Where are the cereals? Contribution of phytolith analysis to the study of subsistence economy at the Trypillia site Maidanetske (ca. 3900-3650 BCE), central Ukraine

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ABSTRACT

Phytolith analysis has been applied in one of the extraordinary Trypillia "mega-site" in central Ukraine. The site Maidanetske, dated to ca. 3900–3650 BCE, is composed of ca. 3000 houses, which were built of earth-based architecture. As these mega-sites were extremely large, their relatively short duration and their population dynamics are under debate. In this study, the focus is set on the detection of daily household activities, including cereal processing. Archaeological contexts have been sampled for phytoliths inside and outside houses, including daub fragments, grinding stones, vessels, floor surfaces and a pit filling. Phytolith records from layers above and below the archaeological contexts were also analysed. The results indicate that cereal by-products such as chaff from pooid cereals, were in use for specific purposes like daub tempering for house building. Thus cereals were a relevant part of the site subsistence economy despite the scarce preservation of archaeobotanical macro-remains. While chaff and straw suggest on-site processing of cereals, the location of processing is unclear. Since house floors and cultural layers are poorer in chaff phytoliths than expected, the future analysis of other special buildings for instance might help to detect specialised areas of processing apart from houses. Besides cereals the phytolith record attests also the presence of wild grasses with probable indication of steppe grassland components. Further investigation of soil sequences outside the site and comparison with modern reference material in future will help to assess the development of the grassland vegetation through time.

1. Introduction

The investigation of phytolith assemblages has been affirmed to be a useful and widespread tool for plant use reconstructions from archaeological contexts worldwide. Monocotyledons, including plants of the Poaceae family, because of their abundant phytolith production, their distinctive phytoliths morphotypes and their importance as cultivars, are one of the highlights of phytoliths research (Ball et al., 2016). Instead, dicotyledons are generally characterized by lower and uneven phytoliths production and their phytoliths are highly under-represented in the microfossil record (Piperno, 2006). Therefore, in regions with grassland environments where archaeobotanical remains are scarcely preserved, such as in the case of Trypillia mega-sites, phytoliths are a direct means to investigate plant use.

The Trypillia ("Tripolye" in Russian) mega-sites, defined as big agglomerations of more than a thousand houses over 100 ha, have been on focus of archaeological research since the discovery about 50 years ago (see Videiko and Rassmann, 2016 for a summary on research history). Archaeological research on these sites included aerial pictures and geomagnetic investigation from Soviet times until more recent when extensive geomagnetic surveys and several large-scale excavations took place, especially at the sites of Taljianki, Dobrovody, Nebelivka and Maidanetske (Fig. 1a). Concerning Maidanetske, a collaboration is on-going since 2013 between the Ukrainian Academy of Science in Kyiv, the Borys Grinchenko Kyiv University, the Roman-Germanic Commission (RGK) and the German Kiel University, with first results published recently (Müller et al., 2017). Altogether, the work on Trypillia sites by various scientists and institutions led to a thorough
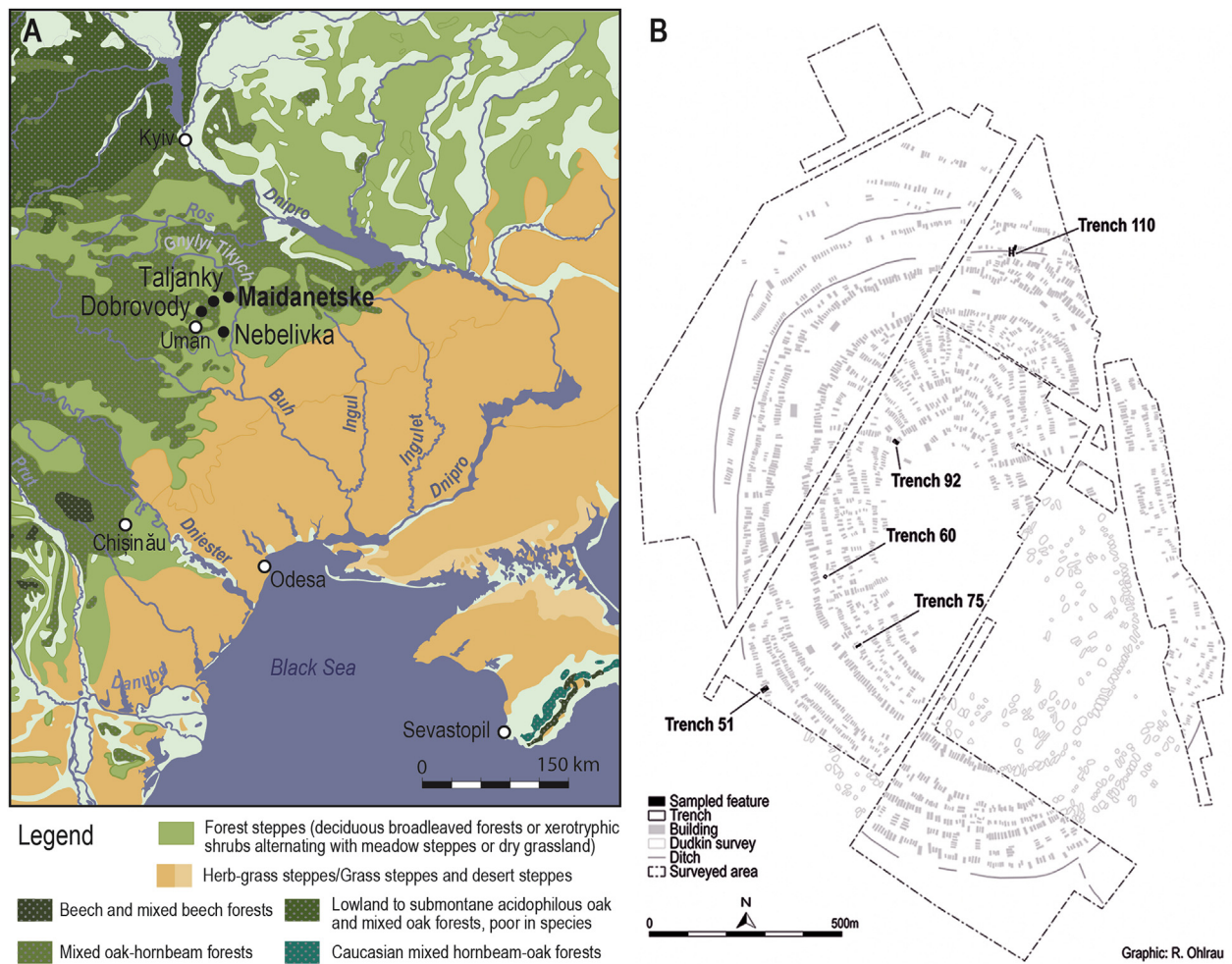
Fig. 1. A. The location of the Chalcolithic site of Maidanetske and of other sites mentioned in the text within the map of the natural vegetation (modified after Kirleis and Dreibrodt, 2016, graphic K. Winter, Kiel University). B. The reconstruction of Maidanetske based on geomagnetic survey (modern and from the 1970s by Dudkin), with the position of the trenches mentioned in this study.

reconstruction and documentation of the main archaeological contexts composing Trypillia mega-sites (e.g. Burdo and Videiko, 2016; Kruts et al., 2013; Menotti and Korvin-Piotrovskiy, 2012; Müller and Videiko, 2016; Videiko, 2004). However, for certain aspects agreement is lacking among scholars (Chapman, 2017; Menotti and Korvin-Piotrovskiy, 2012; Müller et al., 2016), and in general many research questions are still open. The extreme size of mega-sites gives rise to multiple questions concerning the level of social complexity of Trypillia groups and the triggers behind the development and successive "collapse" of mega-sites after only few generations of occupation (e.g. Diachenko and Menotti, 2012; Harper, 2017; Menotti and Korvin-Piotrovskiy, 2012; Müller et al., 2016; Videiko, 2004). Recently, the relevance of arable farming was questioned (Chapman, 2017) in contrast to long standing excavation results (Kirleis and Dal Corso, 2016; Menotti and Korvin-Piotrovskiy, 2012; Pashkevich and Videjko, 2006) due to the extreme paucity of the macro-remains from archaeological sites showing direct evidence of cereals. Moreover, Trypillia mega-sites occupied an area corresponding to the transitional ecozone of the north Pontic forest-steppe (Fig. 1A), where we face the almost irresolvable challenge of an allocation of grassland versus woodland patches at the time of site occupation. The reconstruction of environmental conditions before, during and after the mega-site phenomenon is of extreme relevance to understand their economy and the availability of natural resources. While it is difficult to find natural, undisturbed, continuous pollen archives in the Trypillia region phytoliths analysis could provide insight into the impact of large population agglomerations on the

natural environment by evaluating the importance and spread of grasslands in the Chalcolithic.

The study presented here focuses primarily on the subsistence economy of Maidanetske and on the landscape and natural resources available at the site using phytolith analysis of the standard Trypillia household. Were crop-processing activities taking place at the household level in the mega-site? Besides cereals, can we trace the presence of other plants from the phytolith record of houses?

In addition, we are interested in the distribution of dry grasslands at the time of Trypillian sites. Through a comparison of the phytolith record of archaeological *versus* natural and control samples from topsoil and natural soil below archaeological stratigraphy, do we have hints of the presence of steppe vegetation?

To address these questions, phytoliths analysis is included into our multi-proxy archaeobotanical approach at the Trypillia mega-sites of Maidanetske in Ukraine.

1.1. Why apply phytoliths analysis to Trypillia "mega-sites"?

Phytoliths and macro-remains play an important role for the characterization of the subsistence economy, which is crucial for the understanding of the mechanisms behind the origin and development of population agglomerations in "mega-sites". Phytolith studies in archaeological contexts are well suited for the detection of crops, they are particularly relevant in the absence of macro-remains (Ball et al., 2016). At Trypillia sites macro-remains preserve only as charred or

mineralized material and they are rare finds, the more so as the archaeological features lie close to the modern soil surface, as at Maidanetske for e.g. Post-depositional processes with active soil formation, such as weathering and intense bioturbation possibly explain this scarce preservation of charred remains. For this reason, plant imprints in clayey artifacts have played a major role for the investigation of plant use at Trypillia sites, the focus on direct archaeobotanical remains is a recent development (Kirleis and Dal Corso, 2016; Pashkevich and Videjko, 2006). In terms of cereals, at Maidanetske few charred grains of *Triticum turgidum* ssp. *dicoccon*, *Hordeum vulgare* var. *vulgare* and *T. monococcum* have been found (Kirleis and Dal Corso, 2016).

Phytoliths are biogenic opal particles, released after the decay of plant matter and survive fire. Therefore, different preservation conditions and deterioration processes affect phytoliths compared to macro-remains. Phytoliths allow the identification of grass (and cereal) plant parts like the leftovers of cereal processing, such as straw and chaff that usually are considered as a sign of local processing and indirect evidence of the consumption of the cereals. This processing to clean the grains from the non-edible parts is subdivided in different steps that could be organized in different ways, some usually requiring collective work (e.g. harvesting and threshing) and other by daily final processing (e.g. dehusking) (Hillman, 1984; Nesbitt and Samuel, 1996). Furthermore, phytoliths can provide integrative information about the uses of grasses, sedges, reeds and other monocotyledons for non-food purposes such as thatching, temper in earthen architecture, fodder, litter, matting, roofing, basketry etc. (e.g. Lancelotti et al., 2014; Ryan, 2011; Tsartsidou et al., 2009). Such kinds of plant uses that do not strictly involve any grains are difficult to detect in other ways. Indeed, the soft tissue of culms and leaves of grasses and sedges is usually subject to decay, with few exceptions in extremely dry/wet conditions, and it does not survive contact with fire. Apart from on-site investigations, phytolith analysis is also broadly used in palaeo-environmental research on natural soil/sediment archives. Its application is common especially in open habitats dominated by grasslands, such as steppe and savannah (e.g. Barboni et al., 2007; Blinnikov, 2005; Fernandez-Honaine et al., 2006; Neumann et al., 2009), also because through phytoliths it is possible to distinguish grasses with a C3 (e.g Pooideae, Stipeae tribe) and a C4 (e.g. Panicoideae, Chloridoideae) photosynthetic pathway growing in different habitats.

In this case study, we aim at providing new data to assess cereal processing, other kinds of plant use at the site and/or of local grassland vegetation in the Trypillia "mega-sites" by comparison of the phytolith record from natural units and from different archaeological contexts of burnt houses.

1.2. Archaeological setting at the site of Maidanetske, Ukraine

From ca. 4800 to 3350 BCE, Trypillia settlements were widespread over parts of eastern Romania, Moldova and Ukraine (Menotti and Korvin-Piotrovskiy, 2012; Müller et al., 2016; Videiko, 2004). Maidanetske (Fig. 1B) is one of the so-called "mega-sites" which developed during ca. 3900–3400 BCE in central Ukraine, in the Uman region (Cherkasy district) (Müller and Videiko, 2016; Müller et al., 2017). In this region, nine of these "mega-sites" have been found. Mega-sites are characterized by a regular plan with concentric rings of houses around a large empty central space, additional quartiers, with radial and peripheral track ways (Fig. 1B). The three mega-sites Maidanetske, Taljanky and Dobrovody, lay ca. 15 km apart from each other (Fig. 1A); other mega-sites are located within a 50 km radius around Maidanetske. Archaeologically, these mega-sites consist of the remains of buildings most of them burnt, although a minority of unburnt buildings is known of as well (Burdo and Videiko, 2016; Müller and Videiko, 2016; Ohlrau, 2015). Most of these buildings have a standardized regular size (average 6 × 12 m) and architecture including domestic installations and a standardized assemblage of artifacts. At Maidanetske beside normal sized houses there are few larger rectangular buildings that are

located regularly along the main pathways. Further archaeological contexts include pits, pottery kilns, and peripheral ditches. A huge variety of mostly painted pottery (including many with figurative animal and plant motives), some flint artifacts, rare copper objects, querns, adzes and a broad range of anthropomorphic and zoomorphic figurines are attested within houses and mega-structures. In terms of organic remains, animal bones are fairly common, while botanical macro-remains appear to be scarce and poorly preserved (Kirleis and Dal Corso, 2016; Pashkevich and Videjko, 2006).

1.3. Environmental setting at Maidanetske

The Trypillia sites in central Ukraine, including Maidanetske, are located in a semi-arid forest-steppe ecozone, a mosaic-like ecosystem stretched between the dry steppe grasslands in the south and temperate woodland biomes in the north (Fig. 1A). In this transitional zone the natural vegetation is supposed to be patchy and sensitive to climate and topography (Feurdean et al., 2015; Molnàr et al., 2012; Walter, 1974). Since most of the accessible plateaus are converted to agricultural land and the scarce broadleaf woodlands are managed, the natural landscape heterogeneity is difficult to trace within the current landscape (Kuzemko et al., 2014). Besides agricultural fields and villages, narrow river valleys incised into the loess plateaus are present, with riparian vegetation and artificial lakes. This western Pontic area has a humid continental climate with wet winters and warm summers (Köppen and Geiger, 1939), which corresponds to a semi-arid 0.2–0.5 aridity index value according to UNEP (1997). Nevertheless, the reconstruction of past climatic as well as environmental conditions is not straightforward, since undisturbed archives for pollen analysis are lacking in the region and published climatic reconstructions combine evidences from peripheral areas (Gerasimenko, 1997; Harper, 2017; Kirleis and Dreibrodt, 2016). In the Transylvanian forest-steppe region, palynological investigations suggest that dry grasslands have expanded since the end of the 4th millennium BCE, fostered by Bronze Age forest clearance, while before this the area was largely forested (Feurdean et al., 2015). In the Hungarian forest-steppe, the mixed oak forest on Loess almost disappeared by the end of the 18th century AD, hampered by factors such as fragmentation, slow regeneration, spread of invasive species and lowering of the water table due to increased aridity (Molnàr et al., 2012). It is clear that forest-steppe environments are very sensitive to aridity and land use practices. To understand whether similar landscape change can have occurred in central Ukraine already at the time of Chalcolithic mega-sites, an understanding of the extent of crop growing and deforestation is crucial.

The site of Maidanetske is situated on a plateau covered by Loess deposited during the Last Glaciation. This plateau is dissected by valleys of different sizes with perennial rivers present within the large valleys. One of these rivers passes the site in a distance of less than 500 m. The soils that are present nowadays are Chernozems. They show dark greyish-brown A-horizons of thicknesses between 30 and 50 cm and a texture dominated by silt. Numerous filled crotowinas indicate an intensive bioturbation during the formation of these soils. The Chernozems cover the archaeological record. The variations in thickness of the A-horizon are probably reflecting post-depositional soil erosion processes. Buried soils discovered at lower slope positions below colluvial layers show properties of Cambisols, thus pointing towards a forested past of the surrounding landscape (Kirleis and Dreibrodt, 2016).

From previous archaeobotanical investigation at Maidanetske (Kirleis and Dreibrodt, 2016) it emerged that common ash (*Fraxinus excelsior*), oak (*Quercus* sp.) and elm (*Ulmus* sp.) dominate the charcoal assemblage indicating the presence of mixed deciduous oak woodland and alluvial hardwood woodland, accompanied by riverine species such as willow (*Salix* sp.) during the site occupation. Besides, charred feather-grass awns (*Stipa* sp.) from uppermost cultural layers may show the presence of dry meadows in the area too. However, these tiny

Table 1
AMS radiocarbon dates from the trenches in Maidanetske presented in this paper. *Dates published in Müller et al. (2017).

Trench and context	Sample	Feature	Date uncal. BP	Date cal. BCE (1σ, 68.2%)	Material
51 House	Poz-60162 (*)	51018	5015 ± 35	3929–3877 (28.8%) 3805–3761 (27.9%) 3742–3715 (11.6%)	Animal bone (*Sus* sp.)
	Poz-60161 (*)	51007	4965 ± 35	3782–3702 (68.2%)	Animal bone (*Sus* sp.)
75 House	Poz-60352 (*)	75002	4820 ± 30	3650–3631 (28,4%) 3577–3574 (2,4%) 3564–3536 (37,4%)	Animal bone (*Bos* sp.)
92 House	Poz-87523	92007	5030 ± 35	3939–3860 (45.1%) 3814–3772 (23.1%)	Animal bone (*Bos* sp.)
	Poz-87526	92009	5040 ± 40	3942–3856 (46.2%) 3842–3836 (2.5%) 3821–3781 (19.5%)	Animal bone (*Ovis/Capra* sp.)
	Poz-87528	92023	5055 ± 35	3942–3856 (51.9%) 3842–3837 (2.9%) 3820–3798 (13.4%)	Animal bone (*Capreolus/Cervus* sp.)
110 House	Poz-87545	110003	4910 ± 40	3710–3646 (68.2%)	Animal bone (*Bos* sp.)
	Poz-87546	110004	4850 ± 40	3694–3678 (11.2%) 3669–3632 (45.1%) 3556–3539 (11.9%)	Animal bone (*Bos* sp.)
	Poz-87549	110013	5000 ± 35	3894–3881 (7.3%) 3800–3710 (60.9%)	Animal bone (*Ovis/Capra* sp.)
60 Pit	Poz-60349 (*)	60009	4980 ± 35	3790–3707 (68.2%)	Animal bone (*Bos* sp.)
	Poz-60191 (*)	60006	4960 ± 30	3777–3707 (68.2%)	Charcoal (*Quercus* sp.)

macro-remains could easily be transported by wind and/or move within the soil these being potential modern intrusions. Therefore it is crucial to carry out multiproxy investigations to characterize the past environmental context of the site and to understand when the recent surface soils (Chernozems) have formed. Integrated with geochemical analyses first results from soil sequences on-site indicate the development of an anthropogenic steppe during the occupation of the mega-site (Kirleis and Dreibrodt, 2016).

2. Materials and methods

2.1. Archaeological contexts and sampling strategy

This study considers five archaeological contexts, each corresponding to a trench excavated during fieldwork in 2013, 2014 and 2016. The contexts in trenches 51, 75, 92 and 110 have been interpreted as standard houses, while trench 60 concerns a pit complex. The excavated contexts belong to different concentric circles of buildings and the trenches are located in different parts of the settlement (Fig. 1B). The investigate contexts date between 3900 and 3650 cal. BCE (Table 1). The on-going program of intensive radiocarbon dating and modeling will address questions such as the duration of the site occupation and the contemporaneity of different house circles.

According to the excavation data (e.g. from the house in T51 see Müller et al., 2017) and to the geomagnetic plan (Ohlrau, 2015; Rassmann et al., 2014), the standard houses at the site have on average a floor size between 70 and 80 m² and were built with a wattle and daub construction technique, where imprints of the wooden architectural elements are often visible on daub (Müller and Videiko, 2016). They were two-storey, with a main first floor on top of a thick earthen platform (in Russian "*ploshchadka*"), underneath which vessels and other materials are found *in situ*, on an earthen floor used as storage (Müller and Videiko, 2016). Most of the samples studied here come from the main floor of the houses above the platform. According to the distribution of artifacts most of the daily activities took place on the platform, while few come from the ground floor below it (Müller et al., 2017). The pit in trench 60 shows several phases of refilling mostly by burnt daub and ashes, which suggests a function related to the disposal of waste from demolished houses and their contents (Müller et al., 2017).

In terms of excavation method the houses and pit in trenches 51, 92 and 60 were fully excavated, while in trench 110 only a part of the house was uncovered. Trench 75 was a 3 m² test-trench crossing through another house. This diversity in the excavation approach resulted in a diverse phytolith sampling strategy. Contextual sampling was performed in the fully excavated houses, with addition of some fixed vertical sequences (here called "series"), as shown in Fig. 2B for trench 51 and in Fig. 2D for trench 92. In the case of partially excavated houses (T75 in Fig. 4A-B; T110 in Fig. 4C-D) and of the pit (T60 in Fig. 3), vertical sequences from profiles were sampled respecting the stratigraphy. All samples were georeferenced.

The large size of the site and of excavation trenches constitutes a challenge for the systematic sampling for phytoliths, which are supposed to primarily represent local plant deposition. In this study the sampling design aimed at characterizing the phytolith record in different contexts, in order to reconstruct aspects of plant use at the site, but also to test the context reliability and taphonomic disturbance. Overall, for this study 39 phytoliths samples have been analyzed. Most of the samples originate from archaeological layers inside the buildings (11 sediment samples, referred to as "inside"), which are useful also as control samples for contextual samples related to specific materials finds. The latter are vessels (3 samples), of which the lowermost filling was sampled after excavation in the field laboratory and grinding stones (4 samples), of which the sediment attached to them was sampled during excavation shortly after discovery. Other contextual samples concern daub from the house structure (3) and fragments of a fired clay floor (2). In addition, two ash layers from the pit filling (2 samples) were sampled as well. Attention was also paid to the surface of the occupation layer closely surrounding the buildings (5, referred to as "outside"), and to the sampling of natural units such as the modern plough horizon (5, "topsoil") and the natural soil below the archaeological stratigraphy (4 samples). A complete sample list with characterization of the phytolith samples is given in Table 2, while information concerning the features where the samples originate is provided in appendix 1 (supplementary material, electronic version only). Further archaeological information concerning trenches 51, 60 and 75 is available in Müller et al. (2017), while post-excavation work on trenches 92 and 110 is still ongoing (R Ohlrau, PhD thesis in progress, GSHDL, Kiel University).

2.2. Phytolith sample preparation and analysis

Ten phytoliths samples were processed at the Pompeu Fabra University, Barcelona ("B" laboratory number in Table 2), and 29 samples were prepared at the Institute of Prehistorical and Protohistorical Archaeology in Kiel. In both cases the extraction followed Madella et al. (1998), based on ca. 4 g of dry sediment per sample. During processing, after the heavy liquid separation the AIF (acid insoluble fraction), primarily representing biogenic silica (phytoliths, sponge spicules and diatoms) and minor mineral component, was measured. The microscope slides were prepared using microscopy immersion oil as a mounting medium, and clear nail polish to seal the slide-cover. At least 250 single cell phytoliths from identifiable morphotypes were counted per sample (cf. Zurro et al., 2016). The relative abundance of each phytolith morphotype was calculated based on this sum, which excluded unidentifiable phytoliths (due to fragmentation or corrosion), silica skeletons and sponge spicules. These groups are excluded from the sum to avoid their possible over-representation in some of the samples. The percentages for such groups have been calculated on the sum of identifiable single cell phytoliths plus themselves (i.e. % of unidentifiable phytoliths = number of unidentifiable phytoliths)/(Σ identifiable single cell phytoliths + number of unidentifiable
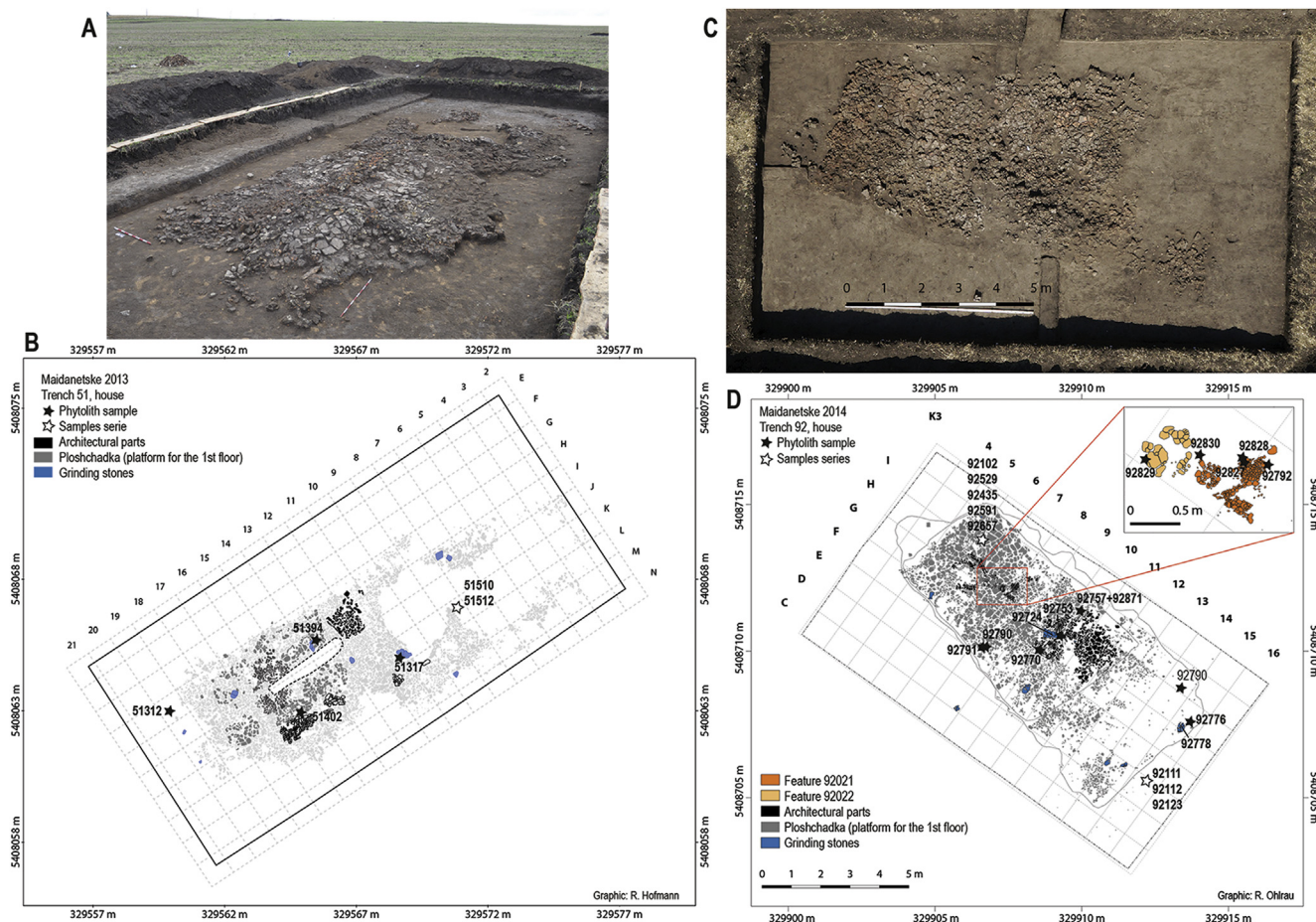
Fig. 2. A. Photos of T51 during excavation (September 2013). B. The location of phytolith samples in trench 51. C. Birds eye view of the house in trench 92 during excavation (September 2014). D. The location of phytolith samples in trench 92. In the zoomed area burnt floor surface from the ground floor is visible.

phytoliths). Identification was carried out at 40x magnifications under the light microscope equipped with a cross-polarized light filter. The samples have been also checked for spherulites. Based on their 3D shape and ornamentation, phytoliths have been attributed to taxonomic groups and anatomical plant parts according to literature, the reference collection of Kiel University and online reference collections as explained in a table about morphotype attributions in appendix 2. The online phytolith reference collections were used (http://www.home-pages.ucl.ac.uk/~tcrndfu/phytoliths.html) (http://phytolith.missour-i.edu). The phytolith nomenclature follows the International Code for Phytolith Nomenclature (Madella et al., 2005).

To investigate the association between the various morphotypes and of the phytolith assemblage with the archaeological context, correspondence analysis (CA) was applied by means of the software PAST version 3.08 (Hammer et al., 2001). Silica skeletons and unidentifiable phytoliths were excluded from this analysis because they were affected by selective preservation.

3. Results

3.1. State of preservation of the phytolith assemblage

Phytolith preservation was generally good enough to allow the study of every sample, with exception of one (51512) from natural soil, where phytoliths were extremely rare and heavily damaged. However, phytolith preservation differed among the samples. Most of the samples had many phytoliths with evidence of pitting, rounded edges and fractures. The average values of unidentifiable phytoliths per context was 5.6% in samples from floors, 4.2% outside houses, 3.7% on daub

and topsoil, 2.2% inside houses, 1.7% from vessel fillings, 1.6% from the ash layers in the pit and 1.4% from samples related to grinding stones. Phytoliths were in good state of preservation in the daub samples, in some samples from the ground floor of House in T92 and in those from the ash layers in the pit. Moreover, in these samples most of the silica skeletons of this study are found (average silica skeletons 3.9% from daub; 1.6% pit samples; 0.8% from vessel fillings; 0.6% topsoil samples; absent from the other contexts), which suggests different deposition patterns and preservation conditions. Fig. 5 shows the weight of acid insoluble fraction (AIF) per sample. Only the samples from trench 110 and one sample from T92 show AIF values that differ from the other samples.

3.2. Composition of the phytolith assemblage

In this study 28 morphotypes of phytolith single cells, 5 types of silica skeletons and some unidentifiable single cell phytoliths have been distinguished. A table that summarizes morphotypes attributions according to literature is given in appendix 2, micro-photos in appendices 3 and 4 and raw counts in appendix 5. Fig. 6 shows the results of the phytolith analysis per trench. Most of the morphotypes refer to monocotyledons and the record is especially very rich in grass short cell phytoliths (GSCP; mean value 26.4%) diagnostic of Poaceae (see the photos in appendix 3). In this study, GSCPs are, from the most common to the rarest: rondels (12.7%), trapeziforms (5.7%), bilobates (1.2%), plateaued bilobates (0.2%), polylobates (0.4%), saddles (0.9%) and plateaued saddles (0.6%).

Rondels characterize the Pooideae subfamily (C3 grasses), the most common grasses in temperate Europe. The high variety of rondels here
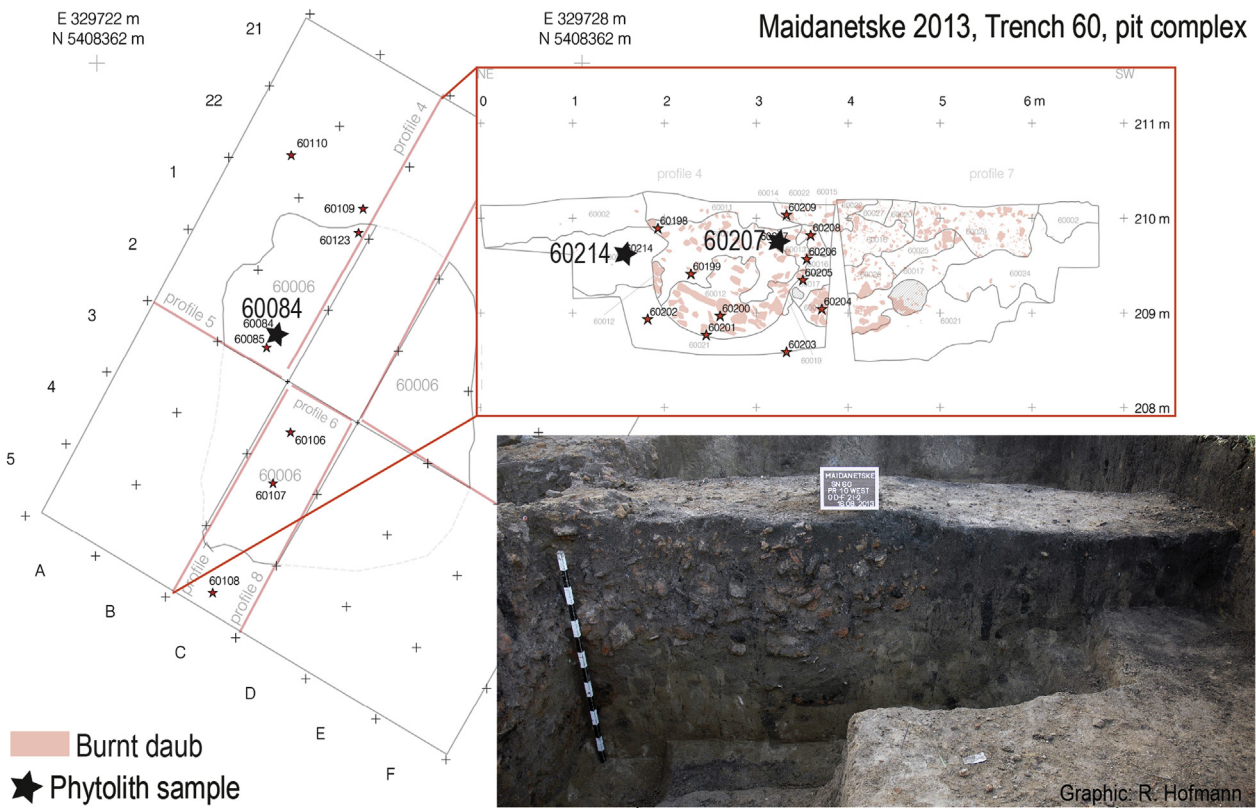
Fig. 3. The location of phytolith samples in the pit in trench 60, planum, profile drawing and photo (September 2013).

observed led to the distinction of several morphotypes, which all have a circular to elliptic base and a more or less high truncated cone shape. Some can be found in literature as mentioned in appendix 2 (sometimes under the name "tower", or "horned tower"), while some are never mentioned as a separate morphotype. This is the case of some rondels with a very thin and long truncated cone shape (here "thin pointed rondels", 0.7%), which can be seen among other phytoliths in a

drawing of a phytolith assemblage from Chernozem soil developed under steppe conditions, i.e. a grassland-dominated landscape (Kamanina 1997, Fig. 3(a)16). At the present stage of research the exact provenance or taxonomic value of these morphotypes is unknown. All these types of rondels seem to reflect the high variability of short cells attested also in studies of modern grassland communities worldwide (Blinnikov, 2005; Fernandez Honaine et al., 2006, 2009; Gallego and
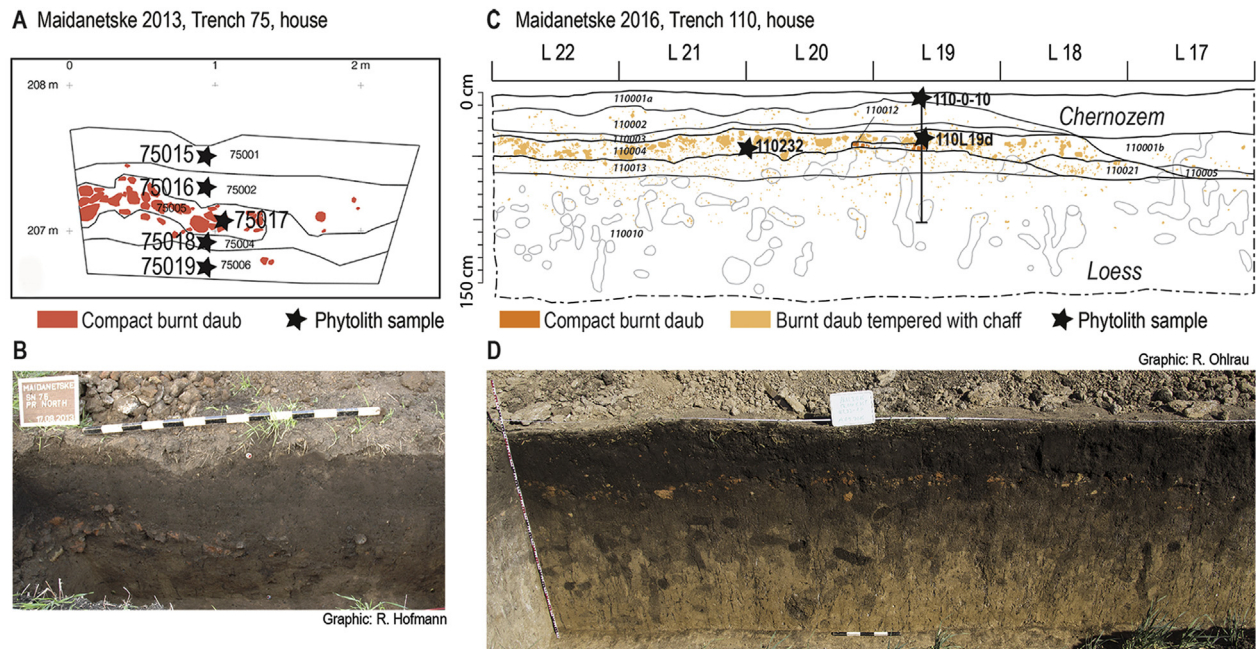

Fig. 4. A. The location of phytolith samples in the house profile in trench 75. B. Photo of the profile of trench 75 (September 2014). C. The location of phytolith samples in trench 110, profile drawing. D. Photo of the profile sampled in trench 110 (September 2016).

Table 2
Information about the samples of this study.

Sample no.	Lab. no.	Trench	Feature	Square/Profile	Context
51312	B 4	51	51002	H19	Sediment outside of the house on a surface of use with archaeological material
51317	B 3	51	51002	K11	Sediment over the house 1st floor, attached to (below) a grinding stone
51402	B 1	51	51003	K15	Daub in the house 1st floor
51394	B 2	51	51003	I13	Daub in the house 1st floor
51510	258	51	51006	K8	Sediment on the house 1st floor
51512	260	51	51008	K8	Natural soil, control sample
75015	B 6	75	75001	profile 75001	Topsoil, modern control sample
75016	B 7	75	75002	profile 75001	Sediment covering the house
75017	B 8	75	75002	profile 75001	Sediment outside the house
75018	B 9	75	75003	profile 75001	Sediment in-between the house daub
75019	B 10	75	75004	profile 75001	Natural soil, control sample
92102	1	92	92002	(I5) I6	Series inside the house, sediment covering house
92435	181	92	92007	I6	Series inside the house, uppermost layer of burnt daub from the house 1st floor
92529	5	92	92009	I6	Series inside the house, sediment from the 1st floor
92591	6	92	92009	I6	Series inside the house, sediment from the 1st floor
92657	7	92	92023	I6	Series inside the house, sediment from the ground floor, below the 1st floor
92111	2	92	92001	E15	Series in front of the house, modern sediment
92112	3	92	92002	E15	Series in front of the house, sediment covering the house
92123	4	92	92013	E15	Series in front of the house, sediment covering the house
92790	9	92	92009	F8	Sediment inside a pot in the house 1st floor (cf. control 92791)
92791	10	92	92009	F8	Sediment below a pot in the house 1st floor, control sample
92871	17	92	92009	I10	Sediment inside a biconical pot in the house 1st floor (cf. control 92757)
92757	18	92	92009	I10	Sediment below a pot in the house 1st floor, control sample
92724	11	92	92009	G/H-9/10	Sediment in-between the pieces of the grinding stone in the house (cf. control 92770)
92753	12	92	92009	G/H-9/10	Sediment directly below the grinding stone in the house (cf. control 92770)
92770	13	92	92009	G10	Sediment ca. 50 cm far from the grinding stone in squares G/H-9/10 in the house, control sample
92778	14	92	92012	H15	Sediment directly below the grinding stone, outside the house (cf. control 92776)
92776	16	92	92012	H15	Sediment ca. 20 cm far from the stone in square H15, outside the house, control sample
92792	22	92	92023	H8	Sediment over the brunt clay surface, ground floor
92830	24	92	92023	H7	Sediment in-between pieces of burnt clay surface, ground floor of the house
92827	176	92	92021	H8	Fragments of burnt, fine, clay surface, ground floor
92829	182	92	92022	H7	Fragments of burnt, rough, clay surface, ground floor
92828	23	92	92023	H8	Natural soil below the burnt clay surface on the ground floor
110 L 19 d	197	110		L19	Daub from a platform in the house
110232	198	110		L21	Sediment inside a pot in the house
110-0-10	192	110		Profile Ost	Topsoil, modern control sample
60084	B5	60	60006	B2	Ash layer in a pit filling
60207	261	60	60013	Profile 60004	Pit filling with ash
60214	262	60	60024	Profile 60004	Control outside the pit

Distel, 2004; Lu and Liu, 2003; Mercader et al., 2010; Neumann et al., 2017).

Trapeziforms are typical of Pooideae as well. They show sinuate to polylobate lower border and a trapeziform section due to a smooth upper plateau. Bilobates present convex or concave ends and short shank, some have an additional lobe and have been called nodular bilobates (0.2%), others have a flat plateau on top and are named plateaued bilobate (0.2%). The last type is known also as "Stipa-type"

because it has been observed in many Stipa species, typical grasses of the steppe environment (Blinnikov, 2005; Fernandez Honaine et al., 2006, 2009; Fredlund and Tieszen, 1994; Gallego and Distel, 2004). This morphotype has recently been observed in Panicoideae too (Neumann et al., 2017). Viceversa, bilobates and polylobates are typically assigned to the Panicoideae subfamily (C4 grasses), although in assemblages of grasslands dominated by feather-grass, bilobates, polylobates and rondels were observed as part of the assemblage too
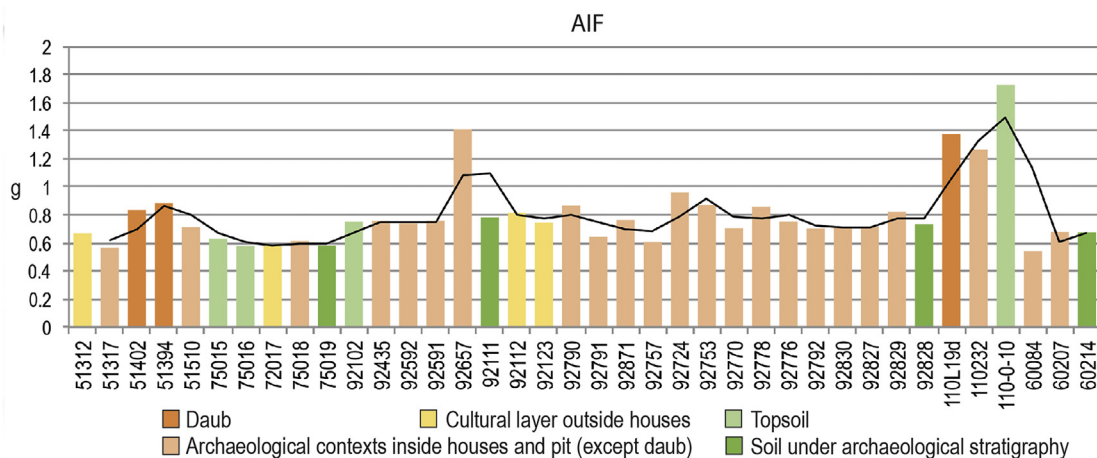
Fig. 5. Grams of acid insoluble fraction (AIF) in the samples per gram of dry sediment; the line shows average values.
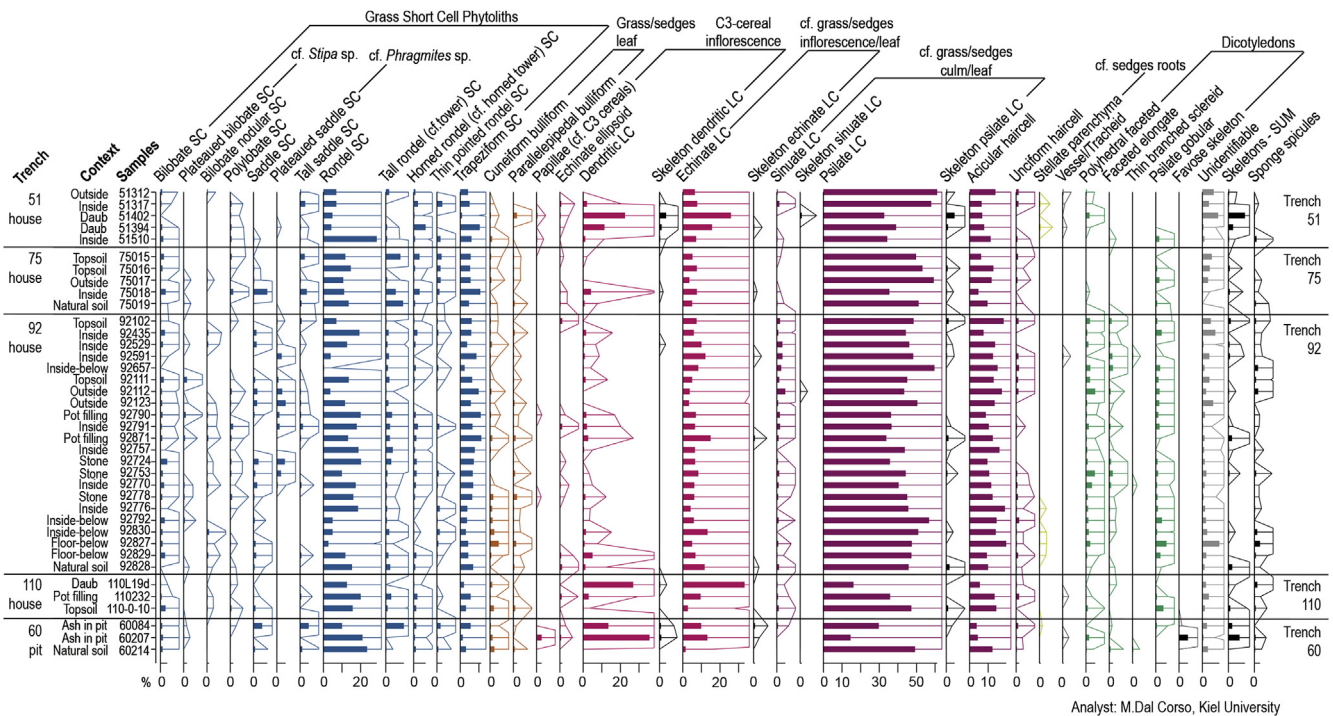
Fig. 6. The phytolith assemblage from Maidanetske per trench. Percentage values are based on the sum of single celled phytoliths (excl. unidentifiable). Exaggeration 10x, diagram produced with CountPol (program by I. Feeser, Kiel University). Abbreviations: long cell (LC), short cell (SC).

(Blinnikov, 2005; Fernandez Honaine et al., 2006; Gallego and Distel, 2004). Saddles are the morphotype that distinguish Chloridoideae, another C4 grass subfamily, while plateaued saddles have been observed in *Phragmites* sp. (common reed) (Ollendorf et al., 1988).

The phytolith assemblage also contains various non-GSCPs, of which many taxonomically non-informative morphotypes could probably derive from grasses as well. This might be the case of long cells (LC) with psilate and sinuate margins (respectively, psilate LC average 44%; sinuate LC average 0.9%), possibly attributed to grass leaf and culm, echinate long cells (8.6%), attested in grass inflorescence and leaf, as well as hair cells (average values for acicular haircells 11.4%; unciform haircell 0.6%). Moreover, here they are attested in connection with other cells in some silica skeletons, which supports their interpretation as derived from grass epidermis. Dendritic LC are attributed to the inflorescence of domesticated grasses, i.e. cereals of the Pooideae subfamily, although they have been observed also on some large seeded wild grasses (Tingvall and Miller, 1997; Fig. 1 g–h). Papillae from the inflorescence of pooid cereals are also evident (0.1%). Another morphotype has been found, here called "echinate ellipsoid" (0.3%) because of an ellipsoid or sub-globular shape and some pointed, irregular, short protuberances irregularly distributed on the whole surface. It shows similarity with a phytolith at hair base of modern-day inflorescence of *Triticum aestivum* L. (e.g. Ball et al., 1996, Fig. 8/T). We observed it also in the same position in reference material from the inflorescence of *Hordeum vulgare* L., prepared following a dry ashing procedure (Carnelli et al., 2004) at Kiel University (see photos in appendix 4).

Bulliform cells are also attested (average values for cuneiform bulliform 0.8%; parallelepipedal bulliform 0.5%), which are produced in grass and sedge leaves. Some morphotypes usually indicative of dicotyledons are also present (average sum of dicotyledonous phytoliths 2.9%). They are mostly irregular, faceted polyhedral (1.1%) or faceted elongate phytoliths (0.4%) attributed to dicotyledonous sclerenchyma, although elongate faceted phytoliths have been observed in monocotyledons, too (M. Madella personal communication). Some psilate globular phytoliths (1.2%), and multicellular favose skeletons (0.1%)

formed in mesophyll of dicotyledonous leaves are also present. Vessels and tracheids are grouped together and they have been considered a taxonomically non-informative type (0.1%). Other siliceous microfossils correspond to some fragments of sponge spicules (0.7%) and very rare diatoms.

3.3. Variations of the phytolith assemblage according to contexts

In this section, results are presented as mean values of morphotypes per sample context, apart when a specific sample is mentioned. For comparison, general mean values per morphotype in the whole study are given into brackets. In Fig. 7, the samples have been grouped according to the context, while phytolith morphotypes have been grouped according to anatomical plant parts or taxonomic plant groups.

Samples from the **soil below the archaeological stratigraphy**, coming from trenches 75, 92 and 60, present 25% GSCP (mean value in the whole study 26.4%), dominated by morphotypes typical of pooid grasses, such as rondels 17.5% (12.7%), followed by trapeziform sinuate 5% (5.7%) and long rondels 4% (2%), among others (see Fig. 7B). The other major components of the assemblage are psilate LC 48.7% (44%), as well as skeleton 0.3% (0.4%), acicular haircells 10.7% (11.4%), bulliform cells 1.4% (1.3%) and a small quantity of dicotyledonous indicators 1.2% (2.9%), of which mostly elongate faceted 0.4% (0.4%) and psilate globulars 0.5% (1.2%). Only in one sample (92828) from below the ground floor of house in trench 92, are echinate LC 12% (8.6%) and dendritic LC 1.2% (3.8%) attested. These were extremely rare in the other samples of this group.

The samples from the **topsoil** come from trenches 75, 92 and 110. They show a similar assemblage to that of the soil below archaeological features with GSCP 21.6%, psilate LC 47.6%, acicular haircell 13%, bulliforms 1.3%, dicotyledonous indicators 3.3%, but they differ in the GSCP spectrum. Among GSCP there are only 12% rondels, some morphotypes typical of panicoid grasses, i.e. 0.5% polylobates (0.4%) and 1.7% bilobates, the latter concentrated in one sample (110010 with 2.7%). Plateaued bilobates at 0.4% (0.2%) might be related to *Stipa* species. Despite the modern cereal field on the surface of the site only
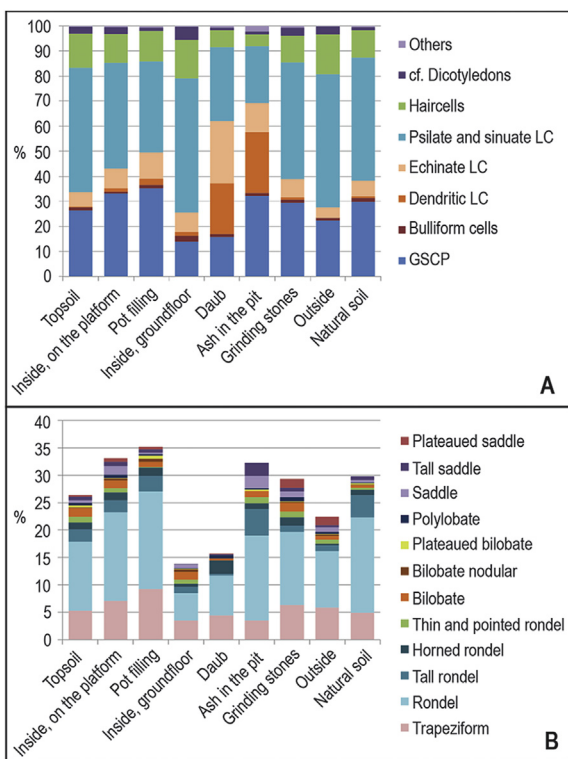
Fig. 7. A. Average relative values of the main components of the phytolith assemblages on samples grouped per contexts, according to the context specified in Fig. 6. B. Focus on the grass short cell phytoliths (GSCP) record.

0.5% dendritic LC from cereal inflorescences in the topsoil are present. Only rare skeletons with psilate LC, 0.6%, have been found.

In the phytolith assemblage of samples that come from **outside the houses** in trench 75, 92 and 51, the GSCP at 15.3%, and especially rondels 8.3%, have quite low values. In addition, saddle 1.1% (0.9%) and plateaued saddle 2% (0.6%), which can be related to common reed, characterize this GSCP assemblage. Similarly to the previous two groups, abundant psilate LC 53.6% with the highest relative value in this study, acicular haircells 14.2% and some dicotyledonous indicators 3.3%, of which mostly polyhedral faceted 1.5% (1.1%) and psilate globulars 1.5%, like in the topsoil. Some sinuate LC 1.4% (0.9%) and

unciform haircells 1% (0.6%) are attested too.

Inside the house in trench 92, two samples from the **groundfloor** under the *plotshchadka*, are characterized by very low relative value of GSCP 13.7%. Among them, mostly rondels 7.3%, followed by trapeziform sinuate 4.3%, bilobates 1.8% and saddles 1.3% are the most prominent ones. Nodular bilobates 0.6% (0.2%) are attested too. Psilate LC 47.4%, some echinate LC 5.9% and some dendritic LC 2.9% are present. Some morphotypes have here the highest mean value respect to the other sample contexts: acicular haircell 14.5%, unidentifiable phytoliths 5.6%, and psilate globular 4.7% (1.2%), contributing to the highest value of dycotiledonous indicators 5.7%. Sponge spicules 2% (0.6%) have the highest value too.

Samples from cultural layers **inside the houses**, on top of the *plotshchadka*, come from four trenches 51, 75, 92 and 110. They present 20.7% of GSCP (rondels 12.9%, trapeziform sinuate 5.7%, long rondel 1.6%, bilobate 1.2%, rondel horned 1.2%, thin pointed rondel 1.1%), psilate LC at 46.7%, echinate LC 7.8%, dendritic LC 1.2%, acicular haircells 12.1%, 0.9% bulliforms, and 2.9% dicotyledonous indicators (globular psilate 1.2%, polyhedral faceted 1%, elongate faceted 0.6%). Silica skeletons are very rare (0.3%).

The samples from **vessel fillings** are three and come from trenches 92 and 110. They present 19.5% GSCP, with mainly rondels 13.3% and the highest value of trapeziform sinuate 7%, followed by long rondel 2.1%, rondel horned 1.1%, bilobate (0.8%). The highest value of plateaeued bilobate 0.5% is also attested. Papillae 0.7% and echinate ellipsoid 0.5% are present too that relate to cereal chaff, indicated by 1.8% dendritic LC and 7.9% echinate LC. Psilate LC at 26.5% and acicular haircells 8.7% are not very abundant compared to the other contexts. Dicotyledonous indicators (0.9%) and silica skeletons (0.5%) are very rare.

The samples from **stone tools** are three and they all come from trench 92. They present 25.3% GSCP, with rondels 15.4% and trapeziform sinuate 6.8%, followed by long rondel 2.1%, rondel horned 1.1%, bilobate 0.8%. Echinate LC at 7.1%, dendritic LC 0.5%, papillae 0.1% and echinate ellipsoid 0.1% are present that relate to grass (cereal, in the case of dendritic LC) inflorescences. Psilate LC at 26.5% and acicular haircells 8.7% are not very abundant compared to the other contexts. Dicotyledonous indicators (4.5%) present the highest values of polyhedral (2.3%) and elongate faceted (1.1%). Silica skeletons (0.2%) are very rare.

Two samples come from **ash layers in the pit** in trench 60. They present an assemblage with the highest GSCP value, 28.8%, which mainly include 15.9% rondels, 4.9% long rondel, 3.5% trapeziform
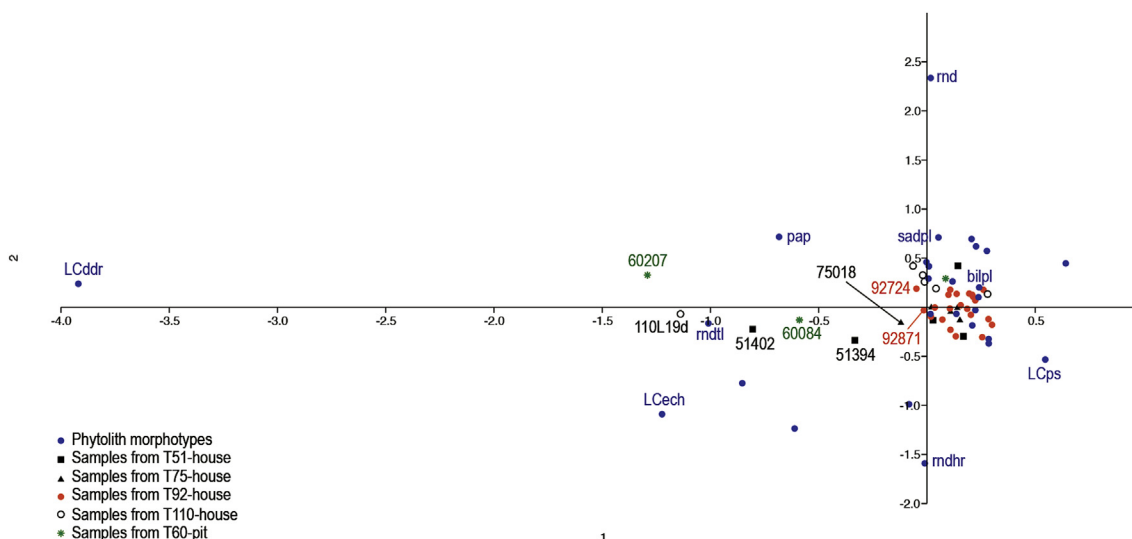

Fig. 8. Correspondence analysis of phytolith morphotypes and samples per trench, first two eigenvectors. Abbreviations: dendritic LC (LCddr), echinate LC (LCech), psilate LC (LCps), rondel (rnd), papillae (pap), plateaued bilobates (bilpl), tall rondels (rndtl), horned rondels (rndhr), saddle plateaued (sadpl).

sinuate, 2.3% saddle and tall saddle, 1.2% bilobates. The assemblage stands out in respect to the other contexts previously described because of long cells proportions: dendritic LC 24.6% and echinate LC 11.6%, present also as skeletons (1.6%), clearly indicate an accumulation of cereal chaff, accompanied also by the 1.4% papillae and 0.5% echinate ellipsoid morphotypes. Psilate LC 22.1% and acicular haircells 4.1% have the lowest values compared to the rest of contexts. Dicotyledonous indicators (3.7%) present the highest value of favose skeletons (2.5%) from mesophyll of leaves.

Three **daub** samples come from trenches 51 and 110. They all show an assemblage in part similar to that of the pit filling, because of the abundance of cereal chaff, although the proportions of short cells and long cells is different in this case. GSCP have the lowest value of the sequence, 11.2%, with mostly 7.3% rondel, 4.5% trapeziform sinuate and 2.4% horned rondel (highest value). Dendritic LC 20.2% and echinate LC 24.9% attest cereal chaff; papillae and echinate ellipsoid are also attested (0.2%). Psilate LC 29.3% and acicular haircell 6.7% have low values. Silica skeletons are found here the most (3.9%) and include some with dendritic (1.7%), echinate (0.3%) and psilate (0.3%) LC. Dycotiledonous indicators are rare (0.9%).

3.4. Variations of the phytolith assemblage according to contexts: correspondence analysis (CA)

Fig. 8 shows the results of the correspondence analysis, which is visible also in the supplementary material (appendix 3, with two separate plots for phytolith samples and for phytolith morphotypes, including one without dendritic LC).

The results show that the first eigenvector explaining 41% of the datasets variation is related to the presence of dendritic and echinate long cells, i.e. to cereal chaff. Tall rondels and papillae, slightly associated, may also derive from cereal chaff (other apparently associated morphotypes are separated by the third eigenvector). Few samples relatively rich in dendritics and echinate long cells originate from ash in the pit (60207, 60084), daub (110L19d, 51402 and 51394), a grinding stone (92724) and inside house in T75 (75018) and are found to the left of the y-axis. Also a sample from a vessel filling (92871), is located close to the y-axis, thus being weakly related to cereal chaff. The majority of the remaining samples are located right of the y-axis and are not related with cereal chaff. They are collected from natural soil locations inside and outside the houses, including from floors, and partially meant as control samples, and other vessels and grinding stones.

The second eigenvector, explaining 14% of the datasets variation, differentiates between samples from house in T110 (at the upper end of the graph and high above the x-axis), characterised by high values of general rondels and also by high AIF values, and most samples from the houses in T92, T75 and T51, which show lower values of general rondels. Control samples from house in T75 are additionally characterised by slightly higher values of horned and tall rondels. The group of samples from the house in T92 show relatively little differentiation apart from the samples mentioned above.

Overall, the correspondence analysis shows a strong difference between contexts with high chaff content, i.e. daub, ash from the pit, a vessel and a grinding stone, and contexts without chaff. The latter do not differentiate from each other substantially.

4. Discussion

The analysis of phytoliths from different archaeological contexts, to be compared with topsoil and natural soil, provides a rich record in terms of local grasslands and cereal components. Due to differential preservation some contexts are preferable to others. At Maidanetske, the contexts that emerged as most informative about cereal processing were daub fragments and pit fillings, while sediment samples from other archaeological contexts as well as natural soils were more difficult to differentiate and interpret. This might be explained by a background signal due to taphonomy, which masks eventual differences in the phytolith assemblages from different contexts, or to the fact that the plant input and the relative phytolith assemblage was similar in different contexts. Further work on taphonomy, reference material and a bigger samples size might help to disentangle this issue.

4.1. Cereal processing

Phytolith analysis attests the presence of cereals as part of the site economy. Cereal chaff obtained after dehusking of cereal grains, was used as temper in daub material used to construct houses from Maidanetske. Dehusking is the final stage of cereal-processing, usually considered to occur shortly before food preparation as grains are most often stored in spikelets or ears to protect them against fungi and insects (Hillman, 1984; Nesbitt and Samuel, 1996). This usually points to a local dehusking in domestic areas, more than in fields or elsewhere. However, in the Maidanetske houses we found only minimal traces of chaff phytoliths, which might indicate periodical cleaning of the surfaces or collecting the remains for other purposes (as the use of chaff as plant temper would suggest). A possible alternative is that they did not process cereals in the areas that we sampled. One possibility for Maidanetske might be that dehusking took place in special (collective?) areas inside or outside the settlement. This assumption has to remain hypothetical at present but will be addressed in future investigations. However, the samples originating from sediment attached to stone tools identified as grinding stones have no striking evidence of chaff. Thus naked grains were most probably ground in the houses, leaving little traces of chaff phytoliths because the grains themselves do not contain phytoliths. The chaff corresponds to what observed in pooid hulled and naked wheat and barley, which fits with the few macro-botanical remains found at the site, emmer, einkorn and hulled barley (Kirleis and Dal Corso, 2016). No phytoliths from the inflorescences of panicoid cereals such as *Panicum miliaceum* or *Setaria italica* emerged from this study. Similar absence was signaled in another phytolith study on Romanian Chalcolithic material from Taraschina in the Danube Delta (Danu et al., 2018), where abundant remains indicating cereal chaff and processing were found, but none suggesting the presence of chaff of domesticated millets.

In the pit, chaff and straw were mixed with leaves of dicotyledons, which suggest no special selection of the material but just a general disposal of burned waste. In the same pit in T60 the charcoal record showed presence of broadleaf wood charcoal from common ash, elm, oak and willow (Kirleis and Dreibrodt, 2016). Following the archaeological interpretation that the pit was filled in with the remains of a burnt house (Müller et al., 2017), the plant material attested through the phytolith and charcoal records could be attributed to that used for house building with possible inclusions of daily activity waste.

Since the percentage of dendritic LC from cereal chaff in the daub and in the ashes in the pit is very high, it is most probably that the phytoliths relating to grass culms and leaves (e.g. psilate LC, sinuate LC and bulliforms, as well as rondels and trapeziforms) in these samples derive from the cereals. Ethnographically, the preference for hulled cereals such as einkorn, emmer or hulled barley (all producing dendritic LC), is due, among various reasons, also to the valuable use of the stems and leaves of the plant for many purposes (e.g. thatching and bedding) and/or for fodder (Nesbitt and Samuel, 1996).

In general, apart from where they have been used as temper, dendritic LC are present only in cultural layers but not in high amounts as compared to other on-site studies (cf. Danu et al., 2018, up to 25% dendritic LC from on-site). They are absent in the samples outside the house, from the natural soil below the house and from the soil covering the archaeological remains, with rare exceptions that could well be due to movement of disarticulated single-celled phytoliths from archaeological layers to natural soil (e.g. 92828, 75019).

The attestation of chaff and (most probably) straw in daub and pit filling suggests *per se* the processing of cereals. Further analyses on the

contemporaneity of the houses, the level of standardization in plant tempering, and the quantification of the plant material used in Trypillia architecture are still in progress. In the future, such data will help to quantify cereal production.

A final remark concerns the absence of evidence for herbivore animal dung, from which the high concentration of grass leaf/stem phytoliths in the archaeological samples could derive too (Lancelotti and Madella, 2012). At present, there is no evidence for herbivore animal dung at Maidanetske, spherulites (frequent in goat/sheep dung) are absent in the studied samples. Further geochemical and micro-morphological analyses are necessary to confirm the presence/absence of dung.

4.2. Signal of local grassland vegetation

Through the presence of many different GSCP that had no association with cereal phytoliths, it was possible to identify some grassland components belonging to the natural vegetation. For instance, pla-teaued bilobates ("*Stipa*-type") are associated to feather-grass of steppe dry meadows. This morphotype was found in low amount in archae-ological contexts including pots fillings (92790, 92871), but it was present also in the natural soil below the house in T92 and below the pit. According to pedological data, this natural soil formed under woodland cover (Kirleis and Dreibrodt, 2016) and the very scarce presence of *Stipa*-type phytoliths may be due to percolation of material from upper layers after bioturbation, or to a local woodland opening preceding the village establishment. In the CA (Fig. 8), the *Stipa*-type morphotype, or plateaued bilobate, is not associated with cereal chaff, but clusters indistinctively with many other types attesting overall the presence of wild grasses. Despite their usual attribution to panicoid grasses, other bilobates, nodular bilobates and polylobates, which were found in different contexts in this study, according to modern vegeta-tion studies could be associated to plants of the Stipeae tribe as well (Blinnikov, 2005; Fernández-Honaine et al., 2006, 2009; Gallego and Distel, 2004). We can hypothesize that during the occupation of the site, some grassland vegetation with feather-grass were visited by people and herds, which is also evident with the attestation of charred awn macro-remains of *Stipa* (Kirleis and Dreibrodt, 2016). Indeed, people could have collected feather-grass and other wild grasses for matting or other purposes, known also ethnographically (Anderson and M'hamdi 2014) and postulated for some Neolithic sites in Europe (Bieniek, 2002). Besides human selection, due to its curly awns, the fruits of this plant could have been easily brought on-site also attached to the hair of animals. However more data from the natural soil on which the settlement was founded and from off-site archives are needed, to understand if these grasslands were local or not, and how extensive they were. Finally, common reeds, attested only by plateaued saddles, as well as other wetland vegetation were scarce in this study. Thus, for the moment from this record there is no explicit indication for the use of plant material from the river valley for architecture or other purposes.

5. Conclusions

At the site of Maidanetske, the phytolith record from different contexts including multiple houses, was studied, which confirmed cereal cultivation as part of the subsistence economy of the site. Furthermore, phytoliths gave information about wild grasses, whereas dicotyledonous material was scarce. For the house structures cereal by-products, chaff and straw were identified as material selected for tempering daub for the wall construction. Ash layers in a pit filled with house remains show similar pattern. Daub fragments and pit filling are the most promising archives for further phytolith work on cereals at Trypillia sites. The sediment inside four burnt houses and the areas outside two houses, where also grinding stones were sampled, showed little presence of the remains of final cereal processing, suggesting that either the surfaces were cleaned and the chaff was collected after de-husking, or the cereal processing activity took place somewhere else. Specific archaeological contexts, such as vessels and grinding stones, did not differ much from the control samples from archaeological se-diment nearby, suggesting disturbance of the record. The topsoil above and the natural soil below the houses show mixed assemblages, espe-cially rich in grass short cells, which however do not differ significantly in the morphotypes and/or proportions. This mixture could be due to a taphonomic problem or to stable presence of various grasses. Phytoliths interpreted to be related to feather-grass, typical for grassland steppe have been detected in almost all the sediment samples (archaeological and not) in small quantities. While for the natural soil the presence of *Stipa*-type phytoliths could be due to bioturbation, for the archae-ological sediment samples it may suggest the presence of some open areas around the site, or the collection of such grasses by people. The future study of local modern plant material will further help in the identification and attribution of the rich GSCP record. Phytoliths of-fered a way of equally comparing different contexts in terms of plant remains, demonstrating good potential especially in the detection of crop processing remains.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jaridenv.2018.06.009.

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