Reconstruction of vegetation and soil-forming conditions in the South of taiga zone (West Siberia)

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Abstract. The pedocomplex of Kireeva’s gully (deciduous forest zone, the South of Tomsk region) is investigated. It includes except modern four buried soils of different ages from 1000 to 7000 years. Soil texture is a key indicator for differentiating of lithogenesis cycles; fractional composition of humus allows to reconstruct soil formation conditions, and phytolith assemblages – plant communities in each stage of pedogenesis. It is established that the formation of the pedocomplex is determined by the processes of denudation from the adjacent slopes of erosional plain and gully-terraced complex. The phytolith assemblages of buried soils differ from that of modern soil. On the certain stages of formation of the pedocomplex, recorded in buried humic horizons, were developed: marshy meadow waterlogged with groundwater, marshy meadow (forest), herbaceous forest, wet steppe meadow, modern herbaceous-cereal meadow. Each of the plant communities was formed under climatic conditions corresponding to different subzones of the modern vegetation of West Siberia – from the southern taiga to forest-steppe.

1. Introduction

Palaeoecological investigations aimed at restoring the sequence of paleocommunities and the conditions of its development are of great importance in the study of environment’s dynamics. Covering rather long periods these investigations allow to estimate climate change in the past indirectly. One of the main objects of reconstruction of landscape-climatic changes over long period of time are pedorelicts buried in the soil profile. Genetic soil horizons in cycles of pedogenesis accompanied by vertical differentiation of substances indicate objectively the direction and sequence of landscape changes. The relative stability of external factors causes gradual formation, differentiation and accumulation of organic and inorganic products in soil body, including the remains of biota life. When the rate of lithogenesis in accumulation-denudation cycles exceeds the rate of pedogenesis the complex construction of informative field of soil is formed. That is why the soils of gully systems are convenient object for palaeoreconstruction. The burial of upper horizons of these soils occurs from time to time, and out of the soil forming process’s influence they retain the signs of environmental conditions at the time of burial [1, 2]. The soil’s organic matter, newly formed minerals and microbiomorphic fractions, including microfossils of plants and animals, are the most informative for the reconstruction of environment. Especially silica forms (phytoliths, diatoms, spicules of sponge and shells of testate amoebas) are important. Unlike organic forms (spores, pollen) it is well preserved in soils [3]. Plant- and soilcover distribution on the plain is naturally associated with climatic
parameters – temperature and precipitation. Therefore it is possible to use physico-chemical properties of soil and palaeoplant communities data to make a conclusion about the climatic conditions during its formation.

The palaeogeographical researches on the territory of West Siberia are mainly connected with the study of spore-pollen spectra of peat and lake deposits [4, 5], genesis of second humus horizons [6], loess pedocomplexes [7]. The study of erosion-accumulative complexes of Holocene soils using new methods of palaeoecological research had not been conducted yet. So the purpose and objective of our investigation is the study and palaeoecological reconstruction of environment and soil-forming conditions of pedocomplex, located in the south of taiga zone, in long erosion-accumulative and climatic cycles of Holocene on the basis of soil properties and phytolith analysis of buried horizons.

2. Materials and methods

The investigated pedocomplex is located 4 km to the East from the village Kireevsk, in the valley of the left tributary of brook Kireeva, which empties into the river Ob’. The valley is flat (200 m wide) but has steep right bank adjacent to ancient erosion plain with maximal elevations 180 m in the riverhead. This valley separates the third terrace of the river Ob’, composed of sandy-loam, from loam interfluvial plain. The depth of incision at the point of sampling is 50 m from the surface of the third Ob’ terrace (157 m) and about 60 m from the surface of ancient plain (166 m). The modern surface of the valley (107 m) is 32 m higher than Ob’ level of low water (75 m). The width of the valley does not correspond to modern state of the river, which is narrow watercourse dried from time to time and blocked by dam.

The study area belongs to the deciduous forests subzone according to the landscape-geographical zoning [8]. Pine herbaceous forests occupy the third Ob’ terrace. Birch forests with the participation of conifers (pine, sometimes fir) and highherbaceous underlayer take places on interfluvial plain. The herbaceous-cereal meadow with Elytrigia repens and Phleum pratense dominating and participation of another cereals (Festuca pratensis, Poa palustris, P. pratensis, Deschampsia cespitosa, Agrostis alba, Dactylis glomerata) and herbs (Ranunculus propinquus, Filipendula ulmaria, Cirsium setosum, Vicia cracca and other species) is formed in the valley. The meadow has been mowed earlier.

The pedocomplex consists of modern and four buried soils. Samples were taken with a step of 10 cm. Soil texture, physico-chemical properties, fractional composition of humus were determined by standart methods [9]. Microbiomorphic analysis was performed in humus horizons of five soils found. The microbiomorphic fractions of soils were extracted by standart method according to the A.A. Gol’yeva recommendations [2]: treatment in 10% solution of hydrochloric acid, laudering of clay fraction (in accordance with Stokes’ law of particle deposition), separating sand fraction with sieve (0.5 mm), extraction of microbiomorphic fraction by centrifugation with heavy liquid CdJ+KJ (specific gravity 2.3). The resulting preparations of microbiomorphs were placed in glycerol and viewed under optical microscope (x400). At least 400 particles were counted in each sample. To quantify phytolith concentration we use relative value – the number of particles in a drop of sample. The interpretation of results was carried out according to ecological classification of phytoliths developed by A.A. Gol’yeva [2, 10]. The radiocarbon age of humus horizons was determined by humic acids on the device Quantulus-1220 by G.V. Simonova (IMCES SB RAS). Radiocarbon dates were calibrated using software OxCal13.

3. Results and discussion

The complex structure of studied soil profile reflects five erosion-accumulative cycles. Each cycle began in the conditions of high wetness and ended by the phase of slow lithogenesis and soil formation. Accordingly there are four buried soils identified in the pedocomplex except modern one. Each of them reflects different landscape-climatic eras. Soil texture clearly delineates erosion-accumulative cycles. Phytoliths and plant detritus compose the majority of microbiomorphic fractions of the pedocomplex’s soils. Besides small amounts of sponge spicules, diatom shells, pollen and single shell of testate amoeba are found in some samples (table 1). In this article we focus on phytolith
assemblages of investigated soils. The phytolith assemblages of modern and buried humus horizons differ from each other in varying degree (figure 1). Although the total phytolith number in samples varies considerably. In part, this may be due to partial denudation of the upper part of humus horizon at the time of next deposit forming.

**Table 1.** Comparable semi-quantitative microbiomorph content in humus horizons of modern and buried soils of the pedocomplex

| Soils | Phytoliths | Plant detritus | Diatom shells | Sponge spicules | Spores, pollen | Testate amoeba shells |
|-------|------------|----------------|---------------|-----------------|----------------|----------------------|
| Modern | +++        | +++            | +             | s               | +              | –                    |
| I      | +++        | ++             | –             | –               | +              | –                    |
| II     | +++        | ++             | –             | –               | s              | –                    |
| III    | +++        | ++             | –             | s               | s              | –                    |
| IV     | +++        | ++             | –             | –               | –              | s                    |

Notes: “+++”- many; “++”- medium; “+”- few; “s”- single; “...” not found

**Figure 1.** Phytolith assemblages of humus horizons of modern and buried soils of the pedocomplex.

The share of morphotypes characteristic for plant groups (a) and total number of phytoliths (b)

The modern soil profile with thickness of 45 cm is formed on stratified loam-sandy loam deposit, where the lower layers contain up to 50% of fine sand fraction, and the upper layers are enriched with clay fraction (21–35%). The accumulation of coarse humus remains in sod horizon and the presence of small clusters of the hydrates of iron oxides indicate high surface wetness of the soil. The humus belongs to fulvic type with Cha/Cfa in the upper horizon 1.08. The profile of the soil with the thickness of humus horizon of 30 cm is formed by sod-gley type with poorly expressed humus-accumulative process. According to radiocarbon dating, the age of the upper humus horizon is 840 years.

The phytolith assemblage of the modern soil is dominated by forms of dicotyledonous herbs (smooth elongates) and that of meadow cereals (trichomes and to a lesser extent polylabates). These morphotypes are characteristic for meadows and light herbaceous forests of deciduous forests subzone (hemiboreal) [2, 11]. So the phytolith assemblage corresponds to herbaceous-cereal meadow with dominating of _Elytrigia repens_ and _Phleum pratense_ developed in the place of sampling. The phytoliths characteristic for forest cereals and conifers found in small amounts seem to be introduced from the third Ob’ terrace occupied with pine forests. This is consistent with higher proportion of sand fraction in the texture of the modern soil. The presence of phytolith morphotypes characteristic for hygrophilous plants (reed), and also diatom shells (2.3% of microbiomorphic fraction) and sponge
spicules (single) together with above-mentioned soil properties reflect wet conditions of soil forming. On the whole the gradual attenuation of sedimentogenesis caused by fire (described below) is noted for the modern soil of investigated pedocomplex.

The underlying first (I) buried soil (45-88 cm) clearly distinguished from the modern by soil texture change from sandy-loam to clay-loam with high content of silty fraction. The high content of fine sand in the upper horizons of the buried soil (14–16%) might to be erected from the modern soil through the pores and root moves. The first buried soil seems to be formed on sediments of slow deluvial runoff from the area, where humus-accumulative process was actively developing. The radiocarbon dating with humic acids shows the minimal age of the soil burial to be 1170 years. Humus horizon has almost black color and well-preserved granular-lumpy structure. The humus content is high (up to 8%). The composition of organic matter is humic (Cha/Cfa 1.8-2.2). Against the background of high content of associated with calcium humic acids the relatively high content of the third fraction of humic and fulvic acids associated with mineral basis is noted.

The set and proportion of morphotypes in phytolith assemblage of the first buried soil also corresponds to meadow (meadow forms more than forest). However in comparison with the modern soil assemblage there are more polylobates among forms characteristic for meadow cereals, besides the morphotypes characteristic for steppe cereals (spiny elongates and rondels) are present. In addition the whole phytolith number increases several times. On the one hand, this may be caused by the abundance of cereals in herbaceous cover of the meadow which has been developing in that period of time. Cereals are known to produce silica bodies in much more amounts than another plant groups [2]. On the other hand, high phytolith content is usual for soils formed under southern plant communities with maximal concentration revealed in ordinary chernozem under steppe meadow [11-13]. On the basis of these considerations the first burial soil seems to form in warmer than modern climatic conditions. Given the relatively small proportion of the “southern” (“steppe”) morphotypes in phytolith assemblage it is probably corresponds to the meadow of forest-steppe zone. The presence in small amounts of fan-shaped and bulliforms indicate high wetness of the soil. Humic composition of organic matter also confirms the formation of this soil in accumulative landscapes of forest-steppe zone. Some phytoliths in sample are found to be black partially or completely, perhaps because of fire. The end of this soil-forming cycle with fire is proved by the formation of sandy-loam sediment on the surface of the first buried soil, which becomes the basis for the modern soil development.

The second (II) buried soil (88-142 cm) has been forming about three thousands years ago (minimal age of burial is 3150 years), also in conditions of quiet sedimentation. Quite monotonous clay-loam strata has grown bottom-up with the sedimentation rate being much more rapid than pedogenesis rate. The lower horizons with humus content up to 1.5% completes the humus horizon with thickness of 17 cm. It is grey with full impregnation of intersoil mass in humus, with high humus content (2.88%). It has finely lumpy structure with abundance of caprogenic elements. The ratio of humic and fulvic acids reveals fulvic-humic composition of humus of the whole profile of buried soil (Cha/Cfa 1.48–1.55).

The number of phytoliths in humus horizon of the second buried soil is close to that of the modern soil. The phytolith assemblage also has much in common with modern: morphotypes characteristic for dicotyledonous herbs (smooth elongates) and meadow cereals (mostly trichomes) dominate. Slight decline in the number of bilobates and polylobates among “meadow” forms and simultaneous increase in morphotypes characteristic for forest cereals and conifers may be the consequence of widespread forests in the period of formation of this soil, that indicates indirectly colder climatic conditions. Unlike modern soil there are no diatom, sponge spicules and also reed phytoliths found in sample. Above-mentioned features of phytolith assemblage together with fulvic-humic composition of organic matter and besides the signs of podzolic process in addition to sod one indicate the formation of the second buried soil in more dry and relatively cold conditions, that corresponds to moderately cold and dry phase of the late Subboreal [4].

The humus horizon of the next (III) soil (142-174 cm) is formed on the complex composition of sediments, characteristic respectively for different sedimentation conditions. Bottom-deposited layers
contain equally of fine and medium-sized sand fraction and clay fraction, and small amount of silty component, which is typical for sediments with high speed flows. Up-deposited layers are clay, characteristic for quiet sedimentation. The intersoil mass of the whole profile of the third buried soil is dense, conjoint. The abundance of iron hydroxides clusters gives a buff-brown tone. The humus content is high in upper layers (2.24-2.34%) and reduced in sand-rich horizon (1.69%). However the composition of humus for profile is fulvic-humic (Cha/Cfa 1.5-1.7), with high content of humic acids associated with calcium.

The phytolith assemblage of the third buried soil is composed mostly of smooth elongates – morphotypes characteristic for dicotyledonous herbs. The number of phytoliths characteristic only for cereals is very small, that indicates its low abundance in palaeo plant community and partly explains the low value of the total number of phytoliths, because unlike cereals dicotyledonous herbs use to produce silica bodies in lesser amounts. Microbiomorphs – indicators of high wetness are detected (reed phytoliths, single sponge spicules). The number of conifers’ silica cells should be considered low relative to the low total number of phytoliths in the third buried soil. Its share is close to that in the phytolith assemblage of the modern soil, that does not allows to confidently diagnose the existence of extensive groups of forest vegetation in that era. In general, from structural characteristics of soil, humus composition and peculiarities of phytolith assemblage it folowes that marshy meadow (probably forest) has been developing in the valley, and soil formation has been proceeding in excessively wet conditions as sod-gley and/or humus-gley. The radiocarbon age of the pedorelict is 5900 years. For a set of attributes that era can be defined as cold and relatively wet.

The profile of the oldest (IV) soil is revealed from the depth of 174 cm. The soil texture is heavy clay, clay content is 42%. Humus horizon is black with a steel shade and brownish stain, solid build, lumpy-granular structure. The content of humus is 3.3%. Below the transition horizon lies, which is dirty-brown with signs of excessive moisture. The composition of organic matter is humic (Cha/Cfa 2.12–2.34). The phytolith assemblage of the fourth soil has a low diversity of morphotypes as well as that of the third buried soil. It is composed of smooth elongates mainly and trichomes with a single polylobates characteristic for meadow and forest cereals. The number of conifers’ phytoliths in comparison with low total number of silica remains is low and can not clearly point to widespread forest vegetation. Forest seems to be formed on slopes, from which morphotypes characteristic for forest cereals and conifer could be introduced in the course of erosion processes. According to the morphological characteristics, humus composition and phytolith set the soil of marshy meadow should be diagnosed, being formed in conditions of excessive moisture by groundwater. The waterlogging of the soil associated more with groundwater occurred at higher than modern basis of erosion and possible backwater from the river Ob’. The quantity of atmospheric precipitation could be even lower than current. The age of pedorelict is conventionally referred to the early Atlantic period in the 7000–7500 years [4]. It should be noted that the upper part of the humus horizon of this soil at the beginning of the next erosion cycle has been washed away. And in the early stages of following erosion-accumulative cycle the more light material deposited being brought from the adjacent Ob’ terrace, which is only possible after a fire in dry years and extreme precipitation in following years.

In general, the features of soil texture of the investigated pedocomplex and very small proportion of diatom shells and sponge spicules in microbiomorphic profile indicate that its formation was mainly driven denudation processes from both gully-terraced complex, and the ancient plain. In connection with wide development of erosion-accumulative processes the phytolith assemblages of studied soils are likely to have a mixed composition of phytoliths from plants that grew in the valley and of phytoliths brought from the slopes. It is typical for phytolith profile of soils of gully system [12].

Differences in phytolith assemblage of modern and buried soils are due to the development of phytoocoenoses corresponding to different zones (subzones) of vegetation. Thus it indirectly points to the changing climatic conditions at certain stages of formation of the pedocomplex profile. At the same time, the presence of phytoliths characteristic for hygrophilous plants (reed), and also sponge spicules and diatom shells seems largely to be a consequence not so much of climatic conditions, as of the position in relief (accumulative). Certain conclusions can be drawn only with respect to the second
buried soil, where these morphotypes are absent, probably due to the relatively dry climatic conditions. The results of phytolith analysis of the pedocomplex are in good agreement with data on humus composition and morphological structure of the investigated soils.

4. Conclusion
The studied soil profile was formed in complex erosion-accumulative cycles reflecting different climatic era. Each cycle of denudation began with active sedimentation and burial of the existing soil profile with the entire set of artifacts, and ended with a quiet phase corresponding to the climatic conditions of the new soil formation. Soil texture is a key indicator for differentiating between cycles of lithogenesis; the fractional composition of humus is characteristic of soil formation conditions; and phytolith assemblages allow to reconstruct plant communities. According microbiomorphic analysis the phytolith assemblages of modern and buried soils are revealed to differ to a greater or lesser extent and correspond to different phytocoenoses. Detected that at certain stages of the pedocomplex formation, recorded in buried soil horizons, were developed: marshy meadow waterlogged with groundwater, marshy meadow (forest), herbaceous forest, wet steppe meadow, modern meadow. These reconstructed phytocoenoses correspond to different zones (subzones) of modern vegetation of West Siberia. Their existence on the investigated territory at certain periods of the formation of the soil profile is evidence of changing climatic conditions that caused the shifting boundaries of zones (subzones) – from colder (possibly southern taiga) to warmer (forest-steppe). The results of microbiomorphic analysis confirm the data of the study of humic substances and largely correspond to the results obtained for the South of West Siberia by other researchers. However, it should be noted that the reconstruction of the humidity of the climate is not as definite in connection with the location of the studied soil profile in accumulative position of the landscape, where the influence of climate humidity is largely screened by the local features of the water regime.

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