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Phytolithic Analysis of Holocene Paleosoils

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Phytoliths are well preserved in the profile of Chernozems buried under mounds 4000–5000 years ago and background Gray Forest soils which have a second humus horizon (SHH) and paleotunnels inherited from the steppe Chernozem stage. In the Chernozems beneath the burial mounds, the phytoliths have a grain-herbaceous composition. In the relict second humus horizon of Gray Forest soils, the phytoliths of the steppe stage are mixed with modern forest phytoliths, while in their upper eluvial horizons, the phytoliths are completely replaced by forest phytoliths.

Key words: Phytolithic analysis, Holocene paleosoils

Analysis of phytoliths is based on the fact that opal silica accumulates in the cells of each plant in the process of its activity, forming units of typical shape, that is, phytoliths, in time. Falling into the soil, they are preserved for a long time, accumulate in the upper humus horizons, and may serve as indicators of the growing or grown vegetation [4]. It should be noted that the phytolith method is still less well developed than the spore-pollen method; therefore, its accuracy in determining the composition of the vegetation is lower. However, phytoliths are not as easily dispersed by the wind as pollen; therefore they may serve for more accurate determination of the areas of natural vegetation which existed on the site of modern settlements, secondary meadows, plowed fields, and different anthropogenic landscapes. Good results come from reconstructing entire plant groupings according to phytolith assemblages; for example, assemblages of phytoliths of herbage have been identified which are typical for broad-leaved forests, assemblages of steppe and meadow groupings, etc. The good preservation of the phytoliths contained in the profile of ancient and buried soils allows layer-by-layer analysis to be used to reconstruct the natural and anthropogenic successions of vegetation of the recent and distant past and in that way establish the conditions under which the soils developed.

Objects were selected for the research which are characterized by clearly expressed, contrasting evolution of soils, which is related to changes of climate and vegetation in the Holocene. These are soils of the Chernozem type, buried beneath mounds of the Bronze Age and Aeneolithic (3000–5000 B.P.) and the surrounding soils with texturally differentiated profile (Light Gray and

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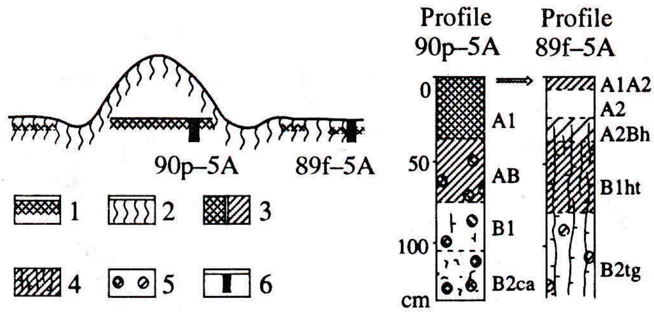

Fig. 1. Bedding conditions of Chernozems under burial mounds of Aeneolithic and Bronze Age (profile 90p–5A) and background Light Gray Forest soils with SHH (profile 89f–5A) in the Carpathian region: (1) sub-mound Chernozem; (2) Gray forest soil with SHH; (3) humus horizons of Chernozem; (4) SHH B1ht; (5) tunnels; (6) location of profiles.

Gray Forest, Sod-Podzolic Eluvial-Gley). Such objects are widely distributed under broad-leaved forests of the Carpathian region, Northern Caucasus, and Central Volga [2]. They are also discovered on the Central Oka, in other regions of the central band of the Russian plain. A feature of the background soils which surround the burial mounds is the clearly expressed second humus horizons, which consist of the preserved lower part of the humus profile of the Chernozem, and also the paleotunnels, which are similar to those in the sub-mound Chernozems (Fig. 1). The upper part of the profile of the Chernozems has degraded under the forest vegetation which has been distributed in these regions for the past 3000 years and transformed into modern eluvial bleached and thin humus horizons.

The purpose of this paper is to establish the character of the original vegetation under which the now buried Chernozems developed and its changes during the second half of the Holocene and also to study the features of formation of the phytolithic profile of the paleosoils and its changes under the influence of modern soil-forming processes.

Samples were taken for phytolithic analysis from the main genetic horizons of buried and background soils of two objects: (1) burial mounds of the Corded Ware culture (Aeneolithic, about 4000–4500 B.P.) from Dashava (Carpathian region) and (2) burial mounds of the Late Pozdnyakovskiy culture of the Middle Bronze Age (Central Oka). The technique for identification, preparation, and microscopic analysis of the phytoliths is described in detail [3]. The phytolith method has been used to reconstruct the history of landscapes and soils [5, 6].

We identified the phytoliths in all samples, calculated their total content in the isolated coarse silt fractions, and determined the number of phytoliths throughout the profile (Table 1). For identification and diagnosis, we photographed the most indicative forms of different phytoliths (Fig. 2). In determining the phytolithic composition, we calculated the percentages of each form of phytolith. The obtained results show the distribution of given forms with regard to the soil profile (Table 2).

Table 1

Distribution of Phytoliths with Regard to Soil Profiles

Profile	Horizon	Depth, cm	Number of phytoliths
89-5A	A1A2	0 - 5	No calculation
	A2	5 - 21	112
	A2Bh	21 - 40	102
90p–5A	[A1]	0 - 25	140
	[AB]	25 - 48	136
152-89A	A1	0 - 18	128
	A2	18 - 45	62
	B1ht	45 - 85	126
150p–89A	[$A1_1$]	0 - 20(25)	170
	[$A1_2$]	20(25) - 50	144
	[AB]	50 - 70	21

Note. Indexes of horizons of buried soils are given in square brackets.

Dashava (Carpathians)

Crest of watershed, absolute elevation 340–350 m. Beech forest with *Carpinus*, in places dead cover, in places with rarefied on-soil cover (*Maianthemum*, *Carex hirta*). Burial mound with a height of about 4.5 m, up to 40 m in diameter, is covered by the same forest. The age of the mound, which belongs to the Corded Ware culture, is about 4500 years. During that time, Sod-Podzolic soil with a thick, highly differentiated profile formed on the mound.

Profile 89f-5A. Background Sod-Podzolic Surface-Gleyed soil. Profile is located 50 m from the mound. Structure of the soil profile is as follows:

A1A2 0–5 cm. Gray-whitish unstably blocky light loam, friable, many roots and incompletely decomposed plant residues.

A2 5–21 cm. Grayish-whitish light loam, wet, blocky-platy, many Fe-Mn-concretions. Gradual transition.

A2Bh 21–40 cm. Gray-brown medium loam with whitish spots, wet, blocky-nutty, weakly compacted. Gradual transition.

B1ht 40–75 cm. Gray-brown medium loam with dark zones, dense, nutty-prismatic, clay cutans and whitish quartz powder (skeletan) on surface of nutty peds. The low part contains paleotunnels. Gradual transition.

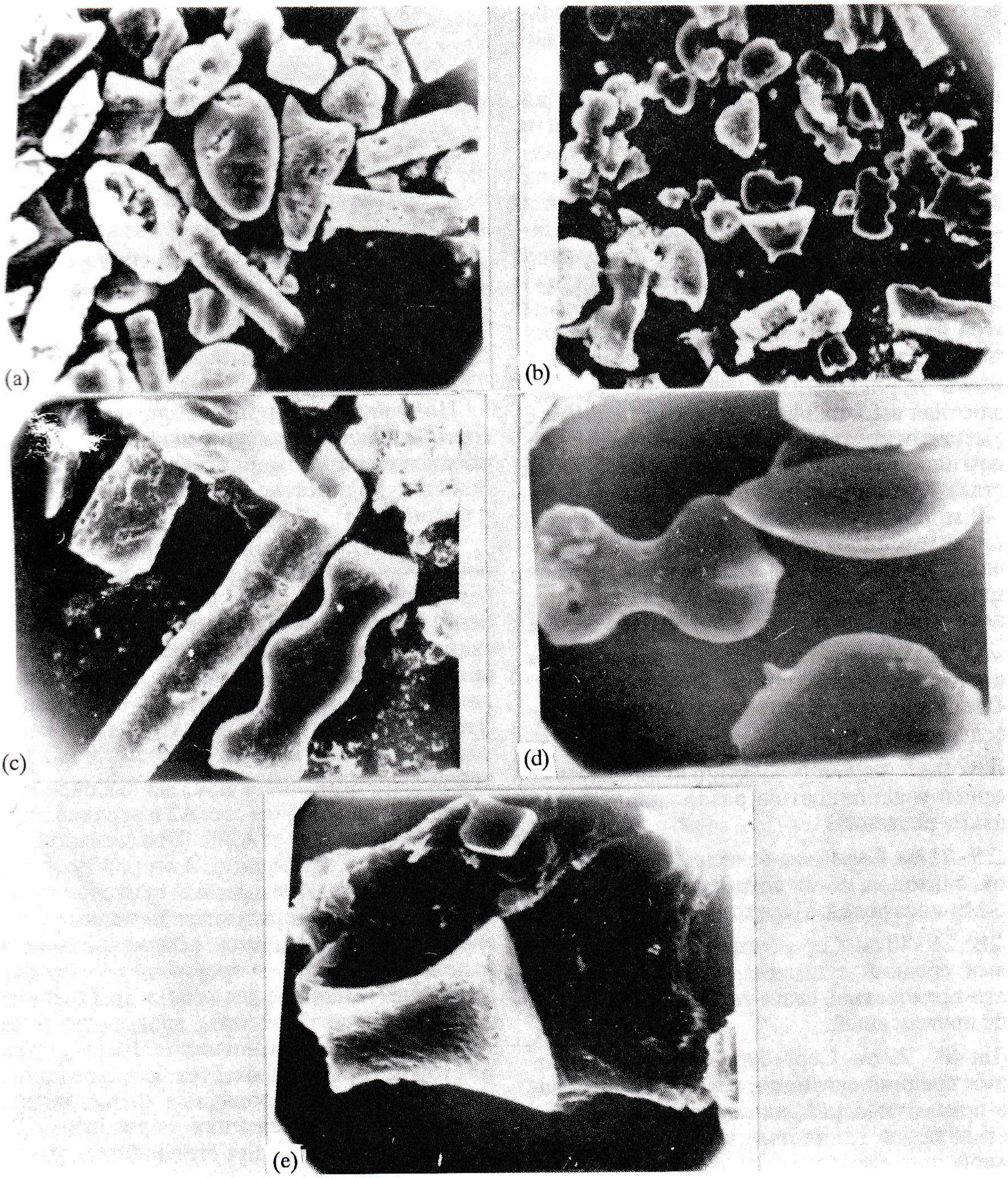

Fig. 2. Typical forms of phytoliths and phytolithic assemblages: (a) × 300, set of phytoliths typical for forest vegetation; rods with even, wavy, and serrated edges, different forms of thorns, cubes, rounded and oval shapes, bottle-shaped forms (profile 89f-5A, horizon A2, 5-21 cm); (b) × 300, phytolith assemblage typical for forest-steppe and steppe vegetation: in the center, a special saddle-shaped form, dumbbells, thorns, rods with wavy and straight edges (profile 89f-5A, horizon A2Bh, 21-40 cm); (c) × 1000, forest assemblage of phytoliths: rods with even and wavy edges (profile 89f-5A, horizon A2, 5-21 cm); (d) × 3000, assemblage typical for dry steppe grain vegetation: ribbed dumbbell and drop-shaped form, flattened on one side (profile 90p-5A, horizon [A1] 0-25 cm); (e) × 1000, saddle-shaped form, typical for dry steppes (the same).

Table 2

Phytolithic Composition of Samples

Profile	Horizon	Depth, cm	Rods	Thorns	Cones	Dumbbells	Spheres	Cubes	Sponge spicules
89-5A	A2	5 - 21	+++	+	±	±	+	++	–
	A2Bh	21 - 40	++	+	±	±	+	++	–
90p-5A	[A1]	0 - 25	+++	++	±	+	±	±	–
	[AB]	25 - 48	+++	++	–	±	±	±	–
152-89A	A1	0 - 18	+++	+	–	–	–	±	++
	A2	18 - 45	++	+	–	–	–	–	++
	B1ht	45 - 85	+++	+	–	±	–	–	–
150p-89A	[$A1_1$]	0 - 20(25)	++	+++	±	±	–	–	±
	[$A1_2$]	20(25) - 50	+	+++	–	+	–	–	±
	[AB]	50 - 70	+	+	–	–	–	–	–

Note. Phytolith of a given group consists of (+++) > 20 percent, (++) 10-20 percent, (+) 5-10 percent, (±) 0.5 percent, (-) none.

B2tg 75–160 cm. Pale yellow-light brown medium loam with dove gray-whitish spots, dense, coarse nutty-prismatic, clay cutans, paleotunnels in upper part.

According to data of micromorphological analysis horizon A2 is weakly structurized, highly porous, poor in clay and iron hydroxides, and contains a large number of concretions of different size and composition.

Combined in horizon A2Bh are signs of eluvial and illuvial processes and relict formations. Eluviation is developed to a weak extent, since bleached zones are small. Signs of the illuvial process are represented by abundant and diverse streaks and separations; relict formations are represented by clusters of coaly humus. This horizon may be viewed as relict-humus, but at the same time as illuvial-clay-humus.

Calculation of the phytoliths demonstrated their high content in eluvial horizon A2 and the upper part of second humus horizon A2Bh. This is due to the fact that the entire profile, including the second humus horizon, is distinguished by high humification. The phytoliths are characterized by a great diversity of forms. An abundance of diverse rods is noted, and triangular forms, conical (typical for sedges), and other shapes are encountered. Dumbbell-shaped phytoliths of grain crops are present, but in a relatively small amount. Moreover, relict horizon A2Bh has a large number of specific saddle-shaped forms not encountered in the overlying horizons. These forms are typical for steppe grain vegetation. We can probably speak about the greater participation of grains in the composition of the vegetation at the stage of formation of the relict horizon than at the modern stage. Thus substantial changes are not noted in the distribution of the forms of the phytoliths throughout the profile of soils with SHH. This can be explained by the relatively steady existence of the ecosystem for a significant time or the substantial restructuring of the phytolith profile at a later stage of development of the texturally differentiated soils, but which preserves relict signs in the SHH.

Profile 90n-5A. Established in the marginal part of the burial mound; height of fill is about 2 m over buried soil. The surface of the buried soil is well evident and according to data of alignment corresponds to the level of the background surface outside the circular excavation associated with the burial mound. The structure of the profile of the buried soil is as follows (depths given from the surface of the buried soil):

[A1] 0–25 cm. Dark gray medium loam, compacted; fine roots are encountered. Gradual transition.

[AB] 25–48 cm. Dark gray-brown compacted, blocky medium loam, spots of tunnels and worm paths. Diagenetic vertical fissures with streaks penetrating the fill and buried soil (less visible in overlying horizons). Gradual transition.

[BA] 48–75 cm. Dark brown (lightens toward the bottom) compacted blocky medium loam; many tunnels; diagenetic fissures with humus-clay streaks. Gradual transition.

[B1] 75–100 cm. Brown dense medium loam, many dark gray large tunnels. Diagenetic fissures with streaks, paths of worms and roots with humus-clay filler. Gradual transition.

[B2] 100–140 cm. Light brown similar loam with diagenetic vertical fissures, dense; ochre and bleached spots are visible. Large tunnels.

The buried soil differs sharply from the background soil and the soil on the mound by its lack of textural differentiation, by deep and intensive humification, and by good preservation of the tunnels. The carbonate horizon [B2ca] is also preserved under other similar burial mounds. The fill and buried soil of the studied marginal part of this mound are intensively leached and devoid of carbonates.

According to the set of stable properties (horizonal structure of profile, thickness of horizons, presence of large tunnels, soil-particle distribution composition), the soil is identified as Leached Chernozem. Less stable properties are changed by diagenesis: compaction, loss of structure, formation of clay streaks and diagenetic fissures penetrating the fill and the buried soil are noted.

According to data of micromorphological analysis of the Chernozems beneath the burial mound the burial causes some dehumification, which is expressed in the general bleaching of horizon [A1] and the presence of quite bleached spots devoid of humus-clay plasma; simplification of the structure and compaction of this horizon is noted. With regard to the modern profile on the mound, horizon [A1] of the buried soil acquires features of an illuvial horizon (presence of cutans). The underlying horizon [AB] also experiences the action of processes of dehumification and eluviation and at the same time has signs of diagenetic illuviation. The structural state of this horizon is somewhat disturbed, and high porosity is noted, giving it a friable consistency. With depth in horizon [BA], the signs of diagenesis weaken, but the cutans are traced to the carbonate screen.

The upper horizons [A1] and [Ab} are characterized by a large number of phytoliths. A significant decrease in the content of phytoliths is observed in the lower part of the profile, and therefore they were not calculated there. The composition of the phytoliths is uniform, testifying to the grain–sedge–herbage composition of the vegetation. The presence of a small amount of cubic forms indicates more the transport of these phytoliths from above than the growth of conifers here (it is not excluded that similar cubic forms may belong to other plant species as well). Investigations of the lower horizons demonstrated the same phytolith composition. Moreover, diatom algae are detected in the sample from a depth of 75–100 cm, which may testify to the existence of humid conditions during the formation of the soil-forming rock. As a whole, we note the overwhelming predominance of phytoliths of grains with possible participation of feather grass (*Stipa*); this allows reconstruction of the vegetation of the given region 4500–5000 years ago as steppe vegetation.

Thus, as a result of the preservation of the buried soil, its phytolithic steppe composition was well preserved. As a result of the change in vegetation, the phytolithic composition of the second humus horizon was substantially transformed and became closer to that in the modern humus horizon. This led to the formation of a complex assemblage of phytoliths which contains forest and steppe forms.

Izhevskoye (Central Oka)

High ancient floodplain of the Oka River, composed of brown loams (outlier). Absolute elevation 6 m above water line, herbage–grain meadow (pasture). The burial mound with a height of about 2 m and diameter of 20 m was excavated by the Central Russian Archaeological Expedition (leader B.A. Folomeyev). Additional burials were established, but additional fills were not discovered.

Profile 152–89A. Established 100 m from the burial mound. Background Gray Forest soil with thick SHH.

A1 0–18 cm. Gray-brown block, friable coarse loam, many roots of grasses and coprolites. Even transition.

A2 18–45 cm. Bright white platy, friable fine loam; Fe–Mn concretions. Fragments of ceramics encountered rarely. Gradual transition.

B1h 45–85. Dark gray loam, medium; in the upper part, it contains whitish spots; dense, nutty-prismatic with clay-humus cutans. Gradual transition.

B25 85–130 cm. Brown medium loam, porous, dense, prismatic; paleotunnels.

Horizons A1 and A2, formed on the site of the upper part of the original Chernozem profile, are characterized by strong eluviation, by the complete loss of relict humus coloration. The SHH of B1h is horizon AB of the original Chernozem, transformed by processes of illuviation, restructurization, etc. In the upper part of this horizon, the humus-clay complex is intensively disturbed (whitish zones along fissures), and transitional horizon A2Bth is formed there.

Typical for this soil is an increase in the number of phytoliths in horizon B1h compared to horizon A2. This increase in the content of phytoliths with depth may be related to the washout of the humus-clay material from the upper horizons and also to the better preservation of the phytoliths, including those inherited from the previous stage. The latter are represented by saddle forms (grains, primarily steppe varieties), which are absent at the top. Sponge spicules, abundantly represented in horizons A1 and A2, are absent here. The lower, evidently relict, horizon also has no phytoliths of conifers, which are noted on the soil surface. Based on the obtained material, it can be assumed that investigations of Gray Forest soil at the previous stages of its development was formed under vegetation which had a clearly expressed grain–herbage character; then there was a period of distribution of other vegetation with the participation of conifer species of trees and an increase in flooding (sponge spicules).

Profile 150n–89A. Buried Chernozem is revealed in the southern part of the mound fill. The thickness of the fill there is 110 cm. A dark gray forest soil was formed on the surface of the burial mound, which is composed of black loam with rare brownish spots (tunnels). The surface of the buried soil is expressed by the change of structure, density, and an interrupted bleached seam. Obtained for the upper horizons of the buried soil are radiocarbon dates in the interval of 5690–5830 years ago (chronological interval between dates of the buried soil and burial time of 1700–1800 years is somewhat greater than expected: for modern Chernozems, the age of the upper horizon is 1000–1500 years according to carbon-14 dating).

We now present a description of the profile (depth from surface of buried soil):

[$A1_1$] 0–20 (25) cm. Dark gray medium loam, weakly compacted, unstably blocky. Fragments of ceramics are encountered. Gradual transition.

[$A1_2$] 20 (25)–50 cm. Black compacted medium loam, diagenetic vertical fissures with humus-clay cutans the color of the background. Gradual transition.

[AB] 50–70 cm. Gray-brown medium loam, darkening toward the top; compacted; signs of diagenetic nutty structure. Gradual transition.

[B1] 70–110 cm. Brown compacted medium loam, porous, tunnels. Diagenetic nutty-prismatic structure.

Unlike the background soil and the soil on the mound, the buried Chernozem is characterized by the absence of textural differentiation, great thickness and intense color of the humus, and good preservation of the tunnels. There are signs of diagenesis: compaction, losses of original structure, appearance of clay streaks and postgenetic nutty-prismatic structure (buried soil is located at the level of the lower part of the modern texturally differentiated profile, formed on the mound). The original buried soil evidently contained carbonates; they were preserved in the center of the burial mound fill, at a depth of 110–200 cm. However, the investigated buried profile is situated in the marginal part of the mound, where the $CaCO_3$ is washed from it, as from the fill.

The soil is characterized by a large number of phytoliths in the upper humus horizons with their sharp decline in the lower part of the profile. Phytoliths of grains and herbage predominate, and sedges are present. Some number of sponge spicules is established, which may indicate the existence of periods of increased humidity of the area or their penetration through fissures or paths of shrews from the fill and soil-forming rock.

Comparison of the phytolithic composition of the SHH of the background soil and buried soil shows their substantial difference. This is caused in many ways by the action of modern processes of washout and destruction of the biogenic opal, which transform the phytolithic spectra of the background soil, including the SHH. Moreover, the inheritance of grain phytoliths by the SHH is well evident, even better than for the previous pair of profiles. Also observed are regular changes in the phytolithic composition which are related to the change of the vegetation: an increase in the modern soil compared to the buried soil is the number of diverse rods, which are a complex of broad-leaved species and herbage, the disappearance of cones (sedge), a decrease in the role of grains (thorns), and an increase in the number of spicules (flooding).

The data obtained also show that the buried soil experienced a hydromorphic stage before the moment of burial, and it developed under automorphic conditions for a long time before that.

Features of Formation and Evolution of the Phytolithic Profile of Soils

As a whole the investigation of buried Chernozems showed a large number of phytoliths and their good preservation in humus horizons buried under thick fills 4500–4000 years ago. The composition of the phytoliths is regular, mainly grain–sedge–herbage, without signs of substantial changes of steppe or meadow-steppe vegetation groupings. Moreover, signs of the wash-in of suspensions from above from the fill and the soil on the mounds, which may lead to a change in the composition of phytoliths in zones of rare diagenetic mainline fissures which cut the buried soil. Similar changes do not take place in the main mass of horizons of buried Chernozems.

Relict SHH of the surface soils, just like the sub-mound Chernozems, testify to the existence of vegetation of a different composition in the past. However, the phytolithic spectra of these horizons are greatly altered. Combined in them are phytoliths inherited from the Chernozem stage and modern forest varieties; the share of the latter should continue to increase with time.

In the overlying horizons, which consist of Podzols and modern humus, the phytolithic composition underwent a complete replacement. A smaller content of phytoliths in horizon A2 than in the SH, more clayey (profile 152–89A, Table 1), can be explained by the fact that the latter is also relict and illuvial. A similar distribution in the profile of Sod-Podzolic soil is typical for pollen [1]. In this case, we note a high concentration of fresh pollen washed in to depth and found in the composition of the clay-humus cutans which fill the mainline fissures in illuvial horizons B1t and B2t.

Conclusion

Phytoliths which are opal bodies formed mainly in leaves and stalks of plants, enter the soil with the leaf fall and accumulate in large quantities in the upper horizons. They are well preserved in humus and especially in more clayey relict second humus horizons.

Phytoliths of many groups of plants have a typical form, which does not change in buried and relict soil horizons. This lets us reconstruct the composition of the vegetation of the past. Unlike pollen, which has great volatility and represents the general composition and tendency of development of the vegetation (macroevolution), the phytoliths let us reconstruct the local flora and areas of concrete plant groupings (microevolution).

Analysis of phytoliths from paleosoils of burial mounds of the Carpathian region and Central Oka showed substantial changes in the Holocene plant cover. In Chernozems under burial mounds 4000–4500 years old, the grain–herbage (with possible participation of *Stipa*) composition of phytoliths of the Middle Holocene steppe stage was well preserved; in the SHH of the background soils, which are the preserved lower part of the Middle Holocene Chernozem, phytoliths of the steppe stage are mixed with modern forest varieties; in the upper eluvial horizons of background Sod-Podzolic soils phytoliths were completely replaced by forest varieties.

Thus we confirmed the data of earlier paleosoil research on the evolution of landscapes and soils toward increased moisture and forestation, leaching degradation of the humus profile, and development of textural differentiation.

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