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MODERN ANALOG ASSEMBLAGES OF PHYTOLITHS UNDER VARIOUS PLANT COMMUNITIES OF THE MIDDLE VOLGA AND THEIR APPLICABILITY FOR ARCHAEOLOGICAL RECONSTRUCTIONS[1]

The article describes the results of investigations of the sub-recent assemblages of silica phytoliths in top soils of various modern plant communities of the Middle Volga region in Tatarstan, Samarskaya and Ulyanovskaya oblasts conducted in 2017–2020. Counts of various phytolith morphotypes from 40 samples suggest a relatively low level of vegetation community specificity as revealed by multivariate statistical analyses. Nevertheless, coniferous and mixed forests can be distinguished based on the presence of a suite of conifer phytoliths, while steppes can be identified based on high proportion of rondels. Deciduous forests of the region can be detected based on high proportion of straight elongates and acutous bulbosus (trichome) type. Some matchings are made to 10 archaeological samples from various strata and ages across the region. Such samples reveal high proportion of cultured grass phytoliths and are most similar to steppes or agricultural assemblages in the modern dataset.

Keywords: archaeology, phytolith analysis, modern soils, cultural layers, forests, steppe, agriculture, Tatarstan, Samara, Ulyanovsk.

Phytolith analysis has become a mature method of paleoenvironmental analysis along with pollen and macrofossil analyses (Blinnikov, 2013; Piperno, 2006). It is generally accepted that any paleoenvironmental reconstructions using phytoliths must begin with analyzing modern phytoliths distribution in plants and soils in the region of research (Carnelli et al., 2001; Blinnikov, 2005; Lu et al., 2006), although studies of phytoliths in modern soils are less common than studies of phytoliths in plants. Despite recent advances in phytolith taphonomy (Blinnikov et al., 2013; Cabanes and Shahack-Gross, 2015), our understanding of how soil phytolith assemblages are formed and preserved is still preliminary. At the same time, archaeological research demonstrate the ability of phytolith analysis to answer many important questions about paleoenvironmental contexts of various archaeological sites (Ryan, 2014), and so advances in modern phytolith studies are relevant to the field of archaeology.

The phytoliths in modern soils primarily accumulate in the top soil (A horizon). They are primarily silt-fraction in size (5 to 60 mkm), with some reaching the fine sand size (200 mkm). Made of opal (hydrogenated silica) they are casts of plant cells and can be very durable under heavy oxygenation/low pH regimes. While precise taxonomic attribution to a genus or species level of plants is rarely possible (Blinnikov, 2013; Piperno, 2006), many vegetation types can be reliably detected by the phytolith assemblage, based on statistical methods (Blinnikov, 2005; Solomonova et al., 2019). The assemblages from the very top of modern soils (<1 cm) are thought to represent anywhere from a few decades to a few centuries of the vegetative cover evolution, so the best results are achieved in less disturbed, more natural sites. At the same time, prior inheritance from succession is well demonstrated and must be accounted for (Blinnikov et al., 2013).

Northern Eurasia, with Russia in par-

[1] Tracking origins of agriculture in Bolgar, Tatarstan through soil micromorphology and phytolith analysis. St. Cloud State University Researchers Grant 2017.

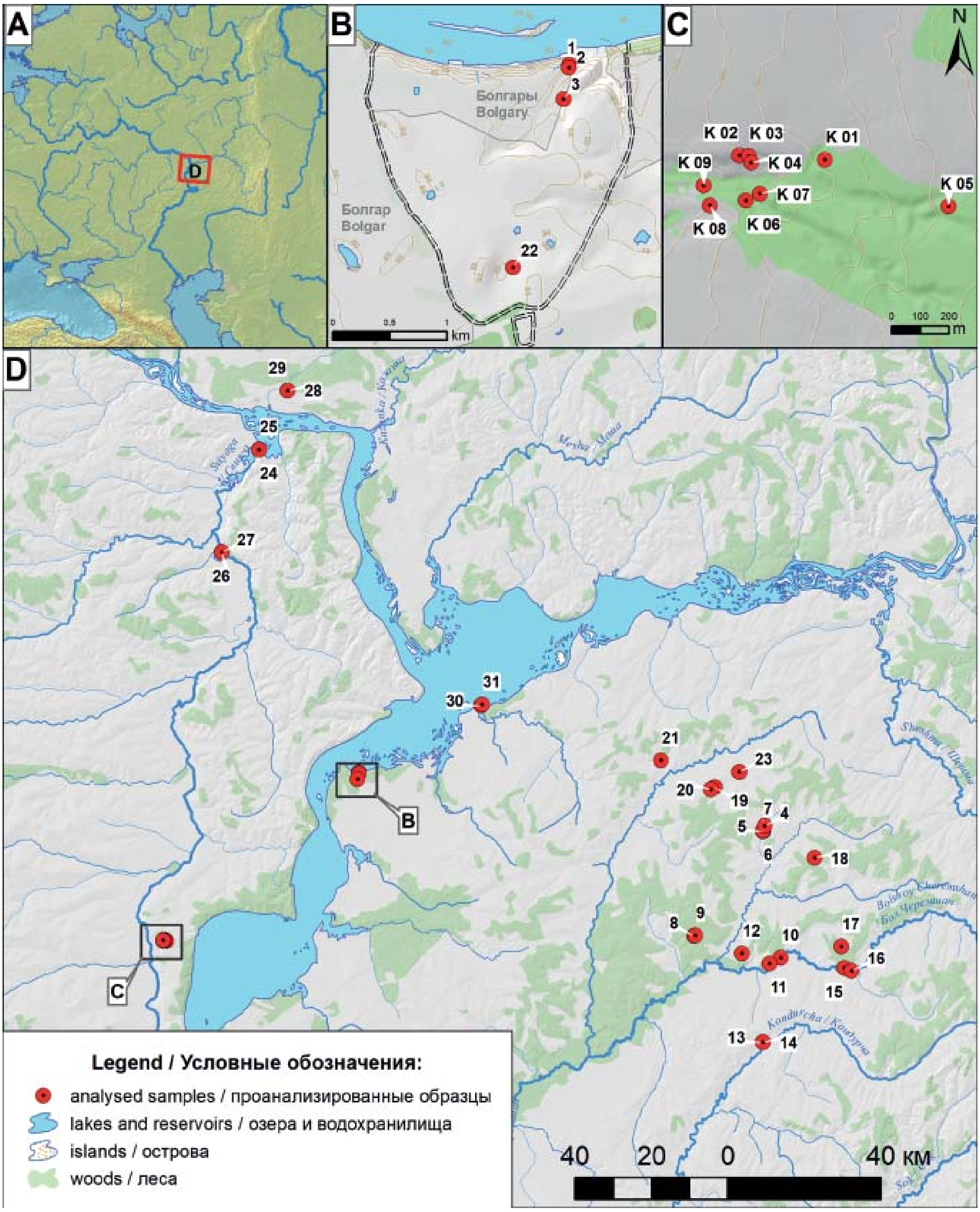

Fig. 1. Map of sampling locations used in this study in the Middle Volga region of Russia. A – area of study, B – samples taken at Great Bolgar, C – samples taken at Komarovka, D – all samples.

Рис. 1. Карта точек отбора образцов в Среднем Поволжьи России, использованных в данной работе. A – район исследований, B – точки отбора проб в Болгаре, C – точки отбора проб в Комаровке, D – все точки.

ticular, has seen a share of the modern analog studies of phytolith assemblages in sub-recent soils (Golyeva, 1987; Kiseleva, 1982, 1992; Kamanina, 1992; Blinnikov, 1994; Lada, 2016; Gavrilov and Loyko, 2016; Silantyeva et al. 2018; Solomonova et al. 2019) in the European part, in the Caucasus, western Siberia and the Altay. So far, there has not been a corresponding effort in the Middle

Fig. 2. Deciduous forest and steppe communities in Tatarstan.
Рис. 2. Внешний облик широколиственного леса и степи в Татарстане.

Volga region. This study collected modern (sub-recent) phytolith samples from soils across Tatarstan and in two locations in Samara and Ulyanovsk oblasts in 2017-2020 for the first time for the region (Fig. 1, Table 1). The samples spanned the typical gradient of native and some cultivated plant communities, mainly forests, steppe and transitional forest-steppe (Fig. 2). Previous studies indicate that phytoliths are robust proxies in ecotonal studies at the interface of forest and steppe (Witty and Knox, 1964; Verma and Rust, 1969; Blinnikov et al., 2013). First, grasses (Poaceae), which contain greater than an order of magnitude more biogenic silica than trees (Piperno, 2006), are abundant in such areas. Short grass cells are diagnostic at least to the subfamily level in Poaceae (Neumann et al., 2017). Detection of forest vs. grassland communities is possible by comparing total opal concentration in modern soils (Wilding and Drees, 1971; Blinnikov, 2005) and by diagnostic presence of tree phytoliths. Second, forest-steppes usually have few lakes or bogs available for pollen or macrofossil analyses. Finally, in the Middle Volga, forest-steppe is of great interest to archaeologists, as a transitional zone between more sedentary forest cultures to the north and more nomadic steppe cultures to the south with constantly shifting boundaries between the two (Vyazov et al., 2019).

Sampling. Forty-one samples of modern plant communities represent three kinds of forests (pine/mixed, deciduous broadleaf and floodplain), three upland graminoid communities (meadow steppe, dry meadow and wet meadow), a marsh, and a few samples from agricultural sites (fields) (Table 1). We did not include highly altered rural environments such as vegetable plots, orchards, or compost dumps in this study. Also excluded were experimental archaeological contexts, e.g., barn or hut floors, pavements, or grain pits. So, in general, our dataset is particularly suited to detecting paleo vegetation communities in the vi-

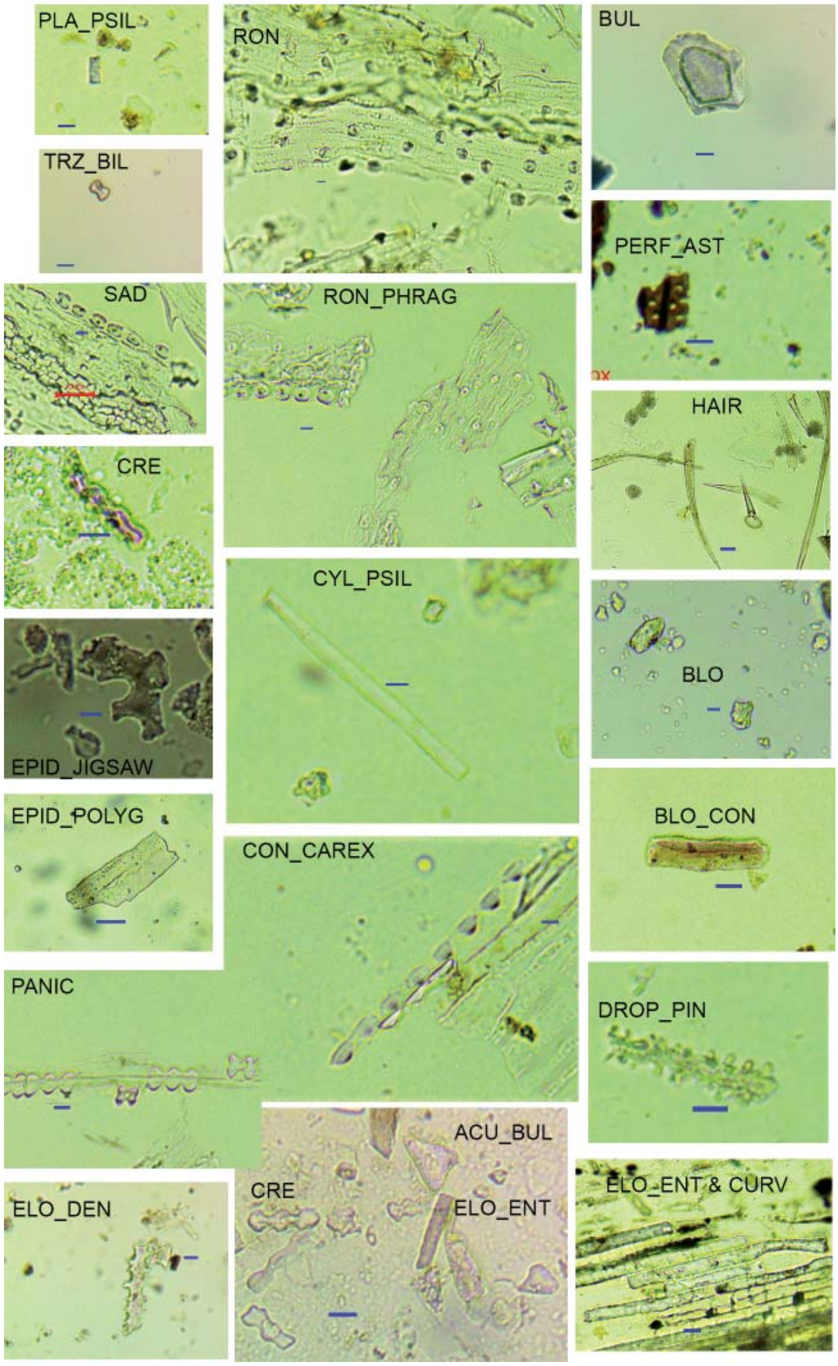

Fig. 3. Photos of phytolith morphotypes recognized in this study. See Table 2 for the full names of each morphotype. Scale bar is 10 mkm.

Рис. 3. Микрофотографии морфотипов фитолитов, использованных в данном исследовании. См. таблицу 2 для расшифровки названий. Шкала 10 микрон.

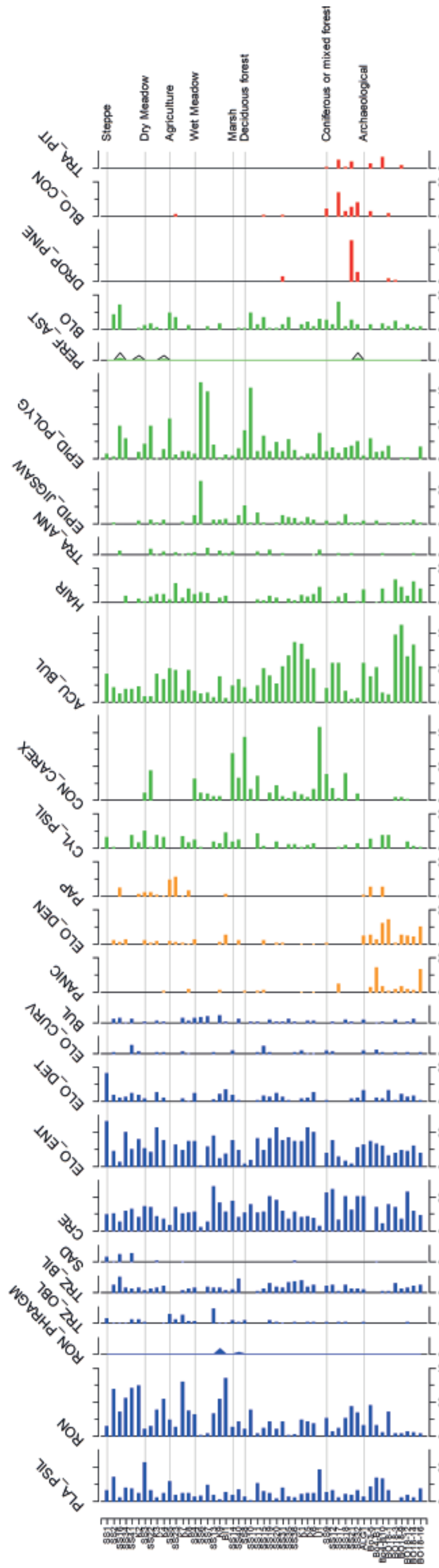

Fig. 4. Percentage of each morphotype in each sample. Rondels are a sum of a few different types, not analyzed further in this study. Panicoids include true bilobate, crosses, and non-trapeziform polylobate forms.

Рис. 4. Процентное содержание каждого морфотипа в пробах. Рондели включают в себя несколько подтипов, не проанализированных дополнительно. Паникоиды выключают в себя двулопастные, крестовидные и нетрапециевидные полилопастные формы.

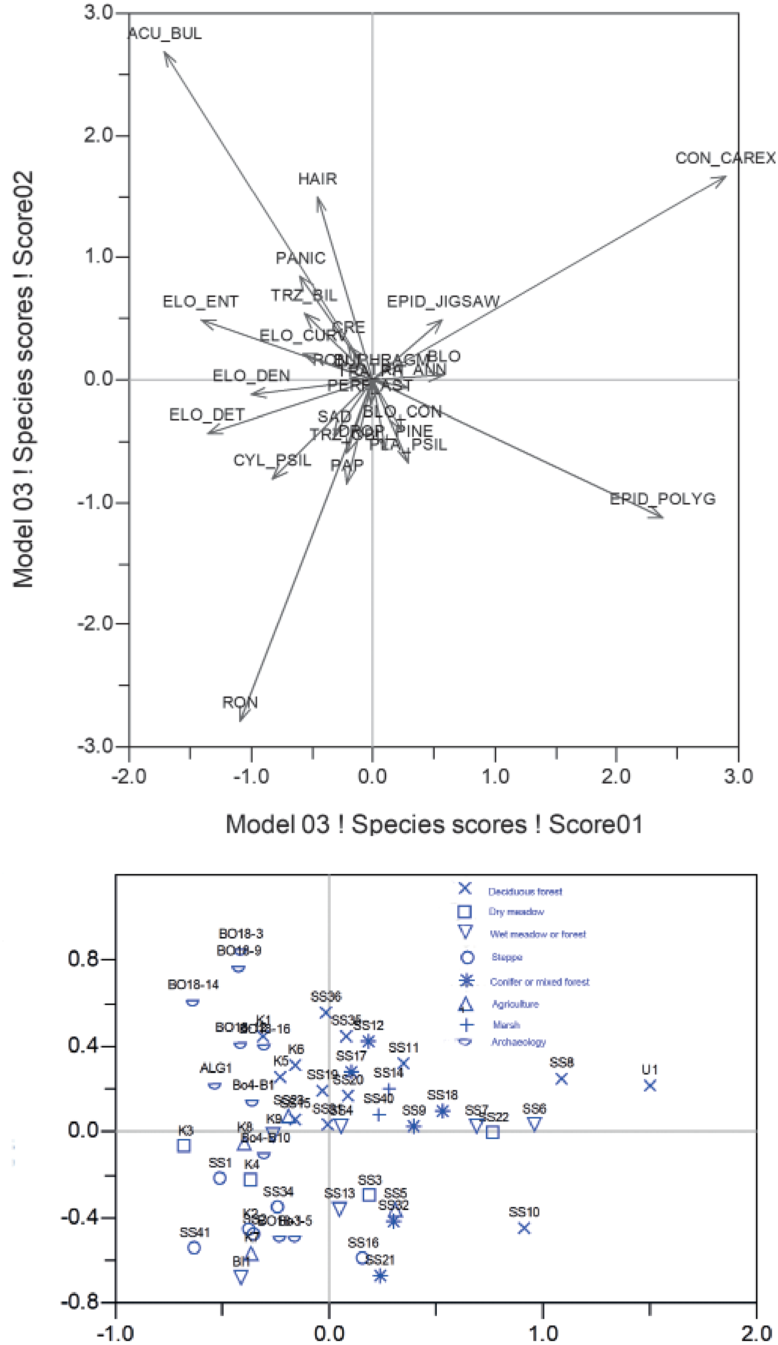

Fig. 5. PCA ordination of a) morphotypes, b) samples along the first two axes. Square root transformation of all percentage values was used before the analysis.

Рис. 5. Результаты ординации а) морфотипов и б) образцов методом главных компонент по двум главным осям. Процентные значения были предварительно трансформированы с помощью квадратного корня.

cinity of archaeological sites (e.g., near the edge of a settlement).

Each sample was collected as an aggregate sample of approximately 15 random pinches from the very top of A horizon cleared of any leaves, twigs, or duff, from a 6 x 6 m plot (Mueller-Dombois and Ellenberg, 1974). Plant species on each plot were recorded based on the in-field identification and their percent cover noted. Tree species were recorded on larger, 20 x 20 plots, and some were cored to obtain average ages of stands, but phytolith samples were still collected from 6 x 6 m plots. Community types were assigned based on the visual observation in the field and using the dominant approach (e.g., an oak forest, a spruce forest, etc.). Some plants were collected and later identified using botanical keys (Majevski, 2006).

Extraction. Soil samples were treated using the modified approach of Blinnikov (2005). Approximately 5 g of dry soil was heated in 50 ml of 10% hydrochloric acid for 1 hour to destroy carbonates followed by boiling in additional 50 ml of 69% nitric acid for about 2 hours to destroy the organics. After the suspension was neutralized at room temperature, phytoliths were subject to deflocculation with 5% solution of sodium metaphosphate and floated in a heavy liquid solution of CdI_2 and KI with the specific gravity of 2.3 g/cm^3. The floated phytoliths were collected by a Pasteur pipette from the top 5 mm of the solution, transferred to clean test tubes and sunk by adding distilled water in proportion of 3:1, dried, and the resulting phytolith-rich residue was stored in ethyl alcohol. Phytoliths were counted floating in the immersion oil type A under an optical microscope (x400-x1000) to examine true 3D shapes under rotation. Between 200 and 300 phytoliths were counted per sample. Phytolith morphotypes were documented by light microphotographs and permanent reference slides.

Counting. All identifiable phytoliths larger than 10 µm were counted, not only short cells of grasses (rondels, bilobates, polylobates, and saddles), but also long cells and other grains of identifiable shape of non-grasses. We followed the classification system of Blinnikov (2005) (Fig. 2 in Solomonova et al., 2019, p. 6) and the Glossary for the International Code for Phytolith Nomenclature 2.0 (Neumann et al., 2019) in describing morphotypes (Table 1 and Fig. 3). In this paper, all rondels are presented as a sum, although we counted a few different rondel types separately (e.g., tall keeled rondel, short keeled rondel, short trapeziform, and short conical), as they could be useful in distinguishing certain communities (Solomonova et al., 2019). However, their distinctiveness can be highly subjective. We also merged three Panicoid morphotypes into one category (true bilobates, quadrilobates or crosses, and polylobates).

Statistics. We performed a two-way principal components analysis (PCA) in C2 software v, 1.7.7 (Juggins, 2014) on square-root transformed percentage values as a form of indirect ordination to extract the most meaningful information signal about the samples and the morphotypes. Additionally, a cluster analysis using Ward's method of linkage and Euclidean distance was done in PAST 3.26 software to distinguish most similar groups of samples (Hammer, 2019).

Results. The analyzed dataset consists of 41 modern samples and 10 archaeological samples for comparative purposes (Fig. 4). The most common morphotypes overall were acute bulbosus (trichomes) with the mean value of 14.79%, followed by entire elongates (11.98%) and rondels (8.8%). Most morphotypes occurred in all samples, suggesting relatively low level of distinction by community type. Some morphotypes were very rare: saddles were found in only 8 samples, perforated plates of Asteraceae were found in only 4 samples,

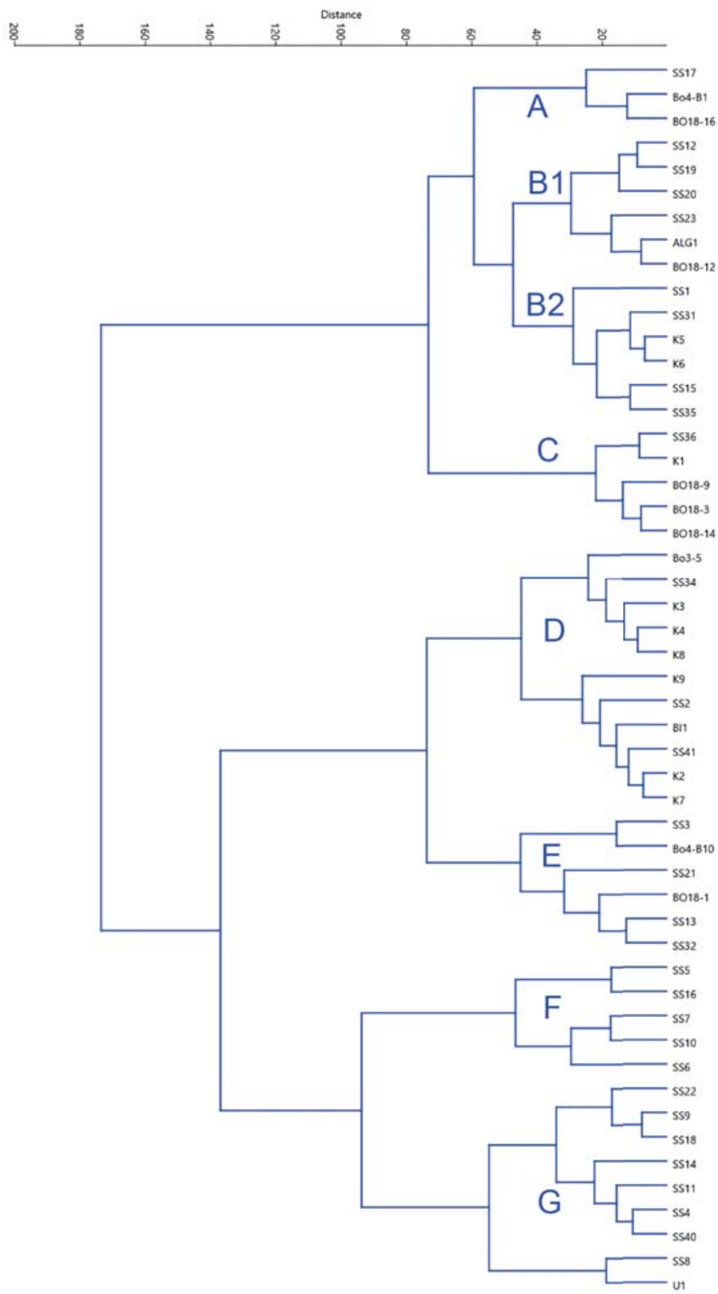

Fig. 6. Cluster analysis dendrogram (Wards' linkage method, Euclidean distance) showing seven main clusters, A+B+C are primarily forest samples, D+E+F are primarily open communities (steppes or meadows). Cluster G and two samples in cluster F are from wet meadows, floodplain forest or marshes.

Рис. 6. Дендрограмма кластерного анализа (метод Уорда, евклидово расстояние) с семью основными кластерами. A+B+C кластеры включают преимущественно спектры лесных сообществ, D+E+F – открытые сообщества (степи и луга), G и две пробы в кластере F из влажных лугов и пойменных зарослей или болот.

and saddle-top rondel of *Phragmites* was found in only two (one in a marsh and one in a wet meadow). Steppes and to a lesser extent dry meadows were well distinguished by a high presence of rondels and occasional presence of perforated plates of Asteraceae. Coniferous and mixed forests were detected based on presence of specific coniferous phytoliths (bordered pit tracheids and distinctive blocky forms). Pine forests usually had drop-shaped phytoliths diagnostic of some pines. Deciduous forests had a high proportion of acute bulbosus phytoliths and sedge conical forms, both probably derived from *C. pilosa.* They also had a large proportion of epidermal polygonal and jigsaw-puzzle phytoliths of dicots (forbs, shrubs or trees). Wet meadow communities had similar assemblages, but with lower proportion of sedge phytoliths. Elongate dendritic and papillae forms, common in cultural grasses and in wild members of Triticeae tribe specifically, were detected mainly in the steppes and dry meadows and even to a higher extent in archaeological samples, but were very uncommon in all forests. Panicoid phytoliths (true bilobate, quadrilobate and polylobate) were virtually absent in modern samples, but were abundant in some archaeological samples.

Principal components analysis reveals the main groupings of the soil samples and morphotypes (Fig. 5). The first two axes have the following eigenvalues: 0.216 for the first and 0.143 for the second axis. Therefore, the two account for slightly less than 40% of the variability in the dataset. On the horizontal axis 1, samples located to the left are open and dry communities of steppe, dry meadows and agricultural. On the right, there are forests ranging from dryer mixed and coniferous to wet floodplain forest and deciduous forests. Thus, we interpret this axis as primarily a reflection of the moisture gradient. With respect to morphotypes, communities on the left are heavy on elongates, while communities on the right are heavy on polygonal epidermal forms of dicots and conical phytoliths of sedges. The vertical axis 2 at the top is plotting the communities from archaeological sites with heavy presence of Panicoid forms common in millet and silicified microhairs common in many cultural grasses, but also possible in nettles, hemp and various dicots. The bottom samples on axis 2 are heavy with rondels and trapeziform bilobate phytoliths. These morphotypes are especially common in modern steppes. Some samples near the bottom have rare, but diagnostic, drop phytolith of Scotch pine. All such samples are in pine or mixed forests today.

Cluster analysis allows to further refine our understanding of distances between various samples (Fig. 6). Of the two major clusters (A+B+C and D+F+G), the top are mainly samples from forests, while the bottom are mainly samples from open communities (steppes and meadows) with some archaeological samples having closer affinity to the former or the latter. Cluster B contains all forest samples, while cluster D contains all steppe or dry meadow samples. The very bottom of the dendrogram (G) contains all wet communities (marsh and wet meadows). Most archaeological samples are not similar to modern communities in our dataset, because they contain a lot of Panicoid, elongate dendritic and papillae forms of cultural grasses, while modern datasets have relatively few such forms even from agricultural sites. Nevertheless, surface sample 23 from a modern rye field matched well with Algashi (likely Middle Bronze age, Vyazov et al. 2019) and Bolgar 18-12 sample (Excavation block 230, Migration period, 400-650 CE). Two other Bolgar samples (Bo4-B1 and Bo18-16) matched surface sample 17. While today this sample comes from a spruce forest plantation, it had some Panicoid forms in the soil likely inherited from an earlier millet field in the vicinity. Another sample from Bolgar (Bo3-5, Excavation block 189, Migration period, 400-650 CE) matches with a few grazed steppe/meadow sites in the modern dataset (SS34, K3, K4 and K8). Yet another Bolgar sample from the Russian colonization period (BO18-1) matched with modern-day mixed coniferous forest with diverse forbs and wild grasses. Three of the Bolgar samples (BO18-3, BO18-9 and BO18-14) matched with two samples from birch-maple or aspen-maple deciduous forests (K1 and SS36) with heavy ground cover of *C. pilosa* and some forest forbs. These samples range from Bolgar to Golden Horde to the middle of Kazan Khanate times and have fewer phytoliths of cultural grasses than some of the earlier, Migration period, samples.

Discussion. Our results confirm earlier findings from the temperate forest-steppe zone of Eurasia from the Altay (Silantyeva et al., 2018; Solomonova et al., 2019) and western North America (Blinnikov, 2005) that many modern communities leave distinct phytolith signatures in sub-recent soils. Steppes tend to have a very high proportion of rondels (>30%), dry meadows – slightly less (20-22%). Both also have lots of trapeziform bilobate forms (mainly derived from *Stipa*) and steppes may also have saddles and Panicoid (true bilobate, cross, or polylobate) forms. The coniferous forests have a moderate and consistent proportion of conifer diagnostic phytoliths (12-15%). Deciduous forests in this study have a high proportion of acute bulbosus (trichome) phytoliths, between 10-35%. This is primarily because in the Middle Volga region the dominant groundcover species is *Carex pilosa* producing a lot of such forms. In the Altay studies, deciduous forests average only about 10% of such forms (‘lanceolates’ in the old terminology). Gavrilov and Loyko (2016) report high incidence of such lanceolate forms from the dark coniferous forests of Vasyugan Plain west of Tomsk in Siberia (*Picea obovata* is the common dominant there). In our coniferous forests, lanceolate forms are less common than in deciduous ones, because ground cover in them has a lot less *C. pilosa* and more of various forest grasses (*Milium, Melica, Festuca gigantea*, *Brachypodium*) and forbs. Another important marker of deciduous forests in our study area is the conical phytolith of sedge, typically 2-9%. However, samples from wet meadows and marshes would have this form as well, because sedges are of course very widespread in wetlands. Crenate phytoliths in this study (called ‘polylobate trapezoids’ in the Altay studies) are numerous in coniferous and mixed forest samples (20-25%) and are less numerous in various meadows (10-15%). This is also corroborated by Golyeva (2001): she classifies such forms as typical “meadow” phytoliths. Wet meadows and forests in our study area have the highest proportion of bulliform cells (4%) and occasionally saddle-topped rondel diagnostic of *Phragmites*, a typical large grass dominant of such habitats. One marsh had long crenate forms of *Glyceria maxima*, another typical large grass dominant of wet habitats. Wet and some deciduous forests have relatively high proportion of jigsaw-puzzle shaped flat epidermal phytoliths of some dicots, 5-25% (e.g., maple). Even more common, 20-45%, are polygonal epidermal phytoliths of other dicots (e.g., birch and many forbs). Cylindrical psilate forms are probably of dicot forb origin (Golyeva, 2001; Lada, 2016) and are found mainly in dry or wet meadows with diverse forb cover. Psilate plates and non-conifer blocky forms do not appear to have a clear affiliation with any specific plant community and their utility is minimal. Lu et al. (2006) suggested that amorphous blocky (‘gobbets’) phytoliths may be a good indicator of semi-deserts and come mainly from Chenopodiaceae. We do not have semi-deserts in our study area, and such forms are rare.

Archaeological samples used here for comparative purposes and spanning time periods from the Middle Bronze to the modern time Russian colonization have high frequencies of Panicoid forms (cf. millet) and dentritic elongates and papillae coming from the chaff of cultural grasses (millet, wheat, barley, rye, or oats). We are now undertaking morphometric studies of such phytoliths to determine genera and species involved. The highest proportions of Panicoids in the archaeological samples reach 15%, but only 2% in the modern samples. The highest values of dendritic phytoliths in archaeological samples are 15% vs. 6% in the modern ones. Therefore, high incidence of such forms in paleosamples may suggest heavily altered archaeological contexts absent from the modern samples today. Additional studies are needed of modern-day analogs of the archaeological sites, e.g., barn and house floors, vegetable gardens, or compost dumps.

Conclusions. Modern phytolith assemblages from under natural and slightly disturbed communities of the Middle Volga allow reliable identification of a few types of forest, steppe, meadows, and marsh communities. Modern agricultural analog sites need to be sampled more thoroughly. Archaeological sites have samples that can look very different from most of our modern analog datasets, primarily due to heavy presence of Panicoid and dendritic forms of cultural grasses, uncommon in the modern samples today even from agricultural sites. Thus, we conclude that archaeological samples came from non-analog heavily altered contexts and more attempts should be made to: a) find suitable modern analogs of such contexts today and b) use morphometry to better identify specific taxa of cultured grasses present in the archaeological sites.

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СОВРЕМЕННЫЕ АНАЛОГОВЫЕ СПЕКТРЫ ФИТОЛИТОВ ПОЧВ РАЗЛИЧНЫХ ФИТОЦЕНОЗОВ СРЕДНЕГО ПОВОЛЖЬЯ И ПОТЕНЦИАЛ ИХ ИСПОЛЬЗОВАНИЯ В АРХЕОЛОГИЧЕСКИХ ИССЛЕДОВАНИЯХ

М.С. Блинников, Б.Р. Хоффман, Ю.А. Салова

Статья описывает результаты исследований субрецентных спектров кремниевых фитолитов почв различных фитоценозов региона Среднего Поволжья в Татарстане, Самарской и Ульяновской областей, проведенных в 2017–2020 г.г. Подсчеты морфотипов в 40 образцах указывают на относительно низкий уровень специфичности каждого сообщества по итогам многомерного статистического анализа. Тем не менее, хвойные и смешанные леса могут быть выявлены по присутствию индикаторных форм хвойных деревьев, а степи – по присутствию значительного количества округлых ронделей. Спектры широколиственные лесов отличаются высоким присутствием прямых удлиненных фитолитов и трихом. По сравнению с современными, 10 археологических проб разного возраста из региона содержат значительно большую пропорцию фитолитов культурных злаков и наиболее напоминают степные либо сельскохозяйственные образцы в современных пробах.

Ключевые слова: археология, фитолитный анализ, современные почвы, культурные слои, леса, степи, сельское хозяйство, Татарстан, Самарская область, Ульяновская область.

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Table 1

Sub-recent soil samples and selected archaeological samples used in this study

Sample number / code	Location	Soil type[1]	Vegetation description
1 / SS01	Mouth of Greater Jerusalem Gully: top of left bank; Bolgar site (Middle Ages); 3rd terrace of the Volga River; Tatarstan	18 Light gray pozdolic	Steppe *Festuca valesiaca*-(*Stipa capillata*)
2 / SS02	Mouth of Greater Jerusalem Gully: left bank at archaeology base; Bolgar site (Middle Ages); 3rd terrace of the Volga River; Tatarstan	18 Light gray podzolic	Steppe (*Festuca valesiaca*)-*Stipa capillata*
3 / SS03	Greater Jerusalem Gully: right bank across from the base; Bolgar site (Middle Ages); 3rd terrace of the Volga River; Tatarstan	18 Light gray podzolic	Dry meadow with *Bromopsis inermis*
4 / SS04	Aksubaevo, Aksubaevo district, Tatarstan Low slope of the Kiremet river valley	33 Granular and layered clay and loam floodplain	Wet meadow with *Poa pratensis 50%, Galium odoratum 1%, Taraxacum vulgare 1%, Geranium 1%, Ranunculus, Trifolium, Filipendula, Plantago lanceolata* and other forbs
5 / SS05	Floodplain at Novaya Kiremet 2 site (250-450 CE); left bank of the River Kiremet; Novaya Kiremet village; Tatarstan	33 Granular and layered clay and loam floodplain	Agricultural (wheat field)
6 / SS06	Floodplain at Novaya Kiremet 2 site (250-450 CE); left bank of the River Kiremet; Novaya Kiremet village; Tatarstan	33 Granular and layered clay and loam floodplain	Wet floodplain forest with black alder and willow, *Acer negundo, Carex spp., Urtica, Phragmites, Phalaroides, Agrimonia, Veronica, Equisetum arvense*
7 / SS07	Old meander scar near Novaya Kiremet 2 site (250-450 CE); left bank of the River Kiremet; Novaya Kiremet village; Tatarstan	33 Granular and layered clay and loam floodplain	Wet meadow *Carex hirta, Ranunculus polyanthemus*
8 / SS08	2 km SW of Butaikha village; watershed between the Rivers Temerlik and Bolshaya Sulcha; Tatarstan	16 Gray podzolic	Open deciduous forest with scattered oaks, aspen, lime, maple, hazelnut, *Aegopodium, Dryopteris, Carex pilosa,* чина, звездчатка, ландыш
9 / SS09	2 km SW of Butaikha village; watershed between the Rivers Temerlik and Bolshaya Sulcha; Tatarstan	16 Gray podzolic	Spruce forest (plantation)
10 / SS10	Right bank of the river valley of the Bolshoy Cheremshan; across to the Vishnevaya Polyana village; Tatarstan	33 Granular and layered clay and loam floodplain	Deciduous forest with oak on the 1st terrace of the river with dry meadow below *Poa nemoralis, P. pratensis, Dactylis glomerata*
11 / SS11	Right bank of the river valley of the Bolshoy Cheremshan; across to the Vishnevaya Polyana village; Tatarstan	16 Gray podzolic	Deciduous forest with lime *10%* and maple *50%, Corylus, Euonymus, C. pilosa 50%, Asarum 2%, Anemone, Polygonatum, Stellaria*
12 / SS12	Middle part of the slope of the River Bolshaya Sulcha; Mamykovo village; Tatarstan	16 Gray podzolic	Pine forest *40%,* lime, maple and elm *70%* in the understory, *Cystopteris, Asarum, Convallaria, Chelidonium, Lysimachia* on the floor
13 / SS13	Near Mamykovo site (Late Bronze age), Vishnevka village, Samarskaya oblast	6 Common chernozem	Wet meadow *Poa, Bromopsis, Alopecurus, Equisetum arvense, Rumex, Geranium, Ranunculus*
14 / SS14	Near Mamykovo site (Late Bronze age), Vishnevka village, Samarskaya oblast	6 Common chernozem	Marsh with willows, *Carex* (2 species), *Potentilla argentea, Juncus* spp.

15 / SS15	Above Proletariy hillfort (Early Middle Ages); Bolshoy Cheremshan valley; Sidelkino village; Samarskaya oblast	6 Common chernozem	Oak-maple old-growth forest with hazelnut, *Convallaria, Anemone*
16 / SS16	Near Proletariy hillfort (Early Middle Ages); slope of the Bolshoy Cheremshan River valley; Sidelkino village; Samarskaya oblast	6 Common chernozem	Well-preserved meadow steppe *Stipa pennata, Festuca valesiaca, Salvia, Artemisia, Cirsium*
17 / SS17	Source of the Kiklinka stream; watershed between the Rivers Bolshaya Sulcha and Bolshoy Cheremshan; 5 km SE of Andreevka village; Tatarstan	16 Gray podzolic	Spruce forest 70% cover, ca. 40 years old
18 / SS18	Watershed between the Rivers Bolshaya Sulcha and Malaya Sulcha; Azat village, Tatarstan	12 Brown-gray redzina	Pine forest 40% cover ca. 35 years old, hazelnut and mountain ash 30% cover in understory, various forest grasses 30%, *Chelidonium* 3%, *Urtica* 3%, *Galium*, *Asarum*, *Rubus*, *Fragaria*, sedges
19 / SS19	Upper part of the slope of the Adamka stream valley; Shama village; Tatarstan	13 Dark gray pozdolic	Oak forest with *C. pilosa* on the forest floor
20 / SS20	Upper part of the slope of the Adamka stream valley; Shama village, Tatarstan	13 Dark gray podzolic	Birch-aspen forest with *Aegopodium* and *C. pilosa* on the forest floor
21 / SS21	Slope of the Baranka stream valley; Arbuzov Baran village; Tatarstan	13 Dark gray podzolic	Mixed pine forest with mountain ash and maple, a lot of diverse forest grasses (5 species)
22 / SS22	Vicinity of excavation block #179 in the southern part of the Bolgar site; 3rd terrace of the Volga River; Tatarstan	14 Dark gray light podzolic	Dry meadow with *Poa pratensis* (20%), *F. valesiaca, Carex praecox*, *Euphorbia, Achillea, Veronica, Ranunculus* and other forbs
23 / SS23	Lower part of the slope of the Adamka stream valley; Stary Tatarsky Adam village, Tatarstan	9 Weak leached chernozem	Agricultural (rye field)
24 / SS31	Mizinovo site (300-500; 600-700 CE); 3rd terrace of the Sviyaga River, left bank; Isakovo village; Tatarstan	33 Granular and layered clay and loam floodplain	Oak forest 150+ years, 15-20% crown cover, on the steep left bank of the Sviyaga valley, 10 deg slope. Forbs with *Calamagrostis*, *Dactylis*, *Poa pratensis*, sedges (40%)
25 / SS32	Mizinovo site (300-500; 600-700 CE); 3rd terrace of the Sviyaga River, left bank; Isakovo village; Tatarstan	33 Granular and layered clay and loam floodplain	Pine forest plantation ca. 30 years old, 30% canopy cover, *Calamagrostis* (10%), *Elytrigia, Festuca rubra, Poa pratensis,* forbs
26 / SS33	Burunduki site (Late Bronze age); 3rd terrace of the Sviyaga River, left bank; Burunduki village; Tatarstan	33 Granular and layered clay and loam floodplain	Wheat field with some stray millet
27 / SS34	Burunduki site (Late Bronze age); 3rd terrace of the Sviyaga River, left bank; Burunduki village; Tatarstan	33 Granular and layered clay and loam floodplain	Disturbed and heavily grazed steppe with *F. valesiaca* (25%), *Bromus japonicus*, *Poa annua*, *Cichorium*, *Inula*, *Artemisia vulgaris* and *A. pratense,* nearby *Salvia, Elymus, Nardus*
28 / SS35	Near the Raifa Monastery; 3rd terrace of the Volga River; Tatarstan	24 Strongly podzolic loamy	Lime forest with 50% crown cover, with maple and elm in the understory, some berry shrubs, *Aegopodium* and *C. pilosa* on the forest floor
29 / SS36	Near the Raifa Monastery; 3rd terrace of the Volga River; Tatarstan	24 Strongly podzolic loamy	Birch forest with some maple, and *Aegopodium* and *C. pilosa* on the forest floor with some male and female ferns

30 / SS40	Beganchik site (Upper Paleolithic); 2nd terrace of the Aktay River; Izmeri village; Tatarstan	34 Coarse sandy floodplain	Marsh with cattails and *Glyceria maxima* at the base of the cliff
31 / SS41	Beganchik site (Upper Paleolithic); 2nd terrace of the Aktay River; Izmeri village; Tatarstan	32 Meadow chernozem	Heavily grazed meadow steppe with *Poa angustifolia, Koeleria cristata* and many forbs on top of the cliff
32 / K01	Komarovka archaeological site complex; Komarovka village; Ulyanovskaya oblast	16 Gray podzolic	Maple-aspen mature forest 55 yrs old with *Aegopodium,* some *C. pilosa,* forbs
33 / K02	Komarovka archaeological site complex, Ulyanovskaya oblast	32 Meadow chernozem	Meadow steppe on a gully slope 15 deg. south aspect, *Stipa pennata* 60%, *Bromopsis inermis* 5%, *Poa angustifolia, Festuca valesiaca,* lots of typical steppe forbs
34 / K03	Komarovka archaeological site complex, Ulyanovskaya oblast	32 Meadow chernozem	Dry meadow near steppe 10 deg. south aspect, with *Calamagrostis epigeios* 70%, *Bromus* spp., many steppe forbs
35 / K04	Komarovka archaeological site complex, Ulyanovskaya oblast	32 Meadow chernozem	Dry meadow, 2 deg. south aspect, *F. valesiaca, Poa angustigfolia,* many steppe forbs. Solitary pine nearby
36 / K05	Komarovka archaeological site complex, Ulyanovskaya oblast	16 Gray podzolic	Deciduous forest with mature aspen (>80 yrs old) 30% with some maple, hazelnut and mountain ash in the understory- *C. pilosa* (10% cover) and some forbs ground layer
37 / K06	Komarovka archaeological site complex, Ulyanovskaya oblast	16 Gray podzolic	Deciduous forest near Hillfort 1 on south side of the southern fork in the ravine with maple 40%, lime 5%, oak 5%, *C. pilosa 20%* ground layer
38 / K07	Komarovka archaeological site complex, Ulyanovskaya oblast	16 Gray podzolic	Deciduous forest surrounding an abandoned Russian homestead, disturbed, aspen, apple, bird cherry, *Bromoposis*, *Festuca, Poa,* many ruderal forbs 30% cover (*Urtica, Chenopodium, Rumex, Verbascum, Rubus, Achillea, Knautia*)
39 / K8	Komarovka archaeological site complex, Ulyanovskaya oblast	32 Meadow chernozem	Agricultural (wheat field south of camp 10% cover) with occasional weeds (*Avena fatua, Chicorium, Hieracium, Chenopodium, Berteroa, Myosotis*)
40 / K9	Komarovka archaeological site complex, Ulyanovskaya oblast	33 Granular and layered clay and loam floodplain	Wet meadow on the 1st terrace at camp. *Calamagrostis epigeios* 70%, *Bromopsis 3%*, *Dactylis* 3%, *Phleum, Geranium pratense, Agrimonia, Fragaria, Phlomis, Linaria*

Code of soil unit on the Soils of Tatarstan map (1935). Почвенная карта Татарской А.С.С. Республики. Составлена Управлением землеустройства мелиорации и торфа НКЗ ТР по материалам почвенных экспедиций : КГУ - 1929 г., Т.Н.-И. Э. Ин-та - 1930 г., Госземтреста НКЗ ТР - 1931-32 гг. http://www.etomesto.ru/map-kazan_1935-pochva/

Table 2

Phytolith morphotype frequencies from sub-recent soils and archaeological samples in the Middle Volga region

Sample	VegType	PLA PSIL	RON	RON PHRAG	TRZ OBL	TRZ BIL	PANIC	SAD	CRE	ELO ENT	ELO CURV	ELO DET	ELO DEN	PAP
SS1	Ste	6.7	6.6	0	3.3	0	0	3.3	10	26.7	0	16.7	0	0
SS2	Ste	14.5	28.2	0	0.8	4.8	0	0.8	10.5	9.7	0.8	4	2.4	0
SS16	Ste	2.5	14.9	0	0.8	9.9	0	5	5.8	3.3	0	2.5	1.7	5
SS34	Ste	8.6	22.9	0	0.7	3.6	0	0	12.1	20.7	0	2.9	2.9	0
SS41	Ste	7.9	28.9	0	2.6	2.6	0	5.3	13.2	10.5	5.3	5.3	0	0
K2	Ste	5.5	30.5	0	3	3.5	0	0	8.5	16.5	1.5	4	0	1.5
SS3	DryMea	23.4	4.7	0	0.9	1.9	0	0	14.9	11.2	0	1.9	2.8	2.8
SS22	DryMea	7.1	6.3	0	0	2.7	0	0	14.3	8.9	0	0	0.9	2.7
K3	DryMea	2.5	16	0	0	3.5	0	1	9	23	1	6	2	1
K4	DryMea	5	22.5	0	0.5	4.5	1	0	7.5	16	1	2.5	0	0.5
SS5	Ag	12	10	0	6	0	0	0	4	0	0	0	2	10
SS23	Ag	4.4	5.9	0	2.9	0	0	0	14.7	13.2	0	0	1.5	11.8
K7	Ag	5	32.5	0	5.5	1.5	0	0.5	10.5	10	1.5	2	1	0.5
K8	Ag	5	15.5	0	1.5	2.5	2	0	11.5	15.5	0.5	0.5	0.5	3.5
SS4	WetMea	3.3	13.4	0	1.7	3.3	0	0	11.7	15	0	5	3.3	0
SS6	WetFor	3.8	1.3	0	0	0	0	0	2.5	1.3	0	0	0	0
SS7	WetMea	10	2	0	0	4	0	0	6	12	0	0	0	0
SS13	Wetmea	4.2	14.1	0	9.2	3.3	0	0	26.6	18.3	0.8	1.7	0	0
K9	WetMea	1.5	22.5	3.5	0.5	3.5	1.5	0	17	5.5	0	4.5	1.5	0
BI1	WetMea	5.6	34.4	0	0.8	1.6	0	0	12	8	0	7.2	5.6	1.6
SS14	Marsh	4	6	0	2	2	0	0	18	16	2	4	0	0
SS40	Marsh	7.5	8.8	1.3	1.3	8.8	0	0	8.8	10	0	1.3	2.5	0
SS8	DecFor	3	5	0	2	0	1	0	11	2	0	0	0	0
SS10	DecFor	1	16	0	0	0	0	0	16	4	0	0	0	0
SS11	DecFor	11	2	0	0	1	1	0	11	17	1	1	0	0
SS15	DecFor	6.4	5.4	0	0	2.7	1.8	0	11.8	10	4.5	3.6	2.7	0
SS19	DecFor	5	9	0	2	6	0	0	21	17	1	3	0	0
SS20	DecFor	2	5	0	1	4	0	0	19	23	0	5	1	0
SS31	DecFor	8.3	9.2	0	0.8	3.3	0	0	12.5	15.8	0	3.3	0.8	0
SS35	DecFor	3.3	0.8	0	0	6.7	0	0	7.5	17.5	0	0.8	0	0
SS36	DecFor	2.7	1.8	0	0.9	7.3	0	0.9	11.8	15.5	0.9	0	0	0
K1	DecFor	4.5	10	0	0	7.5	0.5	0	8.5	15.5	2	2	0.5	0
K5	DecFor	5.5	9	0	1	4	0	0	9	23	0.5	2.5	0	0
K6	DecFor	5	8	0	1	5	0.5	0	8	20.5	0.5	6	0.5	0
U1	DecFor	18.8	0	0	0	0	0	0	3.1	0	0	0	0	0
SS9	ConFor	5.6	11.1	0	0.9	4.6	0	0	23.2	8.3	1.9	0.9	0.9	0
SS12	MixFor	6.7	3.3	0	0	5	0	0	25	15.8	1.7	0	0	0
SS17	ConFor	2.7	5.4	0	0.9	0.9	5.4	0	7.2	6.3	0	0	0	0
SS18	MixFor	4.8	11.4	0	1	4.8	0	0	21.1	3.8	0	0	0	0
SS21	MixFor	4	18	0	0	3	0	0	13	2	0	2	0	0
SS32	MixFor	6.7	14.2	0	0	2.5	0	0	20.8	11.7	0	2.5	0	0
ALG1	Andr	3	7	0	1	2	0	0	21	13	2	7	5	1
Bo3-5	Imenk	9	18.5	0	0	0	3	0	0	15.5	0	0	6	6
Bo4-B1	Imenk	14.1	6.9	0	0	0	14.7	0.5	14.2	13.7	2.5	2.5	2.9	0
Bo4-B10	Ord	13.5	2.4	0	0	1.2	3.5	0	4.7	12.8	1.2	2.3	12.8	5.8
BO18-1	Rus	6.8	14.8	0	0	1.1	1.1	0	15.9	6.8	0	6.8	14.8	0
BO18-3	Kaz	0	2.1	0	0	6.3	2.1	0	14.6	8.3	1	1	1	0
BO18-9	Ord	2.8	1.9	0	0	2.8	3.7	0	7.4	10.2	0	4.6	5.6	0
BO18-12	Ord	4.3	3.2	0	1.1	3.2	2.2	0	23.7	9.7	1.1	3.2	5.4	0
BO18-14	Bolg	2.6	2.6	0	0	4.4	1.8	0	12.4	12.5	0	3.5	4.5	0
BO18-16	preImenk	7.7	2	0	0	4.8	13.5	0	9.6	8.6	0.9	0.9	10.6	0

PLA_PSIL – psillate plates, RON – rondels, RON_PHRAG – saddle top rondel (cf. Phragmites), TRZ_OBL – trapeziform oblong, TRZ_BIL – trapeziform bilobate (cf. Stipa type), PANIC – Panicoid suite (true bilobates, crosses, polylobate), SAD – saddle, CRE – crenate (wavy), ELO_ENT – elongate entire, ELO_CURV – elongate curved, ELO_DET – elongate dentate, PAP – papillae,

Sample	VegType	CYL PSIL	CON CAREX	ACU BUL	HAIR	TRA ANN	BUL	EPID JIGSAW	EPID POLYG	PERF AST	DROP PINE	BLO CON	TRA PIT	BLO
SS1	Ste	6.7	0	16.6	0	0	0	0	3.3	0	0	0	0	0
SS2	Ste	0.8	0	8.9	0	0	2.4	0.8	1.6	0	0	0	0	8.9
SS16	Ste	0	0	5	0	2.5	3.3	0	19.8	0.8	0	0	0	14.9
SS34	Ste	0	0	7.9	4.3	0	0.7	0	12.1	0	0	0	0	0
SS41	Ste	7.9	0	7.9	0	0	2.6	0	0	0	0	0	0	0
K2	Ste	3.5	0	9.5	2.5	0	0	2	4.5	0.5	0	0	0	1
SS3	DryMea	10.3	4.7	3.7	0.9	0	0.9	0	9.3	0	0	0	0	2.8
SS22	DryMea	0.9	17.9	3.6	3.6	3.6	0	2.7	19.6	0	0	0	0	3.6
K3	DryMea	8	0	17	5	0.5	1.5	1	0.5	0	0	0	0	1.5
K4	DryMea	7	0	13.5	5	2	1	2.5	6	0.5	0	0	0	0.5
SS5	Ag	0	0	20	2	0	0	0	24	0	0	0	0	10
SS23	Ag	0	0	19.1	11.7	1.5	0	0	2.9	0	0	1.5	0	7.4
K7	Ag	7.5	0	7.5	3	0.5	3	1.5	5	0	0	0	0	0
K8	Ag	3.5	0	19	8.5	1	1.5	0	5	0	0	0	0	2.5
SS4	WetMea	5	13.3	6.7	5	1.7	3.3	5	3.3	0	0	0	0	0
SS6	WetFor	1.3	5	5	6.4	0	3.8	25	45	0	0	0	0	0
SS7	WetMea	0	4	6	6	4	4	0	40	0	0	0	0	2
SS13	Wetmea	4.2	2.5	3.4	0	0	0	2.5	8.3	0	0	0	0	0
K9	WetMea	3	2.5	15.5	3	2.5	4.5	2.5	1	0	0	0	0	3.5
BI1	WetMea	9.6	0	2.4	4	0.8	0.8	3.2	2.4	0	0	0	0	0
SS14	Marsh	4	28	10	0	2	0	0	2	0	0	0	0	0
SS40	Marsh	5	13.8	13.8	0	0	2.6	5	6.3	0	0	0	0	1.3
SS8	DecFor	0	38	9	0	0	0	11	17	0	0	0	0	1
SS10	DecFor	0	7	2	0	0	1	1	42	0	0	0	0	10
SS11	DecFor	9	15	10	2	2	1	7	5	0	0	0	0	3
SS15	DecFor	1.8	0	20	1.8	0	0	0.9	13.6	0	0	0.9	0	7.3
SS19	DecFor	0	5	16	4	3	2	0	5	0	0	0	0	1
SS20	DecFor	4	9	11	3	0	1	1	10	0	0	0	0	1
SS31	DecFor	0	2.5	20.8	0	0.8	0.8	5	5	0	3.3	0.8	0	3.3
SS35	DecFor	2.5	1.7	27.5	2.5	0	2.5	4.2	11.7	0	0	0	0	7.5
SS36	DecFor	2.7	5.5	35.4	1.8	0	0.9	3.6	5.5	0	0	0	0	0
K1	DecFor	1	3.5	34	4.5	0	0	1.5	1.5	0	0	0	0	3
K5	DecFor	2	2	25	3.5	0	1.5	4	3	0	0	0	0	4.5
K6	DecFor	3	7	20	5.5	0.5	1.5	2.5	3	0	0	0	0	2
U1	DecFor	0	43.8	0	9.4	3.1	0	0	15.6	0	0	0	0	6.3
SS9	ConFor	0	15.7	8.3	0	0	0	1.9	4.6	0	0	4.6	0.9	5.6
SS12	MixFor	0	7.5	23.4	0.8	0	0.8	0	6.7	0	0	0	0	3.3
SS17	ConFor	0.9	1.8	23.3	3.6	0.9	0	1.8	3.6	0	0	14.3	5.4	16.1
SS18	MixFor	1.9	16.3	6.7	5.8	0	1.9	5.8	6.7	0	0	2.9	1	1.9
SS21	MixFor	0	0	2	0	1	1	1	8	0	24	6	4	6
SS32	MixFor	3.3	4.2	2.5	0.8	0	0	0.8	10.8	0.8	5.8	8.3	0	3.3
ALG1	Andr	0	0	23	8	0	2	2	2	0	0	0	0	0
Bo3-5	Imenk	6	0	15	0	0	0	0	12	0	0	3	3	3
Bo4-B1	Imenk	0	0	20.6	0.5	0	0.5	2	4.4	0	0	0	0	0
Bo4-B10	Ord	8.1	0	5.9	8.2	1.2	1.2	0	4.7	0	0	0	7	3.5
BO18-1	Rus	8	0	4.5	1.1	0	0	1.1	8	0	2.3	2.3	0	2.3
BO18-3	Kaz	0	2.1	39.6	13.5	0	2.1	0	0	0	1	0	0	5.2
BO18-9	Ord	0	1.9	45.4	9.3	0	0	0.9	0.9	0	0	0	1.9	0.9
BO18-12	Ord	4.3	1.1	26.9	4.3	0	1.1	1.1	1.1	0	0	0	0	3.2
BO18-14	Bolg	1.8	0	33.5	12.5	0.9	2.6	2.6	0	0	0	0	0	1.8
BO18-16	preImenk	0.9	0	21.2	8.6	0	0	0.9	7.7	0	0	0	0	2

CYL_PSIL – cylindrical psilate, CON_CAREX – conical Carex, ACU_BULB – acute bulbosus, HAIR – silicified microhairs, TRA_ANN – annular tracheids, BUL – bulliform (both parallelpiped and fan-shaped), EPID_JIGSAW – dicot epidermal jigsaw, EPID_POLYG – dicot epidermal polygonal, PERF_AST – perforated Asteraceae, DROP_PINE – Pinus type drop shaped, BLO_CON – conifer ornamented blocky, TRA_PIT – conifer pitted tracheids, BLO – irregular blocky (‘gobbets’).