Phytolith research in the South of Western Siberia

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The research of modern and fossil soils was conducted at three archaeological sites: Nizhniy Kayancha, Novoilinka-3, and Tytkesken-2. Nizhniy Kayancha is a burial ground (dated 5th century BC) situated on the left bank of the Katun River (400-700 m above sea level). An archaeological site is a burial mound with seven mounds which can be visually separated within the site, and which are placed by small chains with 2–3 objects. The south mound of the first group was examined for a phytolith analysis. Ehe Novoilinka-3 settlement (dated 3rd millennium BC) is situated in the north of Kulunda, in the southern part of a hill formed by the false River Burla. The Tytkesken-2 settlement is situated on the verge of the stream Tytkesken, the left tributary of the Katun River, on its second terrace above the flood plain.

Geobotanical research was conducted in the territory of the archaeological sites under study. Grass phytoliths of modern flora were examined. Soil samples from different layers of the walls of excavation sites were collected. Phytolith extraction was based on the methods described by A.A. Golyeva. 20 g of soil, and 100 g of plant material of each species were processed during the initial period. The examination of the phytoliths of leaves, stalks and flower heads from the samples obtained from the plant material was carried out with the help of an optical microscope (Olympus BX-51). The phytoliths were counted to 250 (in ashed plants) and to 300 (in soils) particles.

More mesophytic plant communities of the ancient epochs have been reconstructed for all three examined archaeological sites. The territory of the Nizhniy Kayancha burial ground was covered by birch forest at the time prior to formation of the archaeological site. The territory of Novoilinka-3 settlement was covered by pine and birch steppificated forest in the Eneolithic period, but the territory was deforested as the settlement developed. Several stages of vegetation change have been reconstructed for the Tytkesken-2 archaeological site. This includes deforestation of pine forest and further steppe formation in the late Neolithic Age, prairiefication in the Eneolithic Age and new steppe formation in the Bronze Age up to the present time.

Keywords: phytolith, grasses, Neolith, Eneolith, Scythian period.

Introduction

Phytolith analysis is a promising and progressive method used for the reconstruction of the environment in palaeogeography, palaeoecology and archaeology.

The phytoliths of different plant taxa are of diverse specificity. Some phytolith morphotypes of *Poaceae, Pinaceae, Ericaceae, Arecaceae, Asteraceae* (Hodson et al., 1997; Golyeva, 2001; Carnelli et al., 2004; Torn, 2004) are unique. The phytoliths of grasses are especially specific (Lu, Liu, 2003). These specific features are observed at the level of subfamilies (Twiss et al., 1969; Lu, Liu, 2003), some genera (Rosen, 1992; Ball et. al., 1999; Golyeva, 2001) and various ecological groups (Golyeva, 2001; Bremond et al., 2005). The grasses with unlike methods of photosynthesis (C-3 and C-4 grasses) (Twiss, 1992; Fredlund, Tieszen, 1994; Bremond et al., 2008) vary as well. The particular features of grass phytoliths determine their significance during the paleoreconstructions in the territories where these plants can form coenosis, namely the south territory of Western Siberia.

Phytolith research in the south of Western Siberia has been conducted by different research teams since 2010 and this research is highly informative for modern and fossil soil analysis (Kiryushin et al., 2012; 2013).

Different morphotypes of grass phytoliths are important diagnostic factors in soil analysis due to their ecological-phytocenotic specificity. The phytoliths of more than 50 species of aboriginal and cultivated grasses of plain and mountainous areas of the Altai region and the Republic of Altai were examined in the period of 2012–2015 (Silantyeva et al., 2013; Speranskaja, Grebennikova, 2013; Speranskaja et al., 2014).

Material and Methods

The research of modern and fossil soils was conducted at three archaeological sites: Nizhniy Kayancha, Novoilinka-3, and Tytkesken-2 (Fig. 1).
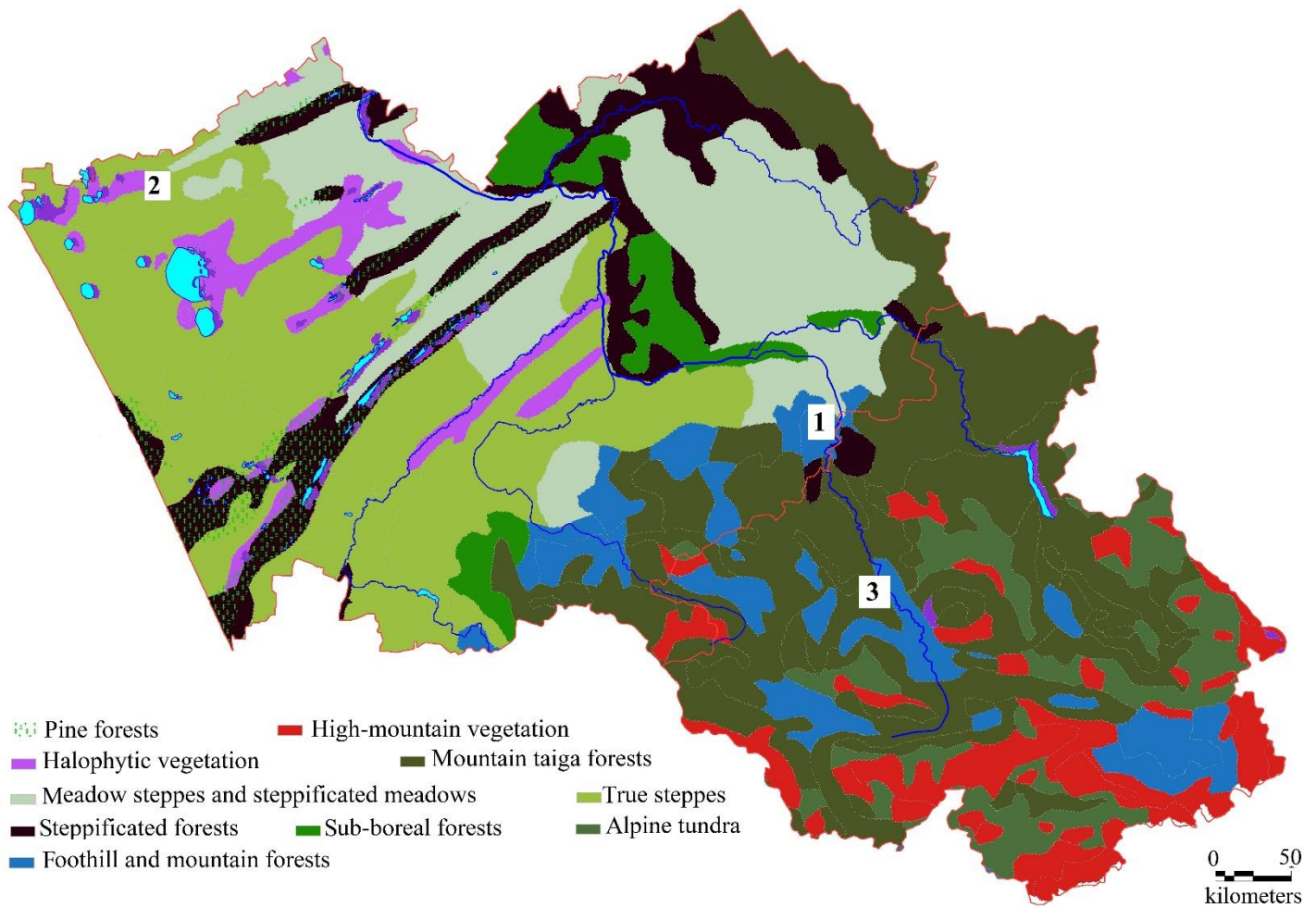

Fig. 1. The vegetation map of the Altai region and the Altai Republic.

Nizhniy Kayancha is a burial ground (dated 5th century BC) situated on the left bank of the Katun River (400-700 m above sea level). An archaeological site is a burial mound with seven mounds which can be visually separated within the site, and which are placed by small chains with 2–3 objects. Archaeological material of the graves is various: quiver hooks, arrowheads, all-metal knife, bronze pin (Tishkin et al., 2011). The south mound of the first group was examined for a phytolith analysis. According to phytogeographical demarcation the research territory lies within the Altai forest steppe area of Nothern Altai (Ogureyeva, 1980).

The Novoilinka-3 settlement (dated 3rd millennium BC) is situated in the north of Kulunda, in the southern part of a hill formed by the false River Burla. Various findings of the Eneolithic ceramics including a great number of horse bones were found in the territory of the site; along with the traces of ancient fire pits and economic facilities (Kiryushin et al., 2011). Due to phytogeographical demarcation, the research territory is a part of the secondary steppe district of Western Siberian Lowland steppes. (Kuminova et al., 1963).

The Tytkesken-2 settlement is situated on the verge of the stream Tytkesken, the left tributary of the Katun River, on its second terrace above the flood plain. Dwellings and fire pits were found within the research site (Kiryushin, 2004). Archaeological material is various: from pottery to working and hunting tools. Regards the phytogeographical demarcation this territory lies within the Chemal taiga forest steppe area of Northern Altai (Ogureyeva, 1980). Phytolith analysis of cultivated soil layers of this site beginning from the late Neolithic was carried out (Srednekatunskaya culture – 4th millennium BC) (Kiryushin, 2004).

The data on paleoclimate of the south of Western Siberia are crucial for the analysis of the obtained results. Climatic optimum of the Holocene is the Atlantic period (4500-8000 yr BP). Spruce and birch forests were typical of Siberian forest zone at that time, however, steppe communities predominated on the plains in the second part of the Atlantic period (5500-6000 yr BP) (Volkova, Levina, 1985; Nenasheva et al., 2006).

Subboreal and Subatlantic periods (the last 4500 years) are characterized as more or less homogeneous stages relating to the changes of the environment. At the same time, if an immense swamp formation was characteristic of the early Subboreal; its xerothermic stage was marked by aridization of climate, steppe formation of grassland communities and loss of forest communities. All of this led to the conglomeration of the ancient cattle rearing population in the flood beds of big rivers and thus to discernible pasture degradation (Nikolayev, 1999).

Geobotanical research was conducted in the territory of the archaeological sites under study. Grass phytoliths of modern flora were examined. Soil samples from different layers of the walls of excavation sites were collected. Phytolith extraction was based on the methods described by A.A. Golyeva (2001). 20 g of soil and 100 g of plant material of each species were processed during the initial period. The examination of the phytoliths of leaves, stalks, and flower heads from the samples obtained from the plant material was carried out with the help of an optical microscope *Olympus BX-51*. The phytoliths were counted to 250 (in ashed plants) and to 300 (in soils) particles.

Classification of phytolith spectrums and interpretation of their results is based on A.A. Golyeva's approach outlining three groups of phytoliths:

1. Shapes typical for many phytocoenosis (globular shapes, plates, long cells), differing only in proportion.
2. Shapes occurring within some phytocoenosis but in different amounts.
3. Shapes indicating one certain phytocoenose – "signal shapes" (Golyeva, 2001).

While examining plant and soil phytoliths the latter two groups were subject to more detailed study relying on methodical results obtained before (Silantyeva et al., 2013; Speranskaja et al., 2014; Speranskaja et al., 2013).

Results and Discussion

Results of geobotanical research and phytoliths study of modern grasses and conifers (Table 1, Fig. 2, Fig. 4). In total, 22 species of grasses and one species of *Pinaceae* were examined in the territory of three archaeological sites.

Table 1. Frequency index of different morphotypes of grass phytoliths characteristic of modern species at the research sites.

Species	Morphotype frequency, %								Ecological group[4]	Life-form[5]
	1*	2	3	4	5	6	7	8		
Agropyron desertorum[3]**	12		20	8		1			X	L-S
Agrostis gigantea[1,2,3]	7	40	1	5		1	12	7	M-H	L-S
Agrostis vinealis[2]	6	47	14	4			10	1	X-M	L-S
Bromopsis inermis[3]	10	19	8	7			15	1	M	L-R
Calamagrostis epigeios[2,3]	1	53	3				22	3	M-X	L-R
Dactylis glomerata[1,3]	6	35	4				19	1	M	L-S
Elymus exelsus[2,3]	17		3	32		2	8		X-M	L-S
Elymus gmelinii[3]	31		20	30	4	1	4		M-X	L-S
Elytrigia repens[3]	10		2	17	13		26		M	L-R
Festuca pratensis[1,3]	25	6	6	32	1		7		M	L-S
Festuca pseudovina[2,3]	40	6	10	21	1	2			M-X	D-S
Koeleria gracilis[3]	14	2	32	12			4		X	D-S
Koeleria cristata[2]	12		37	4	1		3		X	D-S
Leymus angustus[2]	12		14	27	2		6		X	L-S
Leymus dasystachys[3]	41		2	35		5	3		X	L-S
Poa pratensis[3]	12	2	8	4	22		12		M	L-R
Poa stepposa[3]	23		6	15	18		2		X	D-S
Phleum pratense[1,3]		34	18				22		M	L-S
Setaria viridis[2]	1	3	4	2			18	52	M	A
Stipa capillata[3]	12			69		6	3	5	X	D-S
Stipa korshinskyi[2]	32			29	1	7	4	2	M-X	D-S
Stipa pennata[2,3]	24			30			12	13	M-X	D-S

* Column numbers in the table indicate: 1 – trapeziform short cells; 2 - trapeziform polylobates; 3 - trapeziform sinuates; 4 – rondels; 5 – papillae; 6 – saddles; 7 – trichomes; 8 – Stipa-bilobate short cells;

**Numbers within parentheses indicate: [1] – species growing at the site of Nizhniy Kayancha burial ground; [2] – species growing at the site of Novoilinka-3 settlement, [3] – species growing at the site of Tytkesken – 2 settlement

Ecological group[4]: (X) – xerophyte; (M-X) – meso-xerophyte; (M) – mesophyte; (X-M) – xero-mesophy; (M-H) – meso-hygrophyte.
Life-form[5] (Serebryakov, 1964): (L-S) – luss-sod grasses; (D-S) – dense-sod grasses; (L-R) – long-rootstock grasses; (A) – annual grasses.

Geobotanical description.

Before the excavation works the Nizhniy Kayancha burial ground was a pastured meadow covered by *Dactylis glomerata, Phleum pretense, Festuca pratensis.* The area around the Novoilinka-3 settlement consists of steppe zones with *Elymus exelsus, Festuca pseudovina, Artemisia frigid,* steppe zones with *Stipa pennata, Festuca pseudovina, Carex duriuscula,* and an alkaline meadow zone is found to the north of the excavation site. Novoilinka-3 is located 500 meters from the birch-pine forest (*Betula pendula* and *Pinus silvestris*). Grass meadows rich in forbs are spread across Tytkesken–2 from the excavation site towards the bottom of the mountain. The terrace separating the excavation site from the bank of the Katun River is steppe covered by *Festuca pseudovina, Artemisia gmelinii* and *Koeleria gracilis*. Forests with *Pinus silvestris* is located on shoulders of mountains.
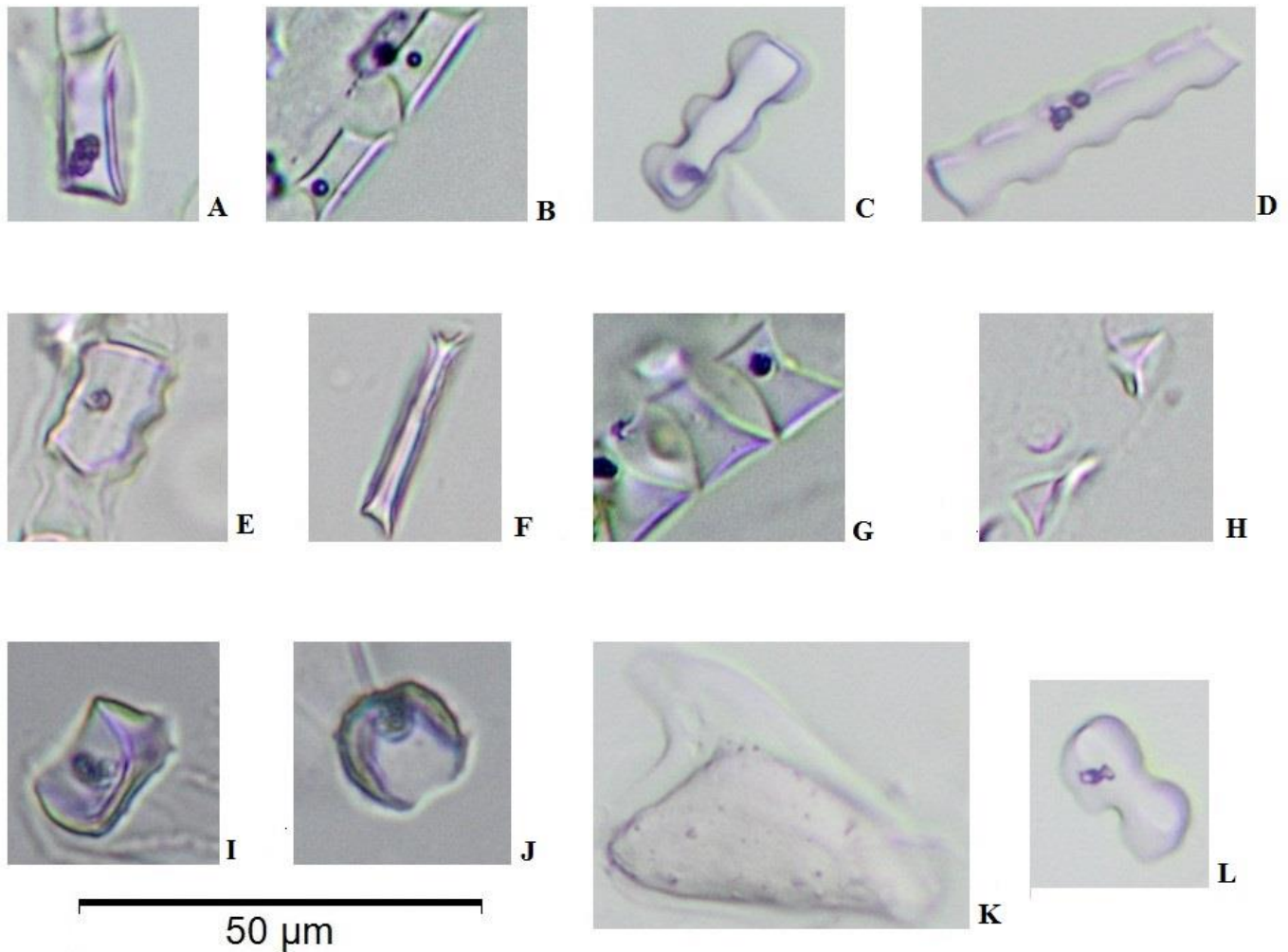
Fig. 2. Types of diagnostic phytoliths of grasses: A, B – trapeziform short cells; C – trapeziform polylobarte, top view; D – trapeziform polylobate, bottom view; E – trapeziform sinuate, top view; F – trapeziform sinuate, side-view; G – rondel; H – papillae; I, J – saddles; K – trichome; L – Stipa-bilobate short cell.

Ecological specificity of types.

Based on the analysis of flora with ecological-phytocenotic features of the grass species (Silantyeva, Yelesova, 2014), the phytoliths of plants that were examined can be divided into the following groups: phytoliths of steppe grasses, phytoliths of meadow and forest grasses, and, phytoliths whose importance for reconstruction is not identified. The differences between the grasses of forests, meadows and steppes appear in their life-forms. True steppe is characterized by dominant dense-sod grasses (*Festuca pseudovina, Koeleria gracilis*) over all other groups; the proportion of luss-sod (*Elymus gmelinii, Dactylis glomerata*) and rootstock species of grasses (*Bromopsis inermis, Calamagrostis epigeios*) rise during the prairiefication. Rootstock grasses prevail in meadows and forests with noticeable field stratum. It is also worth noting that the field stratum in forests can be steppificated as well from high human-induced impact. Table 1 represents the difference in the phytoliths of various life-forms and ecological assemblages.

Trapeziform short cells (Fig. 1A, B), rondels (Fig. 1G), saddles (Fig. 1I, J) refer to phytoliths of steppe grasses. The particles of this type are also marked (by A.A. Golyeva) as indicators of steppe phytocoenosis (Fig. 3D-F). However, for some species of grasses the presence of similar types is determined by generic attribute rather than ecological nature (e.g. *Festuca pratensis*). This group also includes trapeziform sinuates (Fig. 1E, F) since the grasses growing at the sites of research and producing this morphotype as the dominant one, refer to xerophytes (Table 1).

Trichomes (Fig. 1K), trapeziform polylobates (Fig. 1C, D) and bilobate short cells refer to phytoliths of forest and meadow grasses (Speranskaja et al., 2013). Bilobate short cells are still produced by the grasses of *Panicoideae* subfamily, which are represented by cultivated and ruderal species in modern flora of the south of Western Siberia. Trichomes are common in species with different ecology, however, it should be noted that they are more typical of rootstock forest and meadow grasses (Table 1). This conclusion is in accordance with A.A. Golyeva's results on the European territory of Russia. Rootstock grasses are marked by large trichomes often with aristate spurs, which is also confirmed by the research done by Carnelli with coauthors (Carnelli et al., 2004). It is worth noting that the study of the soils of different phytocoenoses in the south of Western Siberia shows that the quantity of trichomes in meadow and forest communities also succeeds the quantities in steppe associations (Fig. 3).
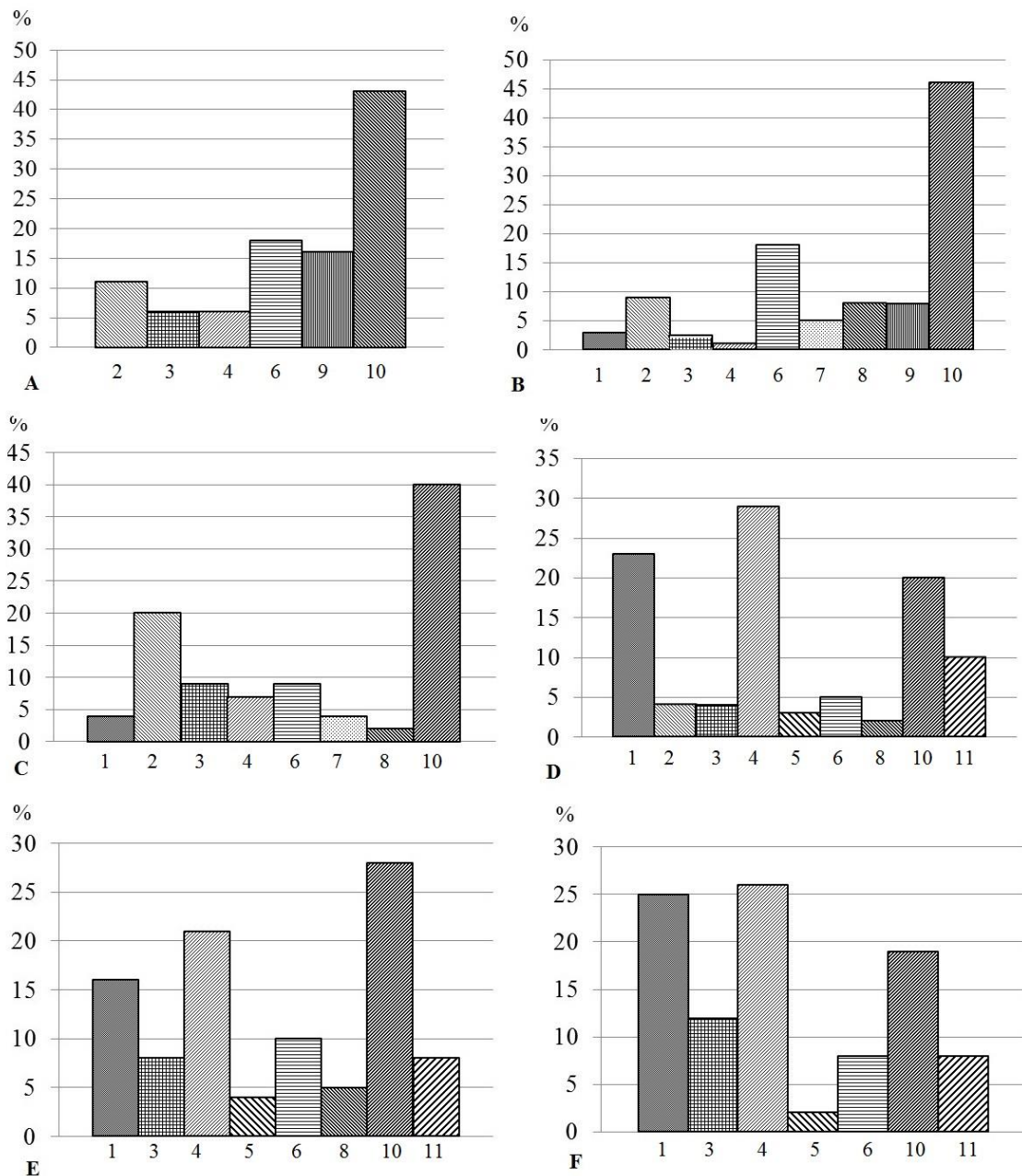
Fig. 3. Phytolith spectra of modern soils of the phytocoenoses in the south of Western Siberia: A – larch-pine forest, B – pine-birch forest, C – Floodplain herb-grasses meadow, D – steppe with *Stipa pennata, Festuca pseudivina, Carex duriuscula*, E – steppe with *Stipa capillata, Festuca pseudivina, Artemisia frigida*, F – steppe with *Festuca pseudivina, Artemisia frigida*; 1 – trapeziform short cells, 2 – trapeziform polylobates, 3 – trapeziform sinuates, 4 – rondels, 5 – saddles, 6 – trichomes, 7 – bilobate short cells, 8 – Stipa-bilobate short cells, 9 – Conifer phytoliths, 10 – long cells, 11 – Other forms.

Stipa-type bilobate short cells (Fig. 1L) are placed in one group as they occur within the species of *Pooideae*, which refer to either steppe (*Stipa capillata, Stipa pennata*) or meadow (*Agrostis gigantean, Calamagrostis epigeios*) species of grasses.

Papillae refer to morphotypes whose ecological specificity for the south of Western Siberia is not identified. However, this type is not characteristic of the soil in the examined samples, therefore it may not be considered for the reconstruction of the palaeocommunity.

All examined species of grasses are marked by different shapes of long cells, and some of these shapes are also characteristic of forbs (*Artemisia laciniata, Centaurea scabiosa*). This suggests that the increase of elongated particles in phytolith spectrums may indicate an increasingly important role of forbs in communities during the paleoreconstruction.

Blocky polyhedron transfusion cells, often pitted, are specific phytolith morphotype for *Pinus silvestris*, which is described for *Pinaceae* by many research workers (Hodson et al., 1997). It should be noted that conifers produce far less phytoliths than grasses, and the proportion of specific forms further used for reconstruction is often small. For example, A.L. Carnelli with coauthors point out that for *Pinus* species found in the European Alps the proportion of these particles in acerose leaves amounts from 0.2% (*Pinus cembra*) to 71% (*Pinus mugo*) (Carnelli et al., 2004). After examining the *Pinus silvestris* we found out that the proportion of this phytolith morphotype in acerose leaves is 23% (Fig. 4). The study of the phytolith spectra of some soils under the forests including conifers in the south of Western Siberia shows an insignificant proportion of blocky polyhedron transfusion cells of conifers (Fig. 3).
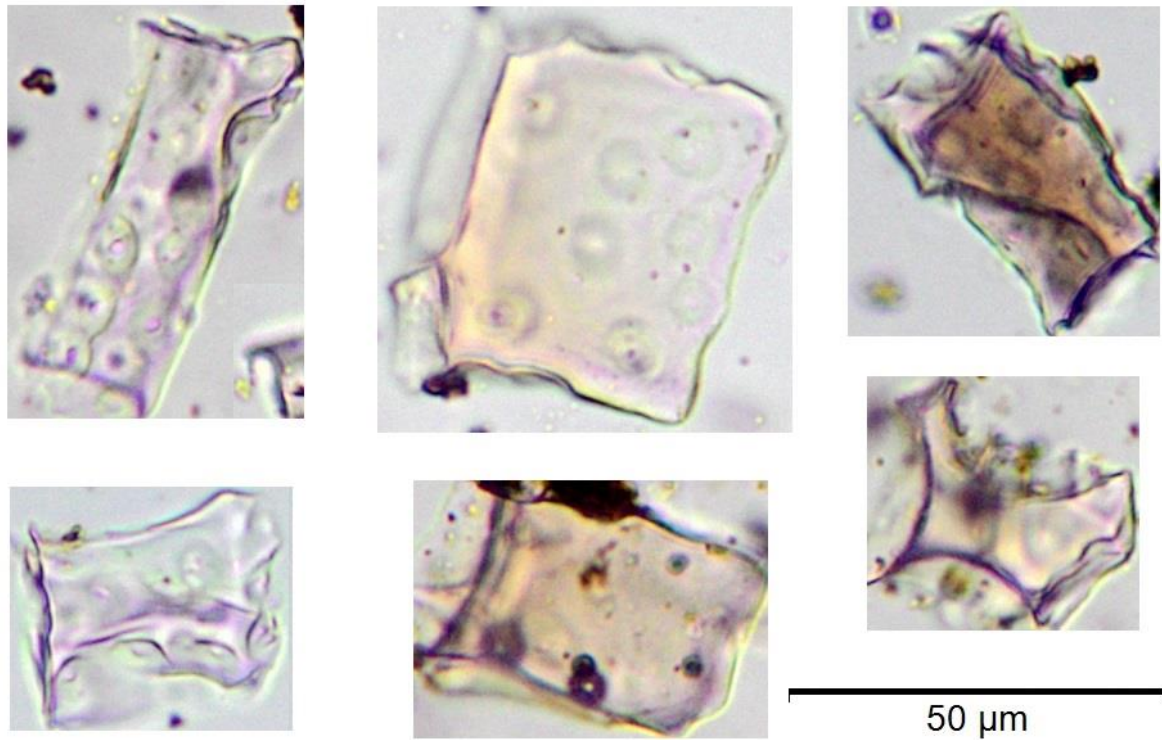
Fig. 4. Conifer phytoliths from acerose leaves of Pinus silvestris

Therefore, it should be assumed that even an insignificant proportion of conifer phytoliths is indicative of a forest formation of the reconstructed vegetation.

Results of phytolith research of the archaeological sites.

Results of phytolith analysis of the Nizhniy Kayancha burial ground.
The depth of soil (58 – 63 cm) conforms to the ancient surface existent at the time of burial (Fig. 5). The bank of the burial mound is 0–65cm above. Phytolith spectrums of different depths of the soil cross sections of the burial mound differ only in shape. The amount of phytoliths of steppe grasses (Fig. 6) slightly decreases in deeper soil cross sections. This suggests that a more mesophytic community existed in this area in the period of the Scythian-Saxon culture. This territory was possibly covered by birch forest. The specific nature of the lower layer of the phytolith cross section, which is marked by the lower amount of steppe types of phytoliths, proves this fact.
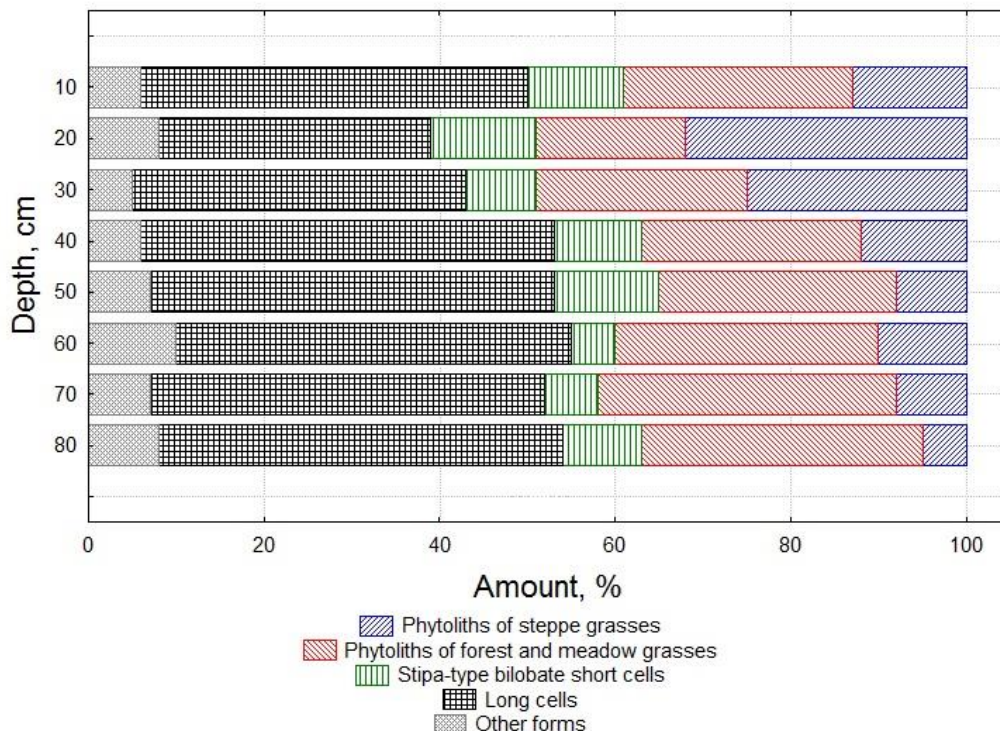

Fig. 5. Phytolith cross section of the wall of Nizhniy Kayancha burial ground.
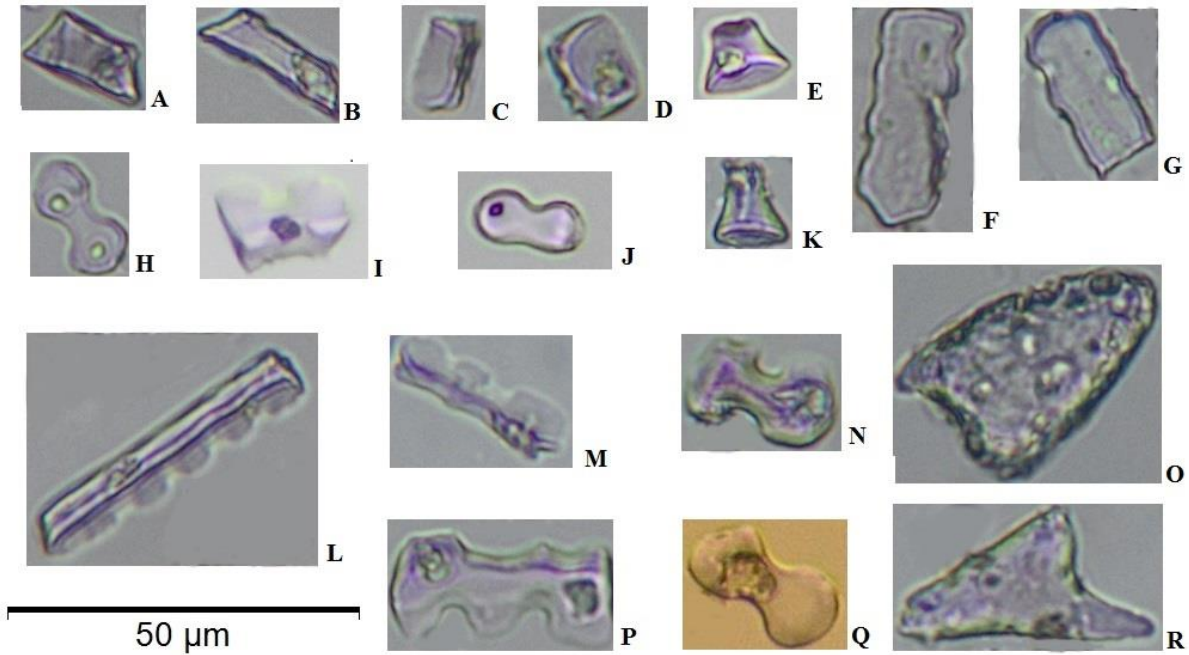
Fig. 6. Diagnostic morphotypes of grass phytoliths in ancient soils: A, B – trapeziform short cells, C, D – saddles, E, K – rondels, F, G – trapeziform sinuates, H-J – Stipa-bilobate short cells, L, M, P – trapeziform polylobates, N, Q – bilobate short cells, O, R – trichomes.

Besides phytoliths the soil is scarce in other fossils. However, the burial mound has the remains of wood used in the production of quiver and arrows.

Results of phytolith research of Novoilinka-3 settlement.
Phytoliths are found at up to 65 cm depth of the soil cross section (Fig. 7). The bones of horses horizontally occurred are found at a depth of 55–60 cm, therefore a 60–65 cm layer is considered as the top horizon of the ancient soil. Upper phytolith spectrums ranging from 0 to 30 cm are typically steppe. Conifer phytoliths (Fig. 8), the amount of which increases with depth, rarely occurs at a depth of 10–30 cm. The representation of the morphotypes of steppe grasses (Fig. 6) goes down starting from the depth of 40 cm except for the soil spectrum at a depth of 55–60 cm. The phytolith spectrum at the 60- 65 cm layer conforms to a more mesophytic community. The amount of conifer phytoliths suggests that the territory of the existent settlement was covered by forest at that time. Yet the considerable amount of steppe grass phytoliths indicates the sparsity of the tree layer. Therefore, sparse forest possibly consisting of pine and birch, with a steppificated herbage cover was characteristic of the territory of this settlement during the Eneolithic Age.
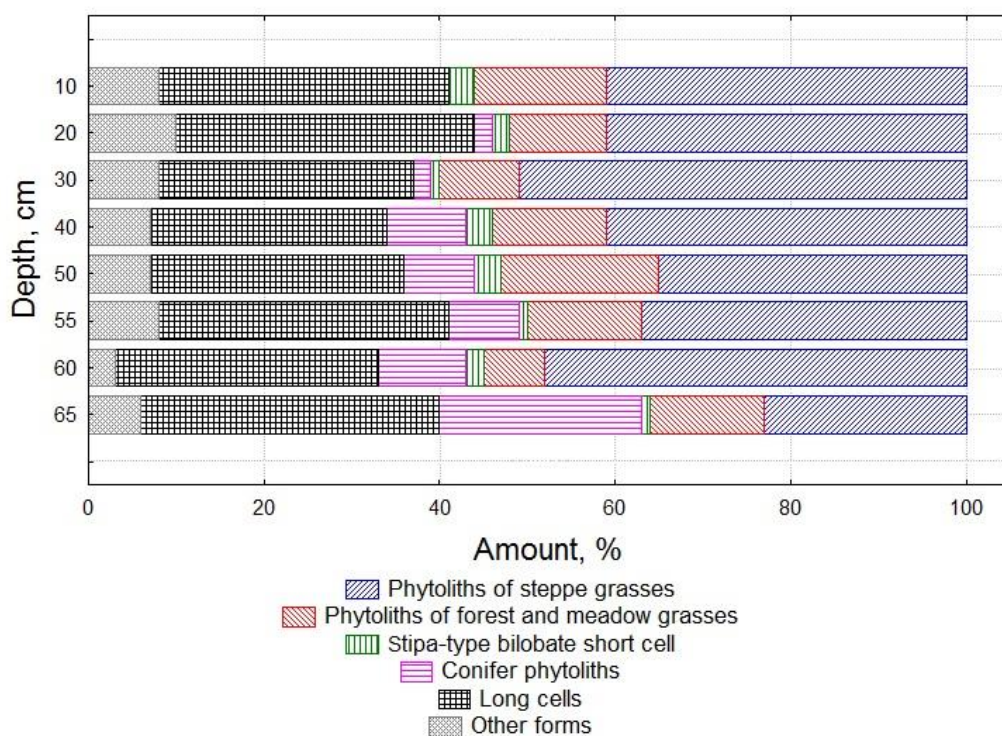

Fig. 7. Phytolith cross section of the wall of excavation site Novoilinka-3 settlement.
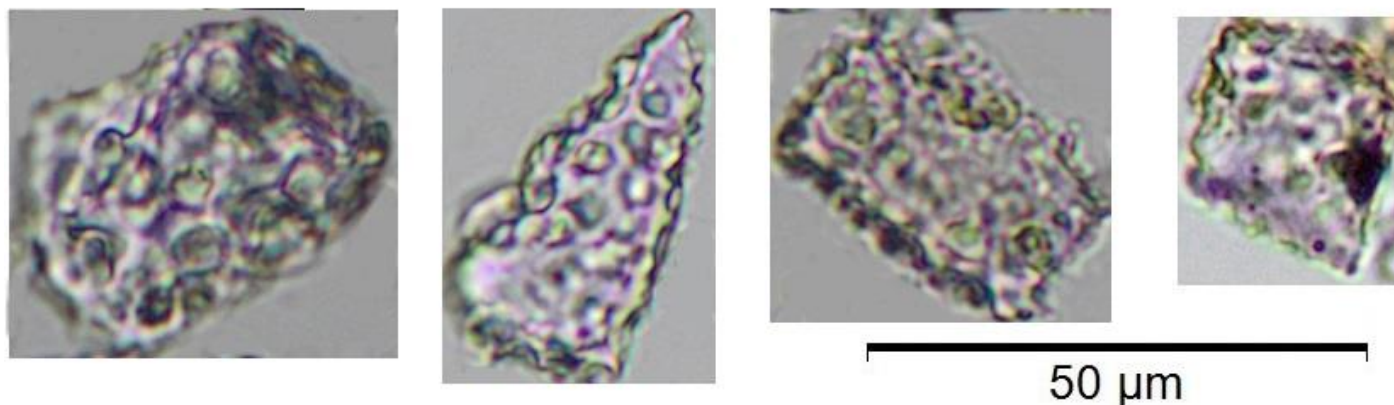
Fig. 8. Pictures of conifer phytoliths from soil.

The transition of phytolith spectrums between the layers of 60–65 cm and 55–60 cm is fairly abrupt. The amount of conifer phytoliths halves sharply, thus pointing to anthropogenic nature of deforestation. The amount of steppe grass morphotypes (Fig. 6) increases, suggesting the steppe formation of the vegetation area in the place of the settlement during the period of reconstruction.

It should be noted that conifer phytoliths as well as the trichomes of grasses are strongly deformed compared with the analogous forms in modern plants. This may have been caused by the process of silicon dissolution. Short cells in the soils are less distorted, probably due to their smaller size. This is also typical for other examined archaeological sites.

Besides phytoliths the spicula, and valves are found in the soil as single elements. All samples have a lot of charred material and traces of burning are found on some horse bones.

Thus it can be seen that the examined territory was covered by forest before the settlement development, and it was deforested by the Eneolithic people. This territory and the surrounding area were then subject to steppe formation under the influence of the anthropogenic factor. This area was marked by different kinds of grassland communities whose xerophytization has been gradually growing up to the present time.

Results of phytolith research of Tytkesken-2 settlement.

The phytolith cross section of the Tytkesken-2 settlement was examined to a depth of up to 77 cm (Fig. 9). There were not any phytoliths found at a deeper depth. The examined layers refer to the following archaeological cultures: the late Neolithic Age (Srednekatunskaya culture), the Eneolithic Age (Bolshemys culture), the Bronze Age and the Scythian period (Kiryushin, 2004).
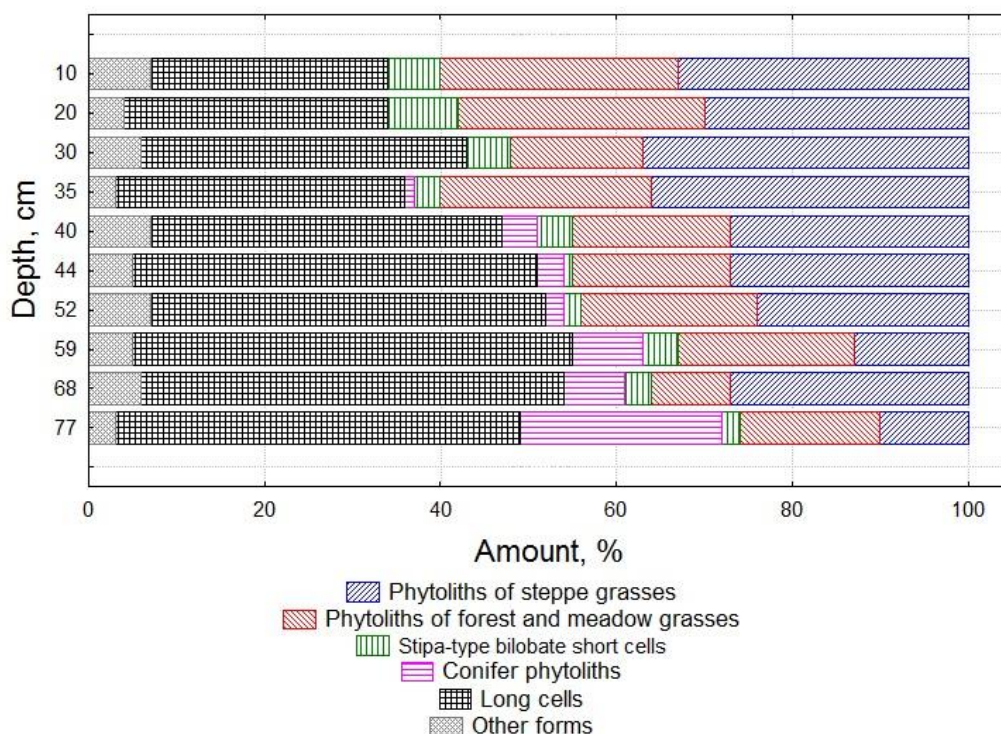

Fig. 9. Phytolith cross section of the wall of excavation site Tytkesken-2 settlement.

The layer 68–77 cm deep (the late Neolithic Age) is marked by a significant amount of conifer phytoliths (Fig. 8) comparable in amount to all specific types of grasses. This suggests that the territory of this settlement was covered by forest in the given period. The next layer is marked by a reduced amount of forms of the silicon particles of conifers. However, the amount of grass phytoliths (Fig. 6), especially steppe grasses, rises. It appears that the territory was deforested with further steppe formation occurring during the late Neolithic period. Phytolith spectrum of the Eneolithic soil layer (52–59 cm) is of pratal nature. Human impact on the vegetation cover possibly decreased in that period thus stimulating the development of more mesophytic grass stand. All upper layers have phytolith spectrums which characterize grassland communities of different degrees of steppe formation. Meadow and steppe phytocoenosis were probably characteristic of the settlement's territory in the Bronze Age and the Scythian period, up to the present time.

Although there are several fire pits registered at Tytkesken-2, there is a lack of charred material in the examined phytolith profile.

Conclusions

The morphotypes of grass phytoliths of the south of Western Siberia are marked by specific eco-coenotic features. Trapeziform short cells, rondels, saddles and trapeziform sinuates refer to steppe types while meadow and forest types are represented by trichomes, trapeziform polylobates, and bilobate short cells.

More mesophytic plant communities of the ancient epochs have been reconstructed for all three examined archaeological sites. The territory of the Nizhniy Kayancha burial ground was covered by birch forest at the time prior to formation of the archaeological site. The territory of Novoilinka-3 settlement was covered by pine and birch steppificated forest in the Eneolithic period, but the territory was deforested as the settlement developed.

Several stages of vegetation change have been reconstructed for the Tytkesken-2 archaeological site. This includes deforestation of pine forest and further steppe formation in the late Neolithic Age, prairiefication in the Eneolithic Age and new steppe formation in the Bronze Age up to the present time.

Acknowledgements

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