only few with some remains; mussels added various sizes – not sorted; plant matter was identified – presented in various shaped pores, some with charred remains (largest – 0.6 mm); clay pellets identified (largest – 0.65 mm); largest ferric concretion – 0.65 mm
2	KR2	Post- Narva (Piestiņa type)	0.64	4.7	Coarse	N	+	++	++	-	-	Mussel shells	24.5	1.3	1.06	W	Mussel shells are not well preserved, in few remains are left, showing reddish or yellowish hue in PPL, no microstructure identifiable, semi sorted before adding as temper; plant matter – presented as oval or elongated pores – often with charred fragments in them (largest – 0.25 mm)
3	KR3	Post- Narva (Piestiņa type)	1.1	7.1	Coarse	N	++	++	+	-	-	Mussel shells	49.5	1.5	1.06	W	Mussel shells are not well preserved, mostly empty pores, occasionally remains distinguished, microstructure unidentifiable, quite sorted; plant matter – round, round-elongated pores with charred remains (largest – 0.7 mm); Clay pellets quite common (largest – 1.5 mm)
4	KR4	Post-Narva (Piestiņa type)	0.95	5.1	Medium	SE	+	++	-	-	-	Mussel shells	17.4	2.5	1.06	W	Mussel shells are not well preserved, mostly empty pores, rarely some remains present, various sizes – not sorted; plant matter – pores with charred remains (largest – 0.6 mm); several clay pellets distinguished (largest– 0.95 mm)
5	KR5	Post- Narva (Piestiņa type)	0.84	8.7	Medium	SE	+	++	-	-	-	Mussel shells	18.9	2.55	1.83	W	Mussel shells partly preserved, some are empty pores, some partly or fully preserved, however, no microstructure identifiable, various sizes – not sorted; charred fragments of plant distinguished (largest – 0.5 mm); few clay pellets identified (largest – 0.65 mm)
6	KR6	Post Narva (Piestiņa type)	0.66	6.1	Coarse	N	++	++	+	-	-	Mussel shells	10	2.6	1.26	W	Majority of the mussel shells are not preserved, few small ones are better preserved, however, no microstructure identifiable, in PPL shows in yellowish hue, various sizes – not sorted; clay pellets (largest – 1.05 mm) distinguished; charred plant remains observed in pores (largest – 0.7 mm)

- sparse/none; + common; ++ abundant; SE – semi-sorted; N – not sorted; W – well homogenised

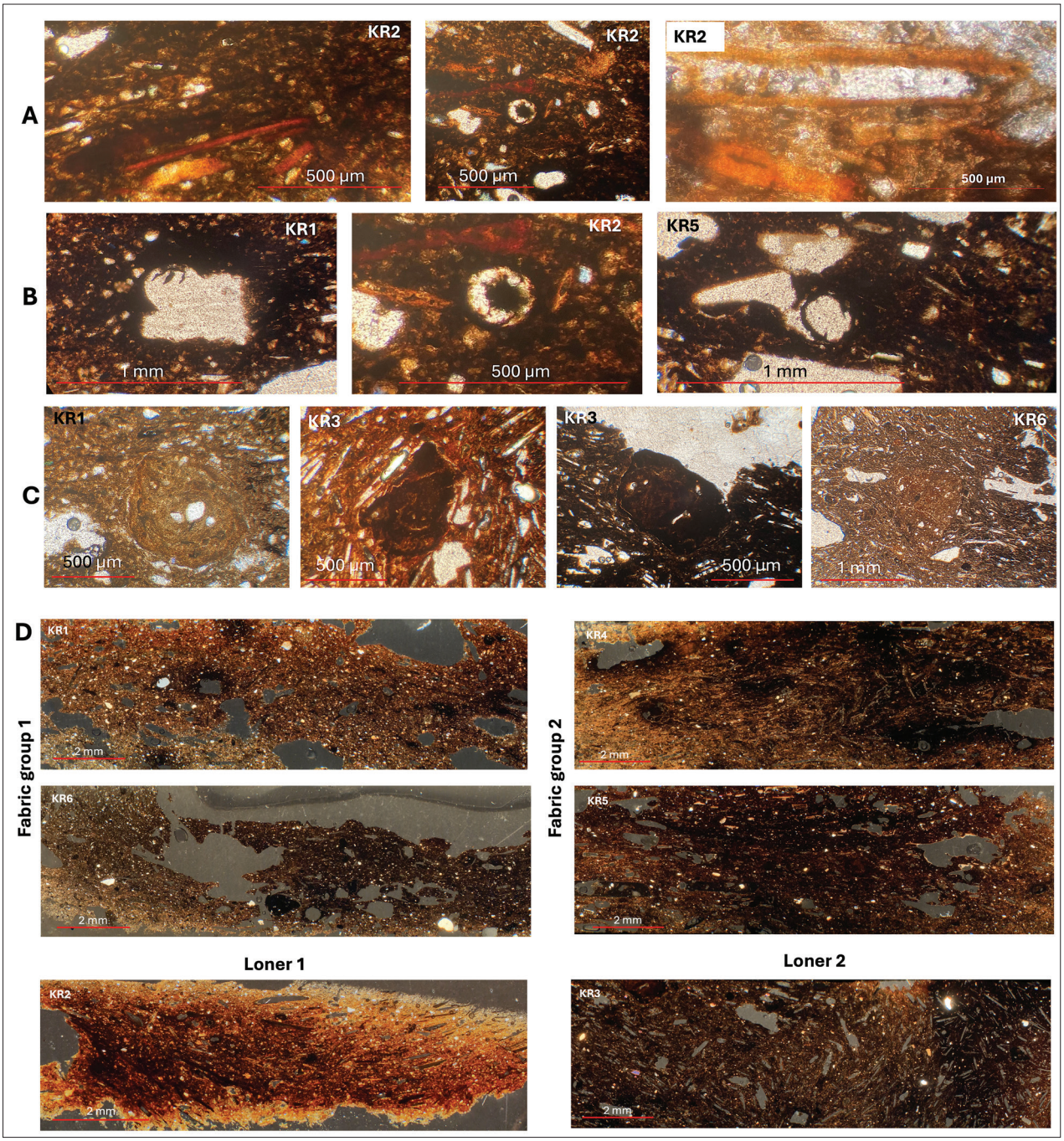


Figure 7. Micrographs of thin sections. A – mussel shells with reddish-yellowish hues; B – pores with charred plant fragments; C – clay pellets (all in PPL); D – pottery fabric groups (all in XPL) (photograph by V. Haferberga).

made of coarse clay rich in fine and coarse sand and tempered with sorted mussel shells in a volume of 25%. Notably, the size variation of mussel shells are observed from the thin section (ratio of 1.3 vs. 1.06 mm) not macroscopic parameters, where the largest observed pore from, likely, mussel shell was 4.7 mm (see Table 2).

Among the rest of the sherds with local tempering traditions, loner '2' (sample KR3) stands out the most as it has been densely tempered with crushed mussel shells, reaching a volume of 50%. The thin section shows that the mussel shells were quite sorted, while the clay was similar to that of fabric '1'.

3. Results of paleoenvironmental research and archaeobotanical data

3.1. Sediment characteristics

Based on the LOI analysis of the sediment monolith (Fig. 2), four distinct lithological zones can be identified (Fig. 8). Throughout the profile, carbonate content remains

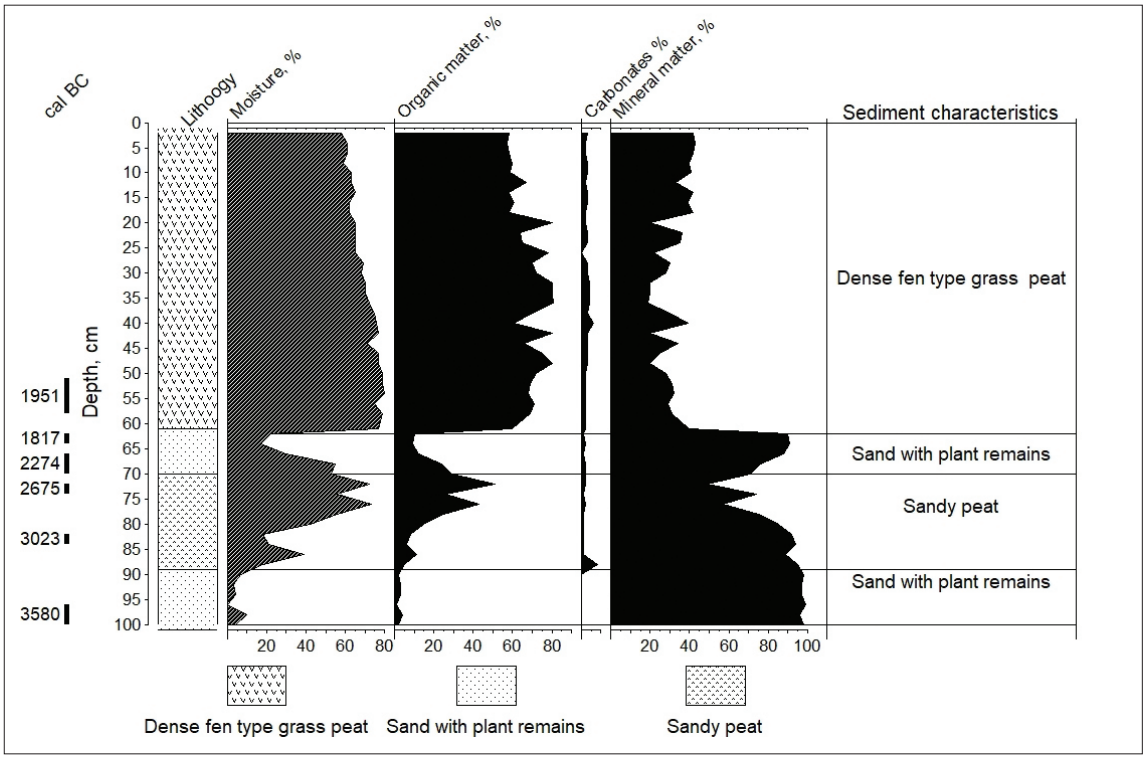


Figure 8. Results of loss on ignition (LOI) analysis of the sediment monolith from the western profile of test pit 2 from 2022 (compiled by L. Kalniņa).

consistently low. This suggests the absence of carbonate-bearing parent materials (e.g. carbonate-rich till) in the immediate vicinity and indicates that the groundwater was not saturated with carbonates, precluding chemical precipitation.

Fluctuations in the LOI curves (Fig. 8) reveal relatively rapid shifts in sediment composition within the lower section of the monolith (0.60–1.00 m), pointing to dynamic environmental conditions and intensified geological processes. Specifically, in the 0.84–1.00 m interval, the sediment is dominated by mineral matter, coinciding with low moisture content. Variations in composition are relatively minor, suggesting stable basin conditions. The overall organic content is low, primarily represented by relatively coarse remains (up to 200 μm) of vascular plants – such as reeds (*Phragmites*), pondweed (*Potamogeton*), bulrushes (*Scirpus*) and sedges (*Carex*) – as well as tree remains (*Betula, Alnus*).

Pronounced fluctuations characterise the 0.72–0.86 m interval (Fig. 8), where the stratigraphy consists of alternating sand and peat interlayers. Both moisture and organic content increase in this zone, which is indicative of ongoing terrestrialisation (overgrowing) processes. The sharp variations in sediment composition reflect rapid environmental shifts and periodic flooding of the area. While the total abundance of plant remains is higher, the material is finer and more fragmented. Furthermore, mineral grains exhibit a higher degree of rounding, providing evidence of more intense hydrodynamic processes. A dominance of mineral matter in the 0.60–0.72 m interval (Fig. 8) suggests a period of prolonged inundation and higher water levels, interrupting the peat accumulation.

In the upper section of the monolith, 0–0.60 m (Fig. 8), environmental conditions appear to have stabilised. Although fluctuations are observable, they are less pronounced and do not significantly disrupt peat formation and accumulation. Microscopic charcoal was detected throughout this interval, with a peak concentration at depths of 0.06–0.20 m. This horizon also exhibits the highest degree of peat decomposition, suggesting a dry climate regime during deposition. These dry conditions likely accelerated decomposition rates while simultaneously reducing the rate of peat accumulation. It is plausible that the peat surface was subject to erosion during this period.

3.2. Spore-pollen analysis results

Based on the spore-pollen analysis data obtained, the percentage diagram can be subdivided into six pollen assemblage zones, which allow tracking of the composition changes of vegetation on both a regional and local scale (Fig. 9).

The bottom part (depth 0.92–1.00 m) of the monolith or zone KR-6 (Fig. 9) corresponds to sediments composed of sand mixed with some organic matter and wood remains. The pollen spectrum is dominated by arboreal pollen (AP) at 80%, while non-arboreal pollen (NAP) accounts

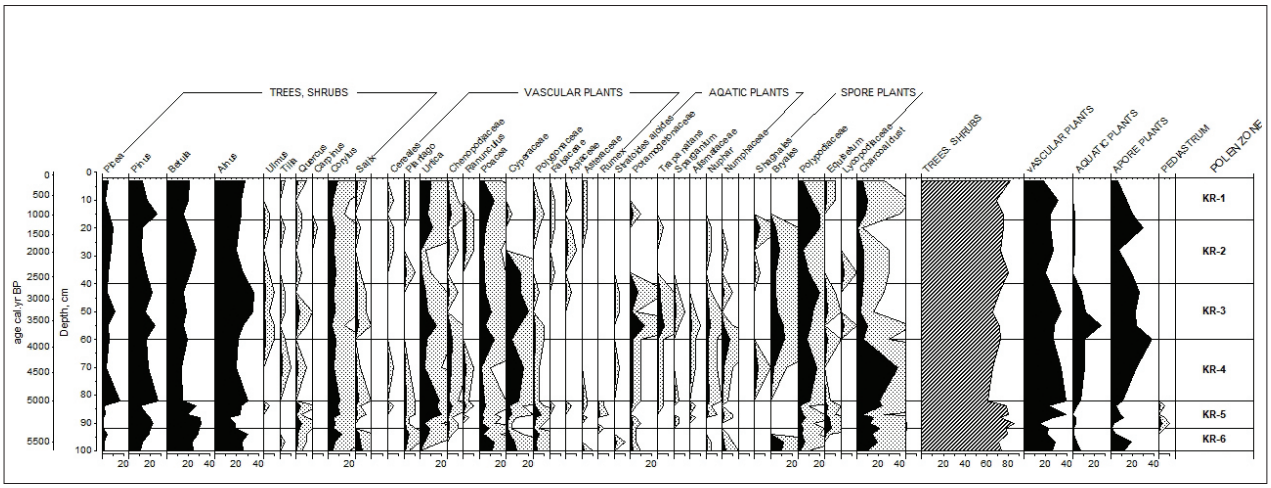


Figure 9. Results of spore-pollen analysis of the sediment monolith from the western profile of test pit 2 from 2022 (compiled by L. Kalniņa).

for 20%. Despite the presence of macroscopic wood remains in the sediment, the pollen composition suggests that the immediate vicinity was relatively open during this sediment accumulation period. Among tree taxa, pine (*Pinus*), birch (*Betula*) and alder (*Alnus*) predominate. The ruderal and grass type plant assemblage is characterised primarily by nettle (*Urtica*), grasses (*Poaceae*) and sedges (*Cyperaceae*). Above zone KR-6, at a depth of 0.82–0.92 m, it is possible to distinguish zone KR-5 (Fig. 9), where the sediment transitions to sandy peat indicate a slightly calmer sediment accumulation environment. In this zone were found remains of *Pediastrum*, which is a photosynthetic planktonic algae that often occurs in biologically productive waters with sufficient sunlight. The proportion of AP in this zone decreases at a depth of 0.82–0.84 m. The composition indicates a short shift in the regional forest structure: the amount of birch pollen decreases, while the abundance of pine, spruce (*Picea*) and alder fluctuates, with a maximum around a depth of 0.82–0.84 m. Within the ruderal plant spectrum, there is an increase in the goosefoot family (*Chenopodiaceae*), but a decrease in nettle and fleawort (*Plantago*). A significant feature of this zone is the increase in water plants such as water lilies *Nuphar* sp. and *Nymphaea* sp. and in cryptogams, represented by polypodium fern spores (*Polypodiaceae*). At the beginning of the zone, the concentration of microscopic charcoal particles (smaller than 25 microns) decreases, reaching a minimum at a depth of 0.88–0.86 m. Following this, it increases rapidly. This elevated charcoal concentration stands out within the depth interval of 0.82–0.60 m, corresponding to zone KR-4 (Fig. 9) and dating to approximately 5000 to 3800 cal years BP, reaching its maximum at a depth of around 0.70 m. The pollen curves of all trees (AP) in this zone are characterised by a downward trend. In turn, the pollen curves of vascular plants increase significantly in this interval. In this zone, the herb pollen spectrum is dominated by grasses (*Poaceae*) and sedges (*Cyperaceae*), accompanied by an increase in aquatic plant pollen. These indicators suggest wetter local conditions. Notably, isolated pollen grains of cultivated cereals (*Cerealia*) and goosefoots (*Chenopodiaceae*) are present in this zone. Furthermore, a decline in coniferous pollen is observed alongside a significant decrease in willow (*Salix*). At the same time, birch (*Betula*) pollen values rise gradually, while the proportions of lime (*Tilia*) and oak (*Quercus*) fluctuate.

At a depth of 0.40–0.60 m, zone KR-3 (Fig. 9) consists of a layer of well-decomposed dense peat, the bottom part of which may also be interpreted as dense peaty gyttja with a minor admixture of mineral matter (silt and clay). The arboreal pollen frequency increases slightly, with a gradual rise in alder and hazel (*Corylus*) pollen. A distinct peak is observed in the curves for aquatic plants – specifically pondweed (*Potamogeton*) and water-milfoil (*Myriophyllum*) – indicating that the territory was subject to periodic inundation. The pollen abundance of the water caltorp *Trapa natans*, which prefers warm, shallow, nutrient-rich freshwater environments, reaches its highest values in this interval. Overall, the pollen spectrum reflects the expansion of alder-spruce forests in the region. Fern spores remain high, while the concentration of microscopic charcoal decreases significantly.

Zone KR-2 in the diagram is subdivided into a depth interval of 0.18–0.40 m. (Fig. 9), which corresponds to a well-decomposed fen-type grass peat layer. In this zone, the birch pollen curve increases, but pine and alder decrease. The presence of moisture-loving and aquatic plants significantly decreases or even disappears. Although the amount of grasses is generally decreasing, there is still a fairly significant presence of ruderal plants, especially nettle, as well as small amounts of cereal pollen. Such a pollen spectrum in the KR-2 zone interval indicates that as early as 2500 BP the conditions in the area were relatively dry,

but still sufficiently moist for continued peat formation and accumulation.

The upper 0.18 m, or the uppermost zone (Fig. 9), zone KR-11, consists of well-decomposed dense fen-type grass peat. This zone is defined by a resurgence in the proportion of non-arboreal pollen, signalling the re-expansion of open habitats. The arboreal composition is characterised by a decline in the pine-alder curve, concurrent with a rise in spruce, hazel and birch values. The herb spectrum is dominated by grasses and ruderal plants. Pollen of barley (*Hordeum*) was also identified in this interval. However, the overall data suggests that the landscape was not as open as in the preceding phases. Overall pollen concentration in the upper part of this zone is low, and the preservation state is poor. Many pollen grains are corroded, suggesting that the sediment was exposed to oxidation and direct sunlight during formation or subjected to subsequent exposure.

Biological and mineral analysis of the monolith from Kreiči test pit 2 reveals a dynamic environment during sediment deposition. The environment transitioned from an open landscape, where sand containing organic and wood residues accumulated due to hydrodynamic processes, to an expanding mixed forest, before eventually returning to a partially open territory. Furthermore, charcoal was detected throughout the profile, indicating local or regional fire events driven by either natural processes or anthropogenic activity.

Considering the settlement's location, changes in sediment composition, and the characteristics of pollen assemblages and their preservation, it can be inferred that this area lay on the margin of a bog. It was likely habitable during the period when dense peat accumulated within the upper 40 cm layer. This interpretation is supported by Konstance Logina's pollen diagram and by Francis Zagorskis's assessment (1963), which suggests that the Kreiči peatland began forming under subarctic conditions. However, peat deposition within the settlement area itself appears to have started only around 4000 cal yr BP, in subboreal conditions, following the climatic optimum.

3.3. Plant macro-remains

Based on the analysis of plant macro-remains from the sediment monolith and the two bulk samples (1 litre each from layer 3 and layer 5, see Appendix 3), five distinct plant macro-remain (MR) zones (Fig. 10) can be distinguished. These zones also correlate closely with the stratigraphic sequence recorded during the archaeological excavation.

The upper part or zone MR III (0–0.37 m) (Fig. 10) is characterised by fine herbaceous detritus, interspersed with occasional fragments of wood and woody twigs. Macroscopic charcoal was identified at a depth of 0.06–0.28 m. An eroded, charred fragment of a burnt cereal grain (*Cerealia*) was recorded at a depth of 0.26 m. Among the faunal remains, isolated freshwater sponge (*Porifera*) gemmules are present, while earthworm cocoons appear in the upper portion of the interval. Seeds of raspberry (*Rubus idaeus*) and stinging nettle (*Urtica dioica*) occur regularly, with sedge (*Carex*) seeds present in select samples. The sediment composition and the plant macro-remains assemblage indicate that these deposits accumulated in a fen (low moor) environment.

At a depth of 0.37–0.61 m, zone MR II (Fig. 10) is distinguished, characterised by woody-herbal peat containing tree and shrub twigs. In this zone, terrestrial plant remains are gradually replaced by an increasing abundance of aquatic animal and aquatic plant remains (Water caltorp

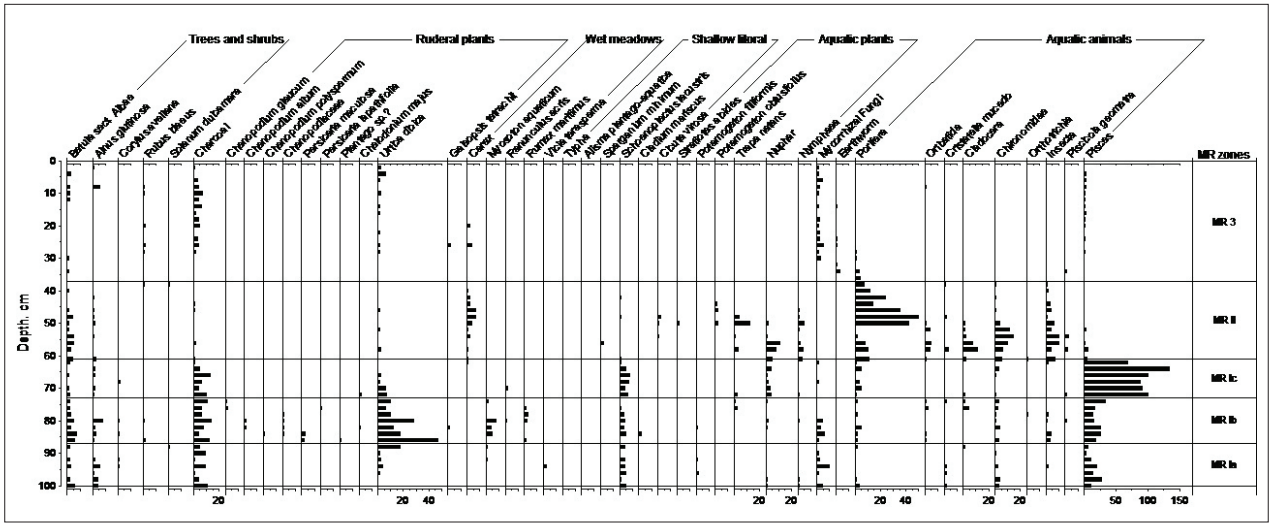


Figure 10. Results of plant macro-remains analysis of the sediment monolith from the western profile of test pit 2 from 2022 (compiled by A. Ceriņa and L Kalniņa).

Trapa natans, water lilies *Nuphar* and *Nymphaea*, blunt-leaved pondweed *Potamogeton obtusifolius*), indicating a shift in hydrological conditions.

Zone MR Ic (Fig. 10), at a depth of 0.61–0.73 m, correlates with archaeological layer 3 and consists of multi-grained sand rich in plant detritus. It contains abundant wood and bark fragments, many of which are rounded, indicating material transport by water. The sediment is rich in charcoal fragments, fish vertebrae and a significant number of calcined bone fragments. Colonies of sponge gemmules are also abundant. The macro-botanical assemblage represents a diverse environment: riparian species (alder, hazel, birch, nettle, sedges, goosefoot); littoral plants (club-rush, water-plantain, yellow iris); and aquatic macrophytes (pondweed, water lily). Small quantities of water caltorp fruit fragments (both charred and uncharred) were also identified (Fig. 10, see Appendix 3).

The lower part of zone MR Ib (Fig. 10), determined at a depth of 0.73–0.87 cm, correlates with archaeological find layer 5 and is defined by alternating layers of sand and sandy peat. The peat component is dominated by detritus from charcoal, wood, tree bark, buds and bud scales. The assemblage is mixed, containing seeds from bank-side vegetation of wet meadows and ruderal plants, among which prevails *Urtica dioica*, shallow littoral plants and deeper water species, alongside fish bones and vertebrae. This heterogeneity suggests a fluctuating near-shore environment.

The bottom part of the monolith, or MR Ia, at a depth of 0.87–1.00 m (Fig. 10), consists of multi-grained sand with gravel admixture and interlayers of plant detritus (wood, bark, twigs, charcoal and common club-rush (*Scoenoplectus lacustris*) fruits). Macroscopic charcoal is present as well, with some fragments reaching 3.5 x 2 mm in diameter. The species composition of plant macro-remains in this zone is similar to that of zone MR Ic, reflecting similar environmental conditions and anthropogenic impact.

4. New ^{14}C dates and their interpretation

In order to establish the chronology of the stratigraphic sequence excavated in test pit 2, six samples from the sediment monolith were dated (on the sampling strategy, see 'Sampling strategy for AMS ^{14}C dating') (Table 3; Fig. 11).

These results not only provide insights into the timing of sediment accumulation at the foot of the Kreiči hillock but in combination with the two samples from the artefact-bearing layers 3 and 5 (Table 3; Fig. 11) represent the first data allowing for a partial refinement of the absolute age of the archaeological material recovered from the settlement's lowland zone. Unfortunately, all four selected bone and antler samples yielded insufficient collagen for radiocarbon dating. The degradation of collagen suggests that the chemical environment of the embedding sediments, likely characterised by fluctuating water levels and acidity, was not conducive to the long-term preservation of organic proteins in the lower part of the site.

The radiocarbon date of 3644–3386 cal BC obtained from plant macro-remains corresponding to layer 6 (bottom of the monolith) (Sample Kreiči M1-1; Table 3; Fig. 11) indicates that this layer accumulated during the mid-Middle Neolithic. Although no archaeological artefacts or osteological material were recovered from this horizon, the presence of charcoal detected in plant micro- and macro-remain analyses potentially could be evidence of human activity. A comparable timeframe is represented by a separate hazelnut shell (*Corylus avellana*) sample from layer 5, which yielded a date of 3492–3386 cal BC (Sample Kreiči S6; Table 3; Fig. 11). The date of 3330–2924 cal BC (Sample Kreiči M1-2; Table 3; Fig. 11) from the upper part of layer 5 (0.82–0.84 m), combined with the date of 2869–2574 cal BC from layer 4 (Sample Kreiči M 1-3; Table 3; Fig. 11), indicates that the artefact-bearing layer 5 can be reliably attributed to the second half of the 4th millennium BC. This chronology correlates with the established period of Piestiņa Ware (Post-Narva Ware) use in the eastern Baltic region (Dumpe 2025), suggesting that the archaeological material was deposited contemporaneously with the formation of the layer. Although precise data regarding the potential freshwater reservoir effect is currently lacking, the recent dates obtained from three burials (Batraga et al. 2025) (Table 3; Fig. 11) from the Kreiči burial ground are most likely also attributable to this period – the end of the Middle Neolithic – and correspond to finds from layer 5 and the second half of the 4th millennium cal BC.

The radiocarbon data indicates that the approximately 8 cm thick layer 3 discovered at a depth of 0.60 m covers a significant chronological span: the bottom part of layer 3 dates to 2452–2147 cal BC (Sample Kreiči M1-4; Table 3, Fig. 11), while the upper part dates to 1896–1696 cal BC (Sample Kreiči M1-5; Table 3; Fig. 11). This sequence is corroborated by a separate hazelnut shell fragment recovered from layer 3, dated to 2851–2476 cal BC (Sample Kreiči S6; Table 3; Fig. 11), aligning it with the chronology established by the monolith samples.

Consequently, the botanical dates demonstrate that layer 3 formed during the Late Neolithic. However, the archaeological assemblage recovered from this stratum contains Middle Neolithic Piestiņa Ware (Post-Narva Ware) pottery, which is typologically identical to the material from the underlying layer 5 and Comb Ware. This discrepancy could suggest that the artefacts in layer 3 are likely secondary deposits, redeposited from older contexts higher up the hillock during the formation of the layer. The date obtained from the bottom part of the upper peat layer

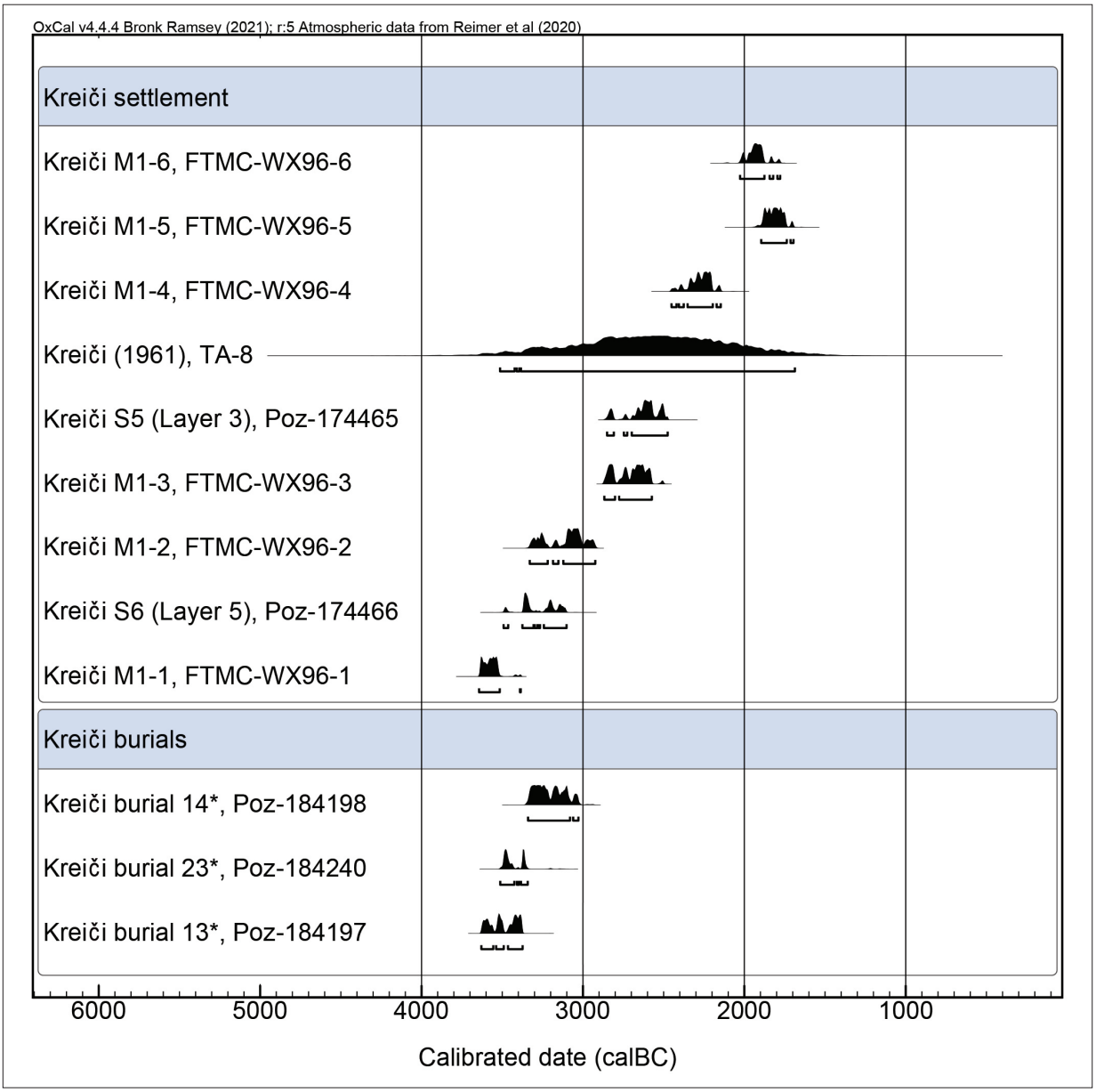


Figure 11. Calibration plot for Kreiči site radiocarbon dates. Created with OxCal version 4.4, calibration curve IntCal20 (compiled by M. Kalniņš).

(layer 4) of 2027–1779 cal BC (Sample Kreiči M1-6; Table 3; Fig. 11) indicates that the intensive geological processes responsible for the formation of the lower sand and peat layers in the lowest part of the site had ceased by the end of the Late Neolithic. Following this period, the hydrological regime stabilized, resulting in exclusive peat accumulation. This shift is clearly reflected in the LOI and botanical micro- and macro-remain analyses as well. Furthermore, during this time, a significant decrease in microscopic charcoal concentration most likely indicates minimal human presence at the Kreiči settlement site itself after the Late Neolithic and likely represents background anthropogenic activity in the wider Lake Lielais Ludzas region.

Conclusions

The 2022 reinvestigation of the Kreiči settlement provides new information about formation processes characteristic of wetland-margin sites in the eastern Baltic. While the fieldwork was limited in scale, the main aim of this research was to collect material for new radiocarbon dates and carry out paleoenvironmental investigations.

Comparative analysis of the recovered archaeological finds from test pit 2 reveals a distinct correlation between the stratigraphic depth and the physical characteristics of the finds. Although the Piestiņa Ware (Post-Narva Ware) serves as a consistent cultural indicator throughout the stratigraphic sequence, a distinct taphonomic shift is evident: artefacts recovered from the deeper layer 5 were

Table 3. Radiocarbon samples and dates (created by M. Kalniņš and V. Haferberga).

No.	Site	Sample	Context	Material	Species	Lab. No.	14C age (BP)	Cal. BC, 95.4%	References
1	Settlement	Kreiči M1-1	Trench 2, monolith, d. 0.98–1 m (layer 6)	cone frag., catkin scales, fruits	*Alnus glutinosa* / *Betula* sect. Albae / *Carex* / *Schoenoplectus lacustris*	FTMC-WX96-6	4787±34	3644–3386	This study
2	Settlement	Kreiči M1-2	Trench 2, monolith, d. 0.82–0,.84 m (layer 5)	cone frag., nut shell, catkin scales, fruits, seeds	*Alnus glutinosa* / *Corylus avellana* / *Betula* sect. Albae / *Schoenoplectus lacustris* / *Urtica dioica*	FTMC-WX96-5	4432±34	3330–2924	This study
3	Settlement	Kreiči M1-3	Trench 2, monolith, d. 0.72–0.74 m (layer 4)	tree branch frag.	-	FTMC-WX96-4	4112±32	2869–2574	This study
4	Settlement	Kreiči M1-4	Trench 2, monolith, d. 0.68–0.7 m (layer 3)	cone frag., fruits, nut shell, wood charcoal	*Alnus glutinosa* / *Schoenoplectus lacustris* / *Corylus avellana*	FTMC-WX96-3	3826±30	2452–2147	This study
5	Settlement	Kreiči M1-5	Trench 2, monolith, d. 0.62–0.64 m (top of layer 3)	cone frag., tree branch, wood charcoal	*Alnus glutinosa*	FTMC-WX96-2	3491±31	1896–1696	This study
6	Settlement	Kreiči M1-6	Trench 2, monolith, d. 0.58–0.60 m (bottom of layer 2)	tree branch frag., wood, bark, fruit	*Sparganium minimum*	FTMC-WX96-1	3576±32	2027–1779	This study
7	Settlement	Kreiči S5	Trench 2, layer 3	nut shell frag.	*Corylus avellana*	Poz-174465	4070±35	2851–2476	This study
8	Settlement	Kreiči S6	Trech 2, layer 5	nut shell frag.	*Corylus avellana*	Poz-174466	4565±35	3492–3386	This study

larger and better preserved compared to the smaller, more fragmented finds from layers 3 and 2. This taphonomic variation could be linked to differing layer formation processes. The better condition of the material in the lower layer 5 suggests a possible primary depositional environment, possibly characterised by rapid burial or stable anaerobic conditions. In contrast, the fragmented nature of the assemblage in the upper layers 3 and 2 may be partially attributed to erosional and colluvial processes. Given the test pit's location at the foot of the Kreiči hillock, it is probable that a portion of the material in these upper layers underwent secondary deposition, having been transported downslope from the higher elevations of the settlement. This movement would account for both the increased fragmentation and the weathered state of the finds in the upper sequence compared to the character of the deeper deposits.

The paleoenvironmental and subsistence data provides a detailed picture of the Neolithic landscape. Plant micro- and macro-remain analyses confirm that the settlement was situated in a dynamic environment that transitioned from a fen to an active lakeshore ecotone. Specifically, zone 5 (0.90–1.00 m), determined from monolith samples, reveals high concentrations of microscopic charcoal in its basal layers, indicating intensive human activity at the site as early as 3644–3386 cal BC, even preceding the excavated layers containing archaeological finds.

Subsistence strategies were broad-spectrum, exploiting both aquatic and terrestrial zones. The faunal assemblage from 2022 fieldwork in test pit 2 includes a combination of large and mid-sized ungulates (i.e. elk, wild boar), carnivores (marten) and aquatic species (i.e. pike, zander, perch). The majority of identified fragments belong to wild boar/pig and elk, which were also the most common species in identifications of zooarchaeological material from the 1950s excavations (Paaver 1965). In contrast, fish remains were identified for the first time during the analysis of faunal material from the 2022 excavations, providing new evidence for the exploitation of aquatic resources at the site. Together with several worked bone fragments and specialised tools such as a harpoon, this evidence indicates that the inhabitants of the Kreiči site were highly adapted to the lake-edge ecotone, utilising both forest and water resources throughout the habitation sequence. The presence of water caltrop fruit fragments in find layers 5 and 3 – representing the first record of this species in Lake Lielais Ludzas (Kalniņa et al. 2018) – further highlights possible gathering activities during the Holocene thermal optimum.

The study of recovered pottery from test pit 2 of the 2022 fieldwork shows that the Kreiči pottery was made of coarse clay, containing silt, sand and also plant matter. Ferric concretions were rarely observed. Clay pellets were quite common for vessels, indicating poor kneading of the clay or other factors related to the quality of the clay. All the vessels were tempered with various sized crushed mussel shells. The majority of shells were not well preserved in the clay in terms of microstructure, which is indicative of either specific firing temperatures or environmental factors (Maritan et al. 2007; Storch 1997). The temper of mussel shells is considered a local pottery production tradition among eastern Baltic hunter-gatherers whose roots are seen in the Early Neolithic Narva Culture pottery (Dumpe 2024). The petrographic and chemical analysis of the Kreiči pottery indicates that at least some of the vessels were made by using the nearby clay source a few hundred metres from the settlement. Notably, no correlation between petrographic and chemical data was observed. This result may indicate the use of various clay sources, not just the one closest to the settlement. More studies of nearby geology and clay sources are needed.

Although the 2022 fieldwork at the Kreiči Neolithic settlement provided valuable new insights and the first more precise radiocarbon dates regarding the site's use, further research is required. It is necessary to determine and date the beginning of habitation at the Kreiči site, as high concentrations of microscopic charcoal as evidence of intensive habitation were still detected in the bottom part of the analysed test pit 2 sediment monolith. Furthermore, a broader spatial investigation of layer 3 is essential to establish its formation processes and to confirm the hypothesis that the artefacts within it were redeposited via erosion from the higher elevations of the settlement. Finally, the new data regarding finds, ceramics and the environmental and chronological framework established by the 2022 research now provides a robust foundation for the re-evaluation and in-depth analysis of the archaeological material recovered during the extensive field campaigns of the 1950s.

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Abbreviations

Archaeometry – Archaeometry

Eur. J. Archaeol. – European Journal of Archaeology

Folia Geogr. – Folia Geographica

J. Paleolimnol. – Journal of Paleolimnology *Latv.*

PSR Z inātņu Akad. Vēstis – Latvijas PSR Zinātņu Akadēmijas Vēstis

Quat. Geochronol. – Quaternary Geochronology

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Sugrįžimas į Kreičių neolito gyvenvietę: nauji archeologiniai ir aplinkos tyrimų duomenys

Mārcis Kalniņš, Aija Macāne, Vanda Haferberga, Laimdota Kalniņa, Aija Ceriņa

Santrauka

Kreičių (latv. *Kreiči*) neolito gyvenvietė yra viena iš geriausiai ištirtų, tačiau anksčiau nepakankamai datuotų akmens amžiaus vietovių. Ji yra prie Didžiojo Ludzos (latv. *Lielais Ludzas*) ežero kranto rytinėje Latvijoje (1 pav.). Siekiant patikslinti vietovės chronologiją, atkurti jos paleoaplinką ir išsiaiškinti 1950-aisiais pradėtos kasinėti pelkėtos žemumos zonos susidarymo procesus, 2022 m. buvo atlikti nauji archeologiniai žvalgomieji kasinėjimai (2 pav.).

Metodologija apėmė kelias disciplinas. Buvo iškasti du šurfai, iš antrojo šurfo paimtas monolitinis 1 m storio dirvožemio mėginys (3 pav.) aukštos skiriamosios gebos paleoaplinkos rekonstrukcijai, įskaitant degimo nuostolių (LOI) tyrimą (8 pav.), sporų ir žiedadulkių analizę (9 pav.) bei augalų makroliekanų identifikavimą (10 pav.; 3 priedas). Gautas faunos rinkinys ištirtas taikant zooarcheologinę analizę, kuria siekta nustatyti pragyvenimo strategijas. Piestinios tipo keramika buvo ištirta taikant keramikos petrografiją ir bangos ilgio rentgeno spindulių fluorescencinę (WD-XRF) spektroskopiją, kuria siekta nustatyti jos sudėtį ir kilmę (1 priedas; 2 priedas). Chronologija nustatyta taikant botaninių makroliekanų ir zooarcheologinės medžiagos AMS radiokarboninį datavimą (3 lentelė; 11 pav.).

Antrajame šurfe (4 pav.) durpių ir smėlio nuogulose aptikti du kultūriniai sluoksniai su archeologiniais radiniais (5 pav.). Giliausiame, penktajame, sluoksnyje buvo rasta gerai išsilaikiusių artefaktų (5 pav.: 19–24), kurių amžius – IV tūkstantmečio pr. m. e. antroji pusė (apytiksliai 3330–2924 m. pr. m. e. pagal kalibruotąjį datavimą) (11 pav.). Be to, pirmosios Kreičių kapinyno radiokarboninės datos sutampa su šiuo laikotarpiu (11 pav.) ir tiesiogiai susieja kapinyną su vidurinio neolito gyvenvietės etapu. Viršutinis, trečiasis, sluoksnis, priešingai, datuotas vėlyvuoju neolitu (maždaug 2869–1696 kal. m. pr. m. e.) (11 pav.), jame aptikta vidurinio neolito keramikos (5 pav.: 10–15), o tai leidžia daryti prielaidą, kad šie radiniai į sluoksnį pateko dėl šlaitinių (koluvialinių) procesų.

Zooarcheologiniai duomenys rodo daugialypę pragyvenimo ekonomiką. Faunos komplekse dominuoja šernų ir elnių liekanos, o naujai identifikuotos žuvų liekanos ir kaulinis harpūnas (5 pav.: 19) patvirtina intensyvų vandens išteklių naudojimą.

Keramikos petrografinės ir WD-XRF analizės (1 ir 2 lentelės) patvirtina, kad ji buvo gaminama iš vietinio molio su natūraliomis priemaišomis, papildomai įmaišant smulkintų moliuskų kriauklių (7 pav.). Kaip rodo sudėties klasterizacija (6 pav.), šių kriauklių galėjo būti gaunama iš kelių vietinių šaltinių.

Paleoaplinkos analizės rodo, kad gyvenvietė transformavosi iš vidurinio neolito pelkės į dinamišką ežero pakrantės ekosistemą. Pažymėtina, kad didelės anglies koncentracijos apatiniuose sluoksniuose (10 pav.) liudija žmogaus veiklą jau 3644–3386 m. pr. m. e. ir sutampa su šukinės keramikos kultūros indais, kurių rasta 2022 m. ir 1950 m. kasinėjimų metu.

Integruoti šio tyrimo duomenys ne tik nustato patikimą Kreičių vietovės chronologinį bei aplinkos kontekstą, bet ir sudaro sąlygas naujai įvertinti 1950 m. kasinėjimų medžiagą.

Appendices

Appendix 1. Raw, unnormalised WD-XRF data (wt%) before element exclusion (compiled by V. Haferberga).

Element/ Sample	SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO	CaO	TiO2	P_2O_5	Na_2O	BaO	MnO	Cl	SO_3	ZrO_2	SrO	Rb_2O	ZnO	Sc_2O_3	CeO_2	Nb_2O_5	V_2O_5
KR1	43.66	13.27	4.89	3.41	1.4	1.2	0.89	0.48	0.5	0.23	0	0.08	0	0.06	0.01	0	0	0	0	0	0
KR2	42.42	11.34	6.39	4.44	1.54	1.87	0.98	0.76	0.74	0	0.04	0	0.29	0.12	0.01	0.01	0.01	0.04	0	0	0
KR3	30.78	12.67	3.74	3.19	0.92	1.7	1.24	1.2	0.43	0	0	0.06	0.1	0.07	0.02	0.03	0	0	0.17	0	0.05
KR4	43.9	14.98	5.56	5.58	1.77	2.2	1.19	1.18	0.71	0.28	0	0.07	0.28	0.03	0.01	0.01	0	0	0	0	0
KR5	36.59	12.58	4	4.09	1.06	2.34	1.23	0.94	0.54	0	0	0	0.36	0.06	0.02	0.01	0.01	0	0	0.02	0
KR6	28.49	8.29	2.95	3	0.48	4.94	1.27	2.16	0.29	0.35	0	0	0.83	0.07	0.06	0	0	0	0	0	0
Kreici-M	38.96	9.96	4.71	3.31	1.1	0.82	0.61	0.11	0.36	0.09	0.08	0	0	0.07	0.02	0.01	0.01	0	0	0	0

Appendix 2. Normalised WD-XRF data (wt%) after element exclusion (compiled by V. Haferberga).

Sample	SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO	TiO_2	Na_2O
KR1	64.19	19.51	7.19	5.01	2.06	1.3	0.74
KR2	62.52	16.71	9.42	6.54	2.27	1.44	1.1
KR3	58.11	23.92	7.06	6.02	1.74	2.34	0.81
KR4	59.58	20.33	7.55	7.57	2.4	1.61	0.96
KR5	60.89	20.94	6.65	6.81	1.76	2.05	0.9
KR6	63.64	18.52	6.58	6.7	1.07	2.84	0.65
Krei-ci-M	66.02	16.88	7.98	5.62	1.86	1.03	0.61

Appendix 3. Plant macro-remains from layers 3 and 5 of Kreiči (large samples, volume 1 litre) (compiled by A. Ceriņa)

	Sample No	Layer 3	Layer 5	Total number of remains	Number of samples from a monolith with a taxon	Ubiquity of taxon (percentage of sample)
Plants	Depth, m from ground level	0.61-0.65	0.84-0.90			
	Sediments	sand with plant remains				
	Volume: liter	1.0	1.0			
Trees and shrubs						
Pinus sylvestris Scots Pine	needles fr.	1		1	1	50
Betula sect. Albae tree Birch	fruit	15	32	47	2	100
	scales	5		5	1	50
Alnus glutinosa common Alder	fruit	25	26	51	2	100
	cone fr.	34	22	56	2	100
Quercus sp. Oak	acorn fr.	2		2	1	50
Corylus avellana Hazel	shells of nut	10	9	19	2	100
Rubus idaeus Raspberry	seeds	1	6	7	2	100
Solanum dulcamara Bittersweet	seed	1	1	2	2	100
Total number of remains		98	101	199		
Total number of taxa 7	**Total number of taxa in the sample**	7	5			
Charred remains						
Corylus avellana Hazel	shells of nut	23		23	1	50
Trapa natans Water Chestnut	fruit fr., har-poon	5		5	1	50
Charcoal	fragments	85	61	146	2	100
Total number of remains		113	61	174		

Total number of taxa 3	Total number of taxa in the sample	3	1			
Ruderals						
Chenopodium album Fat-hen	fruit	2		2	1	50
Chenopodium polyspermum many-seeded Goosefoot	fruit		4	4	1	50
Persicaria lapathifolia dock-leaved smartweed	fruit		5	5	1	50
Chelodonium majus greater Celandin	seed	1		1	1	50
Urtica dioica common Nettle	fruit	30	70	100		
Total number of remains		33	79	112		
Total number of taxa 5	**Total number of taxa in the sample**	3	3			
Wet meadow and herbaceous woodland plants						
Scirpus sylvaticus Club-rush	fruit		1	1	1	50
Carex spp. Sedges	fruit	5	14	19	2	100
Moehringia trinervia three-nerved Sandwort	seed		1	1	1	50
Myosoton aquaticum water Chickweed	seed	1	14	15	2	100
Ranunculus acris meadow Buttercup	fruit	3	2	5	2	100
Rumex maritimus golden Dock	fruit	1	12	13	2	100
Plantago media hoary Plantain	seed	1		1	1	50
Urtica kioviensis Marsh nettle?	fruit		4	4	1	50
Potentilla anserina Silverweed	fruit	1		1	1	50
Lycopus europaeus Gipsywort	fruit		2	2	1	50
Mentha arvensis corn Mint	fruit	1	1	2	2	100
Total number of remains		13	51	64		
Total number of taxa 11	**Total number of taxa in the sample**	7	9			
Shallow water and flooded coastal plants						
Iris pseudacorus yellow Iris	seeds	2		2	1	50
Alisma plantago-aquatica Water-plantain	seed	3	1	4	2	100
Schoenoplectus lacustris common Club-rush	fruit	116	77	193	2	100
Bolboschoenus maritimus sea Club-rush	fruit		10	10	1	50
Ranunculus lingua greater Spearwort	fruit	3		3	1	50
Ranunculus sceleratus celery-leaved Buttercup	fruit		3	3	1	50
Menyanthes trifoliata Bogbean	seeds	1		1	1	50
Cicuta virosa Cowbane	seeds		1	1	1	50
Total number of remains		125	92	217		

Total number of taxa 8	**Total number of taxa in the sample**	5	5			
Aquatic plants						
Stratiotes aloides Water-soldier	leaf-margin spines					
Najas marina holly-leaved Naiad	fruit	1		1	1	50
Potamogeton filiformis slender-leaved Pondweed	fruit	1		1	1	50
Potamogeton natans broad-leaved Pondweed	fruit	1	7	8	2	100
Potamogeton perfoliatus perfoliate Pondweed	fruit	8	1	9	2	100
Potamogeton spp. pondweed	fruit	1		1	1	50
Myriophyllum spicatum Eurasian water-milfoil	seeds	2	7	9	2	100
Trapa natans Water Chestnut	fruit fr., harpun	17	4	21	2	100
Nuphar sp. water lilies	seeds	34	4	38	2	100
Nymphaea sp. water lilies	seeds fr.	9	5	14	2	100
Total number of remains		74	28	102		
Total number of taxa 12	**Total number of taxa in the sample**	9	6			
Unknown plants	seeds fr.	1	2			
Other residues						
Fungi mycorrhizal fungi	sclerotium	6	8	14	2	100
Porifera	individual gemmules and colonies	46	3	49	2	100
Cristatella mucedo freshwater bryozoan	statoblasts		3	3	1	50
Cladocera water fleas	efphippia	1	6	7	2	100
Chironomidae lake flies	larval head capsules	10	2	12	2	100
Orthotrichia purse-case caddisflies	larval cases		2	2	1	50
Insecta	wing chitin fr.	7	10	17	2	100
Pisces Fishes	spikes, scales	200	100	300	2	100
Amber	small flakes	1		1	1	50
Bones	fragments, incl. burnt	12		12	1	50
Flint	flake		2	2	1	50
Total number of remains		283	136	419		
Total number of taxa 11	**Total number of taxa in the sample**	8	9			