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ORIGINAL ARTICLE

Holocene vegetation changes and anthropogenic influence in the forest-steppe zone of the Southern Trans-Urals based on pollen and plant macrofossil records from the Sukharysh cave

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Abstract Pollen and plant macrofossil records from the Sukharysh cave located in the southern forest-steppe zone of the Southern Trans-Urals provide material for reconstruction of palaeoenvironments. The obtained results reveal that within this territory in the Early Holocene before the Atlantic there was a forest-steppe zone with forbs and *Artemisia* communities and birch woodland stands. Anthropogenic influence on vegetation was insignificant at that time. In the Late Subatlantic, ruderal communities, cultivated land and pastures were widely spread across the forest-steppe landscapes. Active development of agriculture by the Southern Trans-Urals population started after the Russians had occupied this territory in the 17–18th centuries A.D.

Keywords Pollen · Plant macrofossils · Vegetation history · Anthropogenic influence · Southern Trans-Urals · Holocene

Introduction

Study of the flora and vegetation history of the Southern Trans-Urals, the territory located at the border between the Urals and Western Siberia, is of great importance for the solution of palaeoecological problems. Palaeobotanical research on this territory started more than 60 years ago. The first attempts at reconstruction of the Southern Urals vegetation were made by Krasheninnikov (1937, 1939). The Holocene organic sediments of the Southern Urals and Trans-Urals forest zone were actively studied in the 1970–1980s by Katz and Katz (1978) and by Khomutova (1978). These researchers obtained palaeobotanical data by the study of lake and bog sediments. The pollen data from eight peat bogs of the Southern Urals highlands provided evidence for a scheme of vegetation and climate dynamics in the Holocene (Panova 1981, 1982; Panova and Makovsky 1987). This attempted to show differences in vegetation at different altitudes and exposures within the Southern Urals highlands during certain periods in the Holocene (Table 1). However, this scheme is difficult to use as is not supported by absolute age determination data.

Only isolated palaeobotanical data are available for the forest-steppe of the plains in the Southern Trans-Urals. The study of sediments from Lake Uvildy, including palynological analysis, provides such data for the northern forest-steppe area of the Southern Trans-Urals (Khomutova et al. 1995; Subetto et al. 2004). These pollen data characterize the Holocene and a considerable part of the Late-glacial (Fig. 1). The only radiocarbon date obtained for the sediments of the lower part of the core represents a Preboreal period but it does not correlate with the interpretation of the pollen data.

The Sukharysh cave was chosen for palaeoecological research as karst cavities located on the plain territory of the Southern Trans-Urals forest-steppe zone had not been studied before. Such sites are widely used for palaeoecological reconstructions of highland natural environments (Coles et al. 1989; Fernández et al. 2007; Smirnov 1990). Soft sediments in this cave contain fossil bones of large and small mammals, and plant micro- and macrofossils that provide complex palaeoecological data. The Sukharysh

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Table 1 Basic stages of vegetation development in the Southern Ural Mountains during the Holocene (after Panova 1990)

Chronology	Central mountainous part		Eastern slope, 300–400 m a.s.l.
	900–1,100 m a.s.l.	700 m a.s.l.	
Subatlantic	Fir-spruce forests with birch, pine, Siberian pine, and alder. Broadleaf trees decreased	Birch-pine and fir-spruce forests with Siberian pine and broadleaf trees. There were alder forests	Birch-pine forests with linden. There were alder forests
Subboreal			Birch-pine forests with oak, linden and hornbeam
Atlantic	Mixed coniferous-broad-leaved forests with elm, linden, oak, maple, hazel, smooth-leaved elm and hornbeam		Mixed forest with elm, oak, linden, hornbeam and hazel
	Spruce-birch forests with pine, Siberian pine, larch and elm	Pine and spruce forests with Siberian pine, larch, birch and elm	Birch-pine forests with spruce, Siberian pine and elm
Boreal		Pine and spruce forests with Siberian pine, larch, and birch	Birch-pine forests with spruce
		Larch-pine-birch forest-steppe	Pine-birch forest-steppe
Preboreal		Grass and shrub vegetation increased	
		Expansion of pine-spruce forests	Expansion of pine-birch forests
Younger Dryas		Cold steppe and tundra vegetation prevailed. There were larch light-forests with spruce	Cold steppe vegetation prevailed. There were larch light-forests

cave is situated in the Southern Trans-Urals which is known for being an area of extensive human activity in the Holocene.

According to the archaeological data, the Southern Trans-Urals territory was actively exploited by ancient man during the Holocene (Fig. 2). The spread Mesolithic culture in this territory during the Early Holocene is proven by finds of Mesolithic artifacts. Neolithic culture spread in the Southern Trans-Urals in the period 5000–4000 B.C., flourishing in the Atlantic period. The people of the Southern Trans-Urals in Mesolithic and Neolithic periods were mostly hunters (Matyushin 1976; Mosin 2000). Chalcolithic culture with its numerous artifacts, dated to around 3000 B.C., appeared at the beginning of the Subboreal period (Matyushin 1982; Mosin 2000). Bronze Age settlements spread on the Southern Trans-Urals territory in the middle of the Subboreal period, at about 3000–2000 B.C. People of that time developed diversified farming, primarily cattle-breeding. Iron Age culture began to develop here in the Subatlantic period, in approximately 8th–7th centuries B.C. People of the Early Iron Age were mainly cattle-farmers. Nomadic cattle-breeding existed until the beginning of farming and industrial development of the Southern Trans-Urals territory in the Middle Ages. At that time the farming by the nomadic tribes became integrated in nature, i.e. it included cattle-breeding, primitive farming, hunting, fishing, trading etc. After the Bashkir territories had been added to the Russian Empire, local populations moved from there to the Southern Trans-Urals territory and started to exploit it more intensively. The migrants had a semi-nomadic way of life with traditional cattle-breeding and the elements of primitive farming. The first Russian settlements appeared in the Southern Trans-Urals territory in 1640–1650s. Since that time, the culture of permanent pasture cattle-breeding, farming and forest exploitation typical of settled Russian populations spread everywhere.

The land use and the changes that occurred in farming by different cultures can be traced by the study of the palaeobotanical data obtained from cultural layers of multiple age sites. In the absence of such artifacts in the Southern Trans-Urals, we have taken cave sediments which provide evidence of vegetation changes caused by climatic factors and anthropogenic influence.

Our article presents complex palaeobotanical data from the Sukharysh cave that allow the reconstruction of vegetation changes in the Southern Trans-Urals forest-steppe zone during certain Holocene periods and the assessment of anthropogenic influence on the vegetation near the cave.

Study area

The Sukharysh cave is situated on the Sukharysh River which feeds the Uvelka River from the north (54°36′N, 61°04′E, Figs. 2, 3). The rivers Sukharysh and Uvelka run through the flat, slightly elevated plain of the Uvelka watershed to the east of the Ural-Tobolsk interfluve of the Trans-Urals peneplain (Milkov et al. 1993). The maximum elevation near the cave does not exceed 260 m above sea level. Karst is a typical relief in the cave area. In the valley of the Sukharysh River it outcrops as a massive ridge of Visean limestone (Komar and Chikishev 1968).

The climate of the region is warm-temperate continental. The mean January temperature ranges from −16°C to

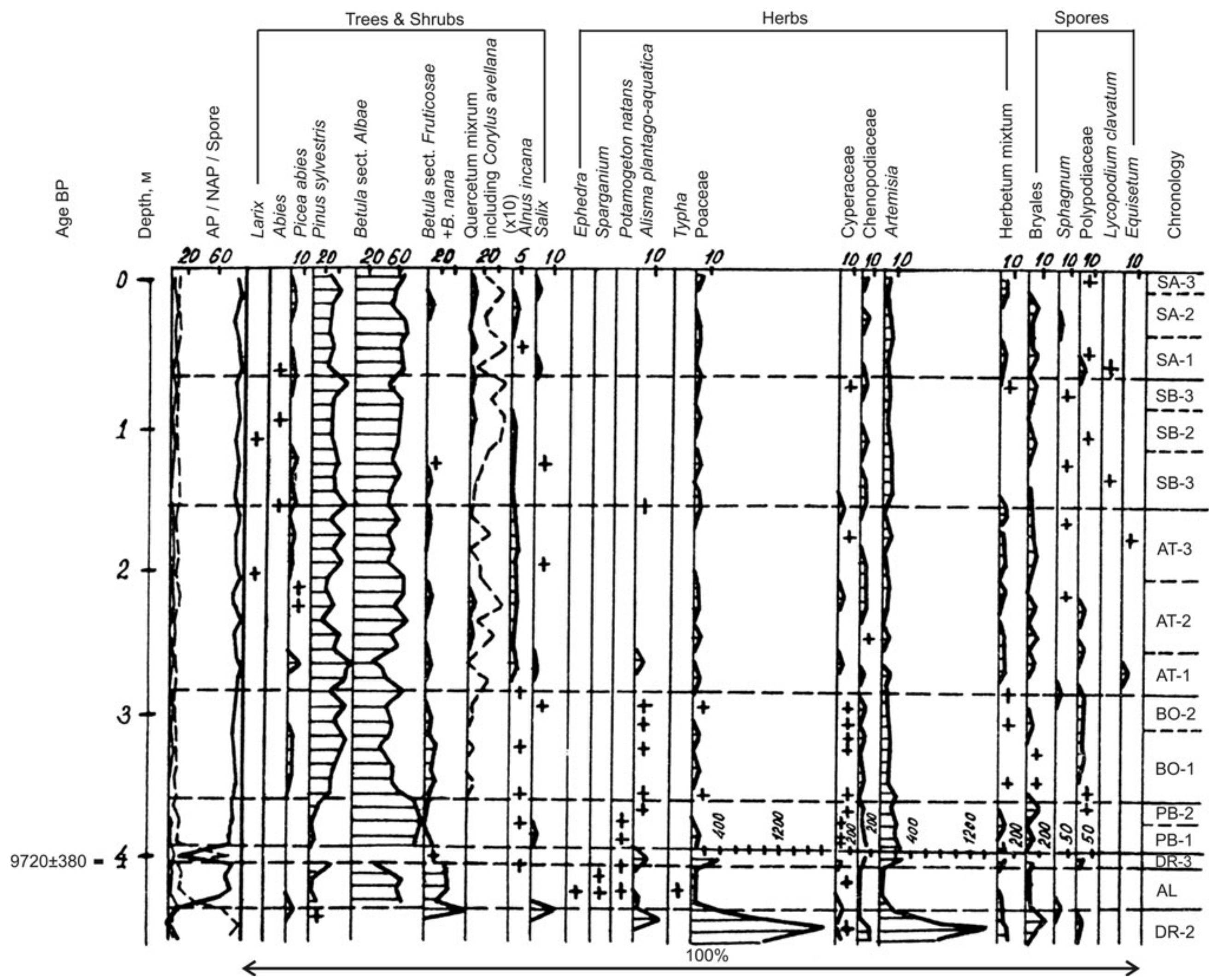

Fig. 1 Pollen percentage diagram for Lake Uvildy (after Khomutova et al. 1995)

−18°C. The average July temperature is from +17°C to +20°C. Mean annual precipitation is around 300 mm (Komar and Chikishev 1968).

The Sukharysh cave is situated in the southern forest-steppe of the Trans-Urals peneplain (Fig. 4). Pine stands and birch woodland stands are typical of this territory (Fig. 5). These birch woodland stands (kolki) or small forests are typical of the more humid habitats of the forest-steppe and steppe, and are usually dominated by *Betula* and *Populus tremula* (Milkov et al. 1993). The Sukharysh cave area is covered by *B. pubescens* and *B. pendula; P. tremula* can also be found here. The treeless areas represent meadow steppe, which is now virtually totally cultivated (Fig. 5). *Fragaria viridis*, *Trifolium montanum*, *Galium verum*, *Pyrethrum corymbosum*, *Filipendula hexapetala*, *Adonis vernalis*, *Origanum vulgaris*, *Phlomis tuberosa*, *Sanguisorba officinalis*, *Poa pratensis*, *Dracocephalum ruyschiana*, *Veronica teucrium*, *Dactylis glomerata*, *Tragopogon orientalis* etc. are typical forest and meadow-steppe species in the herbaceous layer. Xerophytes (*Artemisia austriaca*, *A. sieversiana*, *Dianthus acicularis*, *Helictotrichon desertorum*, *Stipa pennata* etc.) can also be found here. Pine forest outliers (*Pinus sylvestris*) occur quite often.

The South Ural Mountains to the west of the Sukharysh cave display evidence of altitudinal vegetation zonality (Fig. 4). The forest-steppe vegetation of the Trans-Urals peneplain gives way to mountain forest-steppe on the eastern slope (up to 400 m a.s.l.). The mountain forest-steppe in turn gives way to a mountain-forest zone. The lower level is occupied by mountain pine forests (up to 600–800 m a.s.l.) with *Pinus sylvestris* and *Larix* predominant in the area. Dark-coniferous south boreal (south taiga) forests of fir (*Abies sibirica*) and spruce (*Picea obovata*) cover the area at 1,000–1,100 m a.s.l. Dark-coniferous forests are predominant in the central mountain part of the Southern Urals. At the lower levels of the

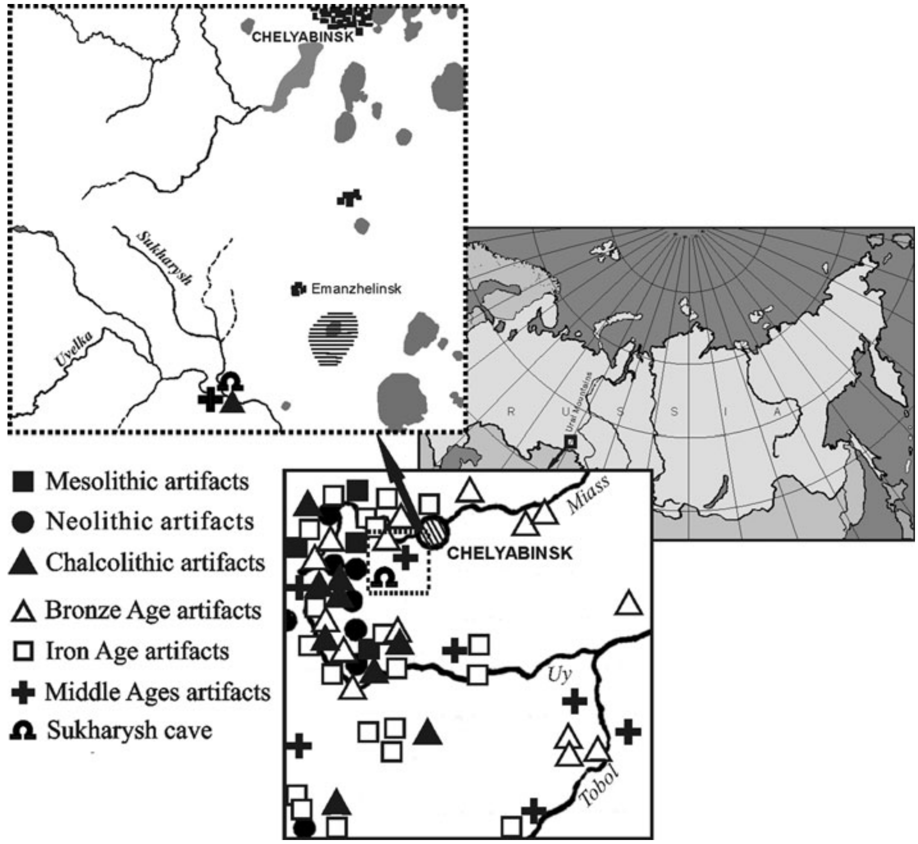

Fig. 2 Location of the Sukharysh cave and archaeological sites in the Southern Trans-Urals

Fig. 3 The Sukharysh cave

western slope (from 600 to 700 m a.s.l.) the dark-coniferous forests give way to mixed coniferous and broad-leaved-forests with spruce, fir, lime (*Tilia cordata*), elm (*Ulmus laevis*) and oak (*Quercus robur*). Subalpine (subgoltsy, Milkov et al. 1993) and mountain tundra belts are situated at high altitudes over 1,000–1,100 m. The mountain tundra belt (up to 1,200–1,500 m a.s.l.) is characterized by grass-moss tundra (Gorchakovsky 1975).

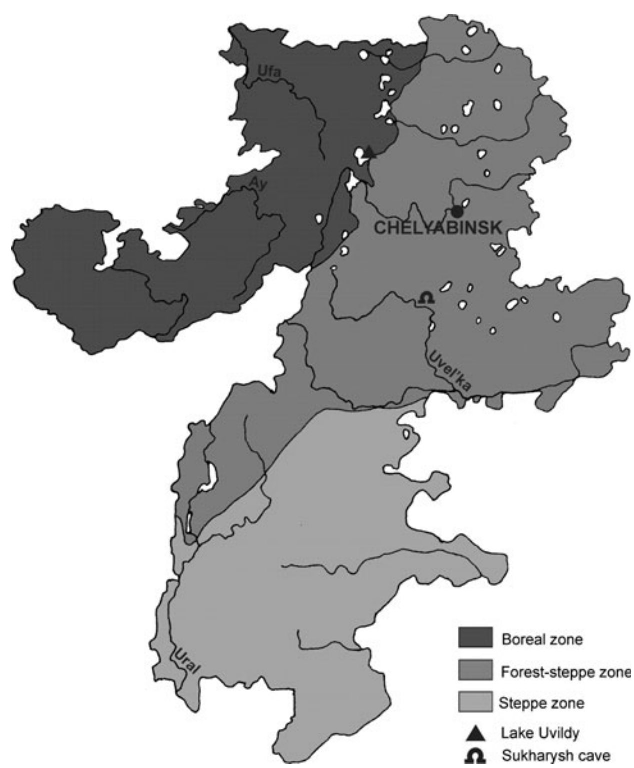

Fig. 4 Recent vegetation in the Southern Urals and Trans-Urals

Fig. 5 Typical recent vegetation near the Sukharysh cave; **a** birch woodland stands, **b** steppe meadow

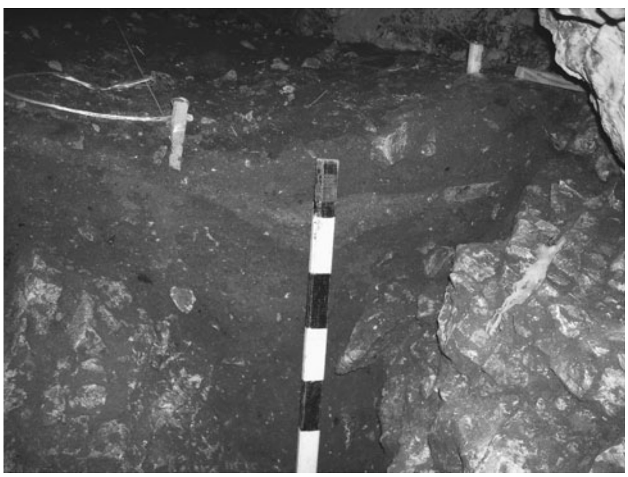

Fig. 6 Stratigraphical cross section of the Sukharysh cave\

Table 2 Description of sediments in the Sukharysh cave

Layer	Depth (cm)	Lithology
1	0–5	Humus loamy sand
2	5–70	Grey loam
3	70–130	Brownish-grey loam
4	130–170	Brown loam

Materials and methods

Stratigraphy and dating

A 1 m^2 soil-pit was collected at the Sukharysh cave entrance for the sediment study. The soil-pit was systematically sub-sampled at 5 cm intervals through all the lithologic levels. The stratigraphical cross section of the Sukharysh cave reveals layers of loam and humus loamy sand (Fig. 6; Table 2). The Sukharysh cave sediments were mainly formed as a result of the lifetime activity of various predators (fox, badger and marten). That is why they are characterized by large quantities of prey skeletal remains from large and small mammals. Visual inspection revealed no signs of bioturbation activity by small mammals (no fossil molehills or burrows). Samples were taken for pollen analysis, plant macrofossil analysis and mammal fossil bone analysis from every horizon. Plant pollen and spores were found in all the selected samples. Plant macrofossils occur from the upper horizons of brownish-grey loam and above (60–0 cm depth).

Radiocarbon analysis of the small mammal fossil bones extracted from the sediment was performed in the Laboratory for Palaegeography and the Quaternary Geochronology, Geography and Geoecology Department, Saint Petersburg State University (Table 3). Fossil bones were used for radiocarbon analysis when the available amount of plant fossils was not sufficient. Previous studies (Smirnov 1990; Kuzmina 2009) showed no inversions of radiocarbon dates obtained for micromammal bone remains from cave deposits of Southern Urals and Trans-Urals, therefore the impact of possible bioturbation could be regarded as negligible. The sample for radiocarbon dating (200 g) from the depth of 40–45 cm. contained micromammal bone remains that were uniform in color and fossilization. The radiocarbon dates were calibrated using CalPal, University of Cologne 2006 (B. Weninger, O. Jöris, U. Danzeglocke, www.calpal.de). AMS-dating of the seeds of *Chenopodium hybridum* (45 mg) was performed in Beta Analytic's Radiocarbon Dating Laboratory (Miami, USA). The Calendar Calibrated result is calculated from the conventional radiocarbon age and is listed as the "Calibrated age (2σ range)" for each sample.

Table 3 Radiocarbon dates from the Sukharysh cave deposits

Sample	Dated material	Method	Lab. code	^{14}C age (B.P.)	Calibrated age (2σ range)
15–20 cm	Seeds	AMS	Beta-300987	290 ± 30	A.D. 1500–1600
40–45 cm	Small mammals bones	Standard	LU-6475	6800 ± 760	7650 ± 800 B.P.

Pollen analysis

For pollen analysis, sampling from the Sukharysh cave was carried out at 5 cm intervals and all 34 samples were prepared using standard chemical methods. This was with HF and heavy liquid (cadmium iodide) separation and excluded acetolysis (Faegri and Iversen 1989). *Lycopodium* tablets (Batch No. 177745) were added for the estimation of pollen concentrations (Stockmarr 1971). This method was used in order to extract pollen and spores from mineral carbonate sediments with low concentrations of organic fossils. Pollen identification was carried out using an Olympus BX51 microscope at ×400 magnification. Aids to pollen identification included the pollen reference collection at the Institute of Plant and Animal Ecology UD RAS (Yekaterinburg) and the pollen atlases of Kuprianova (1965), Kuprianova and Alyoshina (1972) and Reille (1995, 1998). The pollen sum consists of terrestrial arboreal (AP, tree and shrubs) and non-arboreal (NAP, herbs) pollen and excludes the pollen of aquatic plants and spores of mosses and ferns. Their representation is expressed as percentages of the pollen sum. In most instances a pollen sum of 201–1,099 was achieved. Only in the sample from 130 cm depth were as few as 101 pollen grains counted. Programs TILIA and TILIA GRAPH were used (Grimm 1991) for calculations and drawing of the diagram. Zonation of the diagram is based on (1) the proportions of tree and herb pollen taxa (Pollen Zones: PZ) and (2) the presence and proportions of the local pollen types in AP and NAP groups. These PZs were verified with local pollen zones based on square-root transformation of the percentage data and stratigraphically constrained cluster analysis by the method of incremental sum of squares (Grimm 1987).

Pollen types of herbs considered to be human impact indicators were grouped into three groups following Behre (1981), Poska et al. (2004) and Gaillard (2007). These groups were ruderal communities, pastures and meadows, and cultivated land.

Non-pollen palynomorphs

The non-pollen palynomorphs (NPP) were counted in the samples prepared for routine pollen analysis. The types of NPP identified follow Navarro Camacho et al. (2000), van Geel (2001) and van Geel et al. (2003). No taxonomic identification of Nematode bodies was performed. Representation of NPP is expressed as percentages of the pollen sum.

Plant macrofossil analysis

The sediment from 15 samples (about 8 l for each) was prepared for plant macrofossil analysis using standard methods (Nikitin 1969). The sediment was sieved with water using a 0.2 mm mesh. Plant macrofossils were identified using a Zeiss Stemi 2000-C stereomicroscope at ×10–40 magnification. Macrofossil identifications were made using the seed reference collection at the Institute of Plant and Animal Ecology UD RAS (Yekaterinburg), and the keys of Dobrokhotov (1961), Katz et al. (1965) and Velichkevich and Zastawniak (2009).

To detect human impact indicators, the plant macrofossil taxa were divided into indigenous and adventive components of the Southern Trans-Urals flora. Macrofossil taxa of the adventive component were divided into three groups: ruderal plant species, segetal plant species, and cultivated plants (Nikitin 1983).

Results

Pollen analysis

Pollen data of recent forest-steppe vegetation

Interpretation of fossil pollen spectra is largely based on their comparison with pollen spectra of modern vegetation of the area under study. Eight surface soil samples were studied for the palynological characteristics of modern forest-steppe vegetation of the Southern Trans-Urals territory (Table 4).

Pollen spectra of modern forest-steppe plant communities are generally characterized by relatively high arboreal pollen content (Table 5). The pollen spectra are dominated by *Betula pubescens*-type and *Pinus sylvestris* pollen. The content of *B. pubescens*-type pollen in birch woodland stands reaches 35%, while in meadow communities its content reaches a maximum value of 52.8%. *Betula pubescens*-type pollen is morphologically close to the pollen of *B. pendula* and *B. pubescens*. The geographical range of *B. pendula* and *B. pubescens* covers the whole

Table 4 Site information for the modern pollen surface sample from forest-steppe vegetation of the Southern Trans-Urals

No.	Coordinates	Altitude (m)	Material	Vegetation type	Main taxa
1	54°56.563′N 61°21.164′E	254	Soil	Birch woodland stands	*Betula*, *Rosa*, *Cerasus fruticosa*, Rosaceae, Fabaceae, Poaceae, Caryophyllaceae, Lamiaceae, Asteraceae
2	54°40.492′N 61°14.761′E	244	Soil	Steppe meadow	*Stipa*, *Artemisia*, Poaceae, Rosaceae, Caryophyllaceae, Asteraceae
3	54°25.150′N 60°57.047′E	273	Soil	Steppe meadow	*Stipa*, *Artemisia*, *Fragaria viridis*, Rosaceae, Poaceae, Fabaceae, Asteraceae
4	54°12.012′N 60°04.448′E	333	Soil	Pine stands	*Pinus sylvestris*, *Larix sibirica*, *Betula*, *Rosa*, Poaceae, Rosaceae, Ericaceae, Fabaceae, Asteraceae
38	54°19.639′N 59°19.214′E	590	Soil	Steppe meadow	*Stipa*, Poaceae, *Artemisia*, *Fragaria viridis*, Rosaceae, Fabaceae, Rubiaceae, Caryophyllaceae, Asteraceae
39	54°44.351′N 60°07.349′E	397	Soil	Birch woodland stands	*Betula* sp., *Populus tremula*, *Pinus sylvestris*, *Trifolium*, *Stipa*, Asteraceae, Rosaceae, Fabaceae, Apiaceae
40	54°54.915′N 60°34.134′E	310	Soil	Birch woodland stands	*Betula* sp., *Stipa*, Asteraceae, Rosaceae, Fabaceae, Apiaceae, Caryophyllaceae
41	55°28.106′N 61°21.649′E	186	Soil	Steppe meadow	Poaceae, Rosaceae, Fabaceae, Apiaceae, Asteraceae

Urals. Both types of birch form native forest formations in the forest-steppe and steppe of the Southern Trans-Urals and Western Siberia (Usoltsev 2001). With the distributional pattern of birch in the area under study, *B. pubescens*-type pollen represents a regional component of the pollen spectrum reflecting the growth of birch woodland stands in the Southern Trans-Urals forest-steppe. The highest concentration of *P. sylvestris* pollen (89.7%) is characteristic of the pollen spectrum of pine forest outliers; in meadow communities its concentration reaches a maximum value of 55.4%. *Pinus sylvestris* grows as a rare pine forest outlier on the plain parts of the forest-steppe and steppe of the Southern Trans-Urals; it also forms a mountain pine forest belt to the west of the area under study in the South Ural Mountains (Fig. 4). As the regional communities indicate the absence of pine in the local vegetation of the Southern Trans-Urals forest-steppe, it is entering the pollen spectra of birch woodland stands and meadow communities through wind transport. Rare pollen grains of *Abies sibirica* and *Picea* occur in modern pollen spectra. The pollen of *Picea* is dominated by *P. obovata* which, together with *A. sibirica*, forms the belt of dark-coniferous southern boreal (Southern taiga) forests in the central mountain part of the Southern Urals (Kulikov 2005). It is rather difficult to determine which species the *Picea* pollen belongs to, as the Urals is a hybrid zone of *P. obovata* and *P. abies*. Even if the morphological character of spruce demonstrates that it belongs to *P. obovata*, its genetic markers show that it can belong to both *P. obovata* and *P. abies* (Usoltsev 2001; Kulikov 2005). Dark-coniferous species do not grow on the plain part of the Trans-Ural forest-steppe. The pollen of broad-leaved species occurs sporadically. *Tilia cordata*, *Quercus robur*, *Ulmus laevis* and *U. scabra* do not grow in the forest-steppe of the Southern Trans-Urals, having their border 50 km to the west of the area under study, mostly on the western slope of the Southern Urals (Gorchakovsky 1968). The sporadic occurrence of dark-coniferous and broad-leaved species pollen indicates that it was transported here by wind. In fossil pollen spectra only a significant increase of the dark-coniferous and broad-leaved pollen content can indicate the expansion of these species in the areas adjacent to the region under study. Rare pollen grains of *Alnus glutinosa*-type belong to *A. incana* and *A. glutinosa.* Both alder species grow along the banks of the rivers in the forest-steppe zone of the Southern Trans-Urals, with a higher percentage of *A. incana* (Kulikov 2005).

In the non-arboreal pollen group (NAP) Poaceae (0.2–20.3%), *Artemisia* (0.7–14.7%) and Chenopodiaceae (1.1–5.2%) are predominant. Rare pollen grains of Asteraceae, Rosaceae, Lamiaceae, Caryophyllaceae, Fabaceae, Rubiaceae etc. occur. The herbaceous pollen on the whole reflects the typical major families of modern forest-steppe and steppe vegetation. In the group of higher spore-bearing plants, spores of Polypodiophyta, Bryales and *Sphagnum* occur sporadically.

Fossil pollen records from the Sukharysh cave

The palynoflora of the Sukharysh cave consists of 53 taxa, including 10 arboreal taxa. It is the pollen of a boreal floristic complex, i.e. fir (*Abies sibirica*), spruce (*Picea*)

Table 5 Pollen spectra of modern forest-steppe vegetation in the Southern Trans-Urals

Vegetation type	Pine stands	Birch woodland stands			Steppe meadow		
Number of samples	1	3			4		
Value (%)		Min	Max	Mean	Min	Max	Mean
Larix	0.2	0.9	0.9	0.9	0.2	0.2	0.2
Abies	–	0.6	0.6	0.6	0.2	0.2	0.2
Picea	–	1.5	1.5	1.5	0.4	2.8	1.6
Pinus sylvestris-type	89.7	17.7	49.7	33.7	31.3	55.4	38.2
Betula pubescens-type	5.7	12.1	35.0	23.6	18.2	52.8	31.3
Alnus glutinosa-type	–	0.0	0.9	0.5	0.0	1.2	0.3
Quercus robur-type	–	0.0	0.3	0.2	0.0	1.3	0.3
Tilia cordata-type	–	0.0	0.6	0.3	0.0	0.4	0.1
Ulmus glabra-type	–	–	–	–	0.0	0.4	0.1
AP	95.6	52.7	66.7	59.7	54.8	86.8	71.6
Poaceae	0.2	7.0	20.3	13.6	4.0	23.9	10.7
Cerealia-type	–	0.0	1.5	0.8	0.0	2.5	0.5
Artemisia	0.7	10.3	11.8	11.1	2.6	14.7	5.8
Chenopodiaceae	1.1	1.3	5.2	3.2	1.8	4.6	3.2
Cyperaceae	0.9	0.0	1.3	0.6	0.0	1.4	0.3
Asteroideae	0.2	1.8	2.5	2.2	0.2	1.5	0.8
Cichorioideae	0.2	0.0	2.4	1.2	0.0	2.4	1.1
Rosaceae	–	0.6	6.8	3.7	0.4	2.2	1.1
Plantago	–	0.3	1.7	1.0	0.0	1.3	0.4
Polygonaceae	–	0.0	1.8	0.9	0.0	1.4	0.5
Fabaceae	–	0.0	0.9	0.5	0.0	1.6	0.3
Brassicaceae	–	0.0	1.7	0.8	0.0	0.5	0.1
Apiaceae	0.2	–	–	–	0.0	0.8	0.2
Caryophyllaceae	–	–	–	–	0.0	0.7	0.5
Rubiaceae	–	–	–	–	0.0	2.7	0.6
Ranunculaceae	–	–	–	–	0.0	0.8	0.3
Thalictrum	–	0.0	0.9	0.5	–	–	–
Lamiaceae	–	–	–	–	0.0	1.4	0.5
Scrophulariaceae	–	–	–	–	0.0	0.2	–
Geranium	–	–	–	–	0.0	0.2	0.1
Convolvulus arvensis-type	0.2	–	–	–	0.0	0.2	–
Pollen gen. indet.	0.7	0.6	0.6	0.6	0.2	2.7	1.5
NAP	4.4	33.3	47.3	40.3	13.2	45.2	28.4
Typha	–	–	–	–	0.0	0.3	0.1
Polypodiophyta	–	0.3	2.1	1.2	0.0	0.3	0.1
Lycopodium clavatum-type	–	0.0	0.4	0.2	–	–	–
Bryales	1.7	1.5	1.5	1.5	0.6	3.0	1.8
Sphagnum	–	–	–	–	–	0.7	0.4

and pine (*Pinus sylvestris*), together with small-leaved species, i.e. birch (*Betula pubescens*-type) and alder (*Alnus glutinosa*-type). The Nemoral group includes pollen grains of oak (*Quercus robur*-type), lime (*Tilia cordata*-type) and elm (*Ulmus glabra*-type). Pollen of willow (*Salix*) and the Caprifoliaceae family was identified.

In the NAP group 37 taxa have been identified, mostly to family level. Pollen grains of major families of the Southern Trans-Urals modern steppe flora prevail: Asteraceae, including *Artemisia*, Asteroideae (*Matricaria*-type, *Senecio*-type, *Saussurea*-type, *Cirsium*-type, *Echinops*, *Centaurea*) and Cichorioideae (*Scorzonera*-type), Poaceae, Fabaceae, Rosaceae

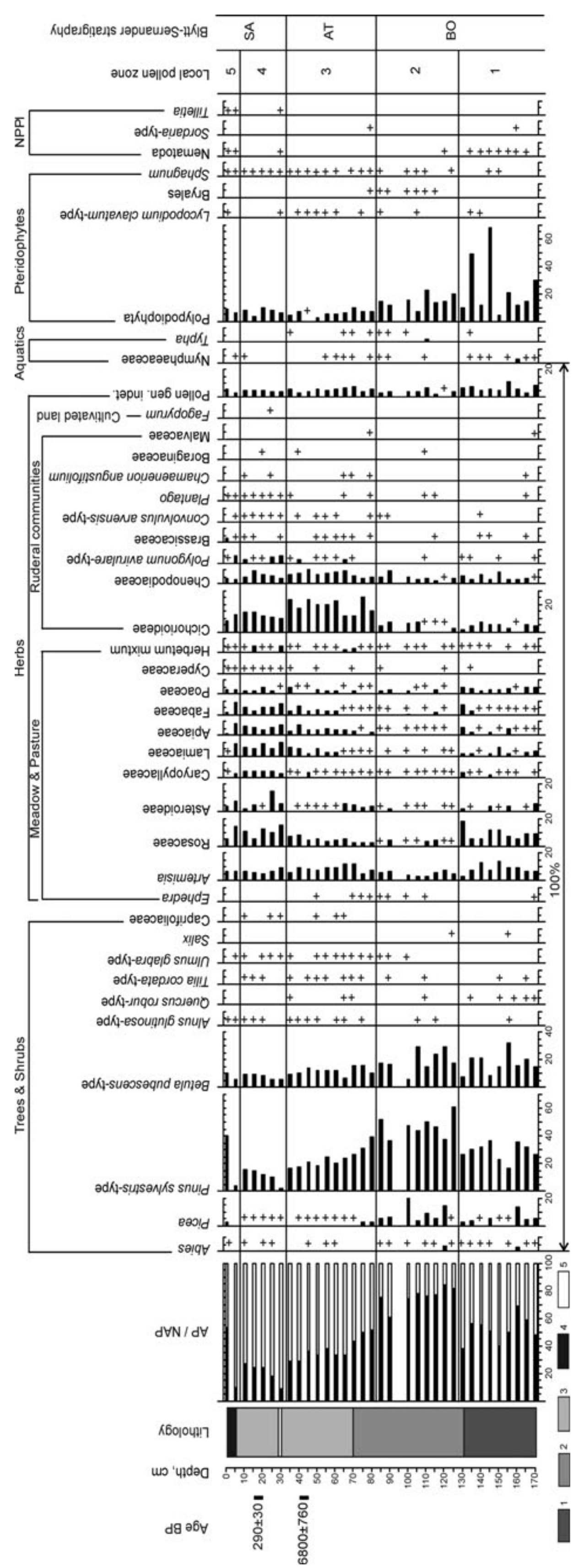

Fig. 7 Pollen percentage diagram for the Sukharysh cave; *1* brown ▶ loam, *2* brownish-grey loam, *3* grey loam, *4* humus loamy sand, *5* non-depositional hiatus

(including *Sanguisorba*), Caryophyllaceae, Brassicaceae, Cyperaceae, Chenopodiaceae, Lamiaceae, Apiaceae and Ranunculaceae (including *Thalictrum*), Scrophulariaceae, Polygonaceae etc. *Ephedra* pollen is recorded.

Aquatic plants are represented by rare pollen (*Typha latifolia*-type and Nymphaeaceae). Higher spore-bearing plants are represented by spores of fern (Polypodiophyta), club moss (*Lycopodium clavatum*-type), true moss (Bryales) and sphagnum moss (*Sphagnum*).

In the pollen spectra of the Sukharysh cave sediments, pollen of anthropogenic indicators is divided into three groups. The pollen group of ruderal plant species includes pollen types of Boraginaceae, Brassicaceae, Chenopodiaceae, Cichorioideae, *Convolvulus arvensis*-type, Malvaceae, *Chamaenerion angustifolium*, *Plantago* and *Polygonum aviculare*-type. Pollen types of Apiaceae, *Campanula*, Asteroideae, Fabaceae, *Geranium*, *Knautia*, *Polygala vulgaris*-type, Ranunculaceae, Rubiaceae and *Veronica* form the pollen group of pasture plant species. The pollen group of cultivated land plant species includes the pollen type of *Fagopyrum*. *Artemisia* pollen has been excluded from the group of anthropogenic indicators as the flora of the forest-steppe and steppe of the Southern Trans-Urals is characterized by 23 species of this genus belonging to meadow-steppe and steppe habitats. Among them only *A. absinthium*, *A. siversiana* and *A. vulgaris* belong to ruderal plant species.

The pollen diagram has been divided into 5 pollen zones (Fig. 7).

Pollen zone (PZ) 1 (depth of 170–130 cm) represents brown loam at the base of the section. This zone is characterized by high arboreal pollen (AP) content (40–85%). AP is dominated by pollen of *Pinus sylvestris* and *Betula pubescens*-type. Pollen of *Picea* is abundant. Pollen of *Abies sibirica*, *Quercus robur*-type and *Tilia cordata*-type occurs sporadically. In the NAP group, pollen grains of *Artemisia*, Rosaceae, Chenopodiaceae, Cichorioideae and Poaceae are predominant. Pollen of forbs is diverse with the occurrence of Lamiaceae, Dipsacaceae, *Scorzonera*-type and *Echinops* (their species grow on dry meadows of the steppe and forest-steppe zone).

PZ 2 (depth of 130–78 cm) represents the brownish-grey loam. In the pollen spectra AP strongly prevails with a maximum content of 85%. In comparison with PZ 1 the pollen concentration of *Pinus sylvestris* and *Picea* has increased. The pollen of *Ulmus glabra*-type has been identified. The herbaceous pollen content has reduced as has the pollen concentration of all the forbs. *Ephedra* pollen is present in this zone. The concentration of Polypodiophyta spores has decreased.

PZ 3 (78–30 cm) represents the upper part of the brownish-grey and the major part of the grey loam. It is characterized by a high NAP content (up to 60–75%). The pollen of ruderal plant species prevails with the pollen of Cichorioideae and Chenopodiaceae dominating. Pollen of *Polygonum aviculare*-type, Brassiaceae, *Convolvulus arvensis*-type and *Chamaenerion angustifolium* has become a permanent component of the pollen spectra. *Artemisia* pollen is also abundant. The pollen of forbs is diverse with pollen grains of Rosaceae, Lamiaceae, Apiaceae and Fabaceae dominating. Poaceae pollen occurs in this zone. The pollen content of *Pinus sylvestris* has become lower and *Picea* pollen has sharply decreased (sporadic occurrence). Pollen grains of *Tilia cordata*-type and *Ulmus glabra*-type have become a permanent component of the pollen spectrum. The spore concentration of ferns has also become lower.

PZ 4 (30–5 m) characterizes the upper part of the grey loam. It is characterized by a high NAP content with a maximum value of 70–90%. The pollen of meadow and pasture plants (such families as Rosaceae, Asteroideae, Caryophyllaceae, Lamiaceae, Apiaceae and Fabaceae) is abundant. The pollen of ruderal plant species is also very frequent; pollen grains of Cichorioideae and Chenopodiaceae prevail, although the pollen content of Cichorioideae has reduced in comparison with the previous PZ. The concentration of *Polygonum aviculare*-type pollen has increased. The pollen of *Convolvulus arvensis*-type and *Plantago* has become a permanent component of the pollen spectra of this zone. *Fagopyrum* pollen is present. The diversity and content of spores have become lower.

PZ 5 (5–0 cm) characterizes the surface sediment with an increase of AP up to 57%. *Pinus sylvestris* pollen is predominant (42.5%) and the pollen concentration of *Picea* has increased. Within the NAP group, pollen of Rosaceae, Asteraceae and *Artemisia* prevails. Pollen of forbs is of sporadic occurrence. The concentration of Cichorioideae and Chenopodiaceae pollen has also decreased.

Plant macrofossil analysis

1,856 plant macrofossils were found in the sediment samples taken from the Sukharysh cave (Table 6). 52.9% of the total remains represent fruits and seeds. Such taxa as *Triticum*, *Chenopodium* spp. and *Scirpus lacustris* are characterized by significant concentrations of fragmented remains. Subfossils form the major part of the plant macrofossils found; only fragments and caryopses of *Triticum aestivum* are charred (Fig. 8a).

The plant macrofossils belong to 49 taxa of vascular plants from 19 families (Table 6). Of them 61.2% of the total number of taxa was identified to species level, 28.6% to genus level, and 10.2% to family level. 96% of the macrofossils studied belong to flowering plants, represented by seeds of monocotyledon and dicotyledon plants. The trees are represented by *Betula pendula* fruits; shrubs by *Cotoneaster* fruit. Mesophyte seeds (*Amoria repens*, *Betula pendula*, *Chenopodium album*, *Ch. hybridum*, *Ch. rubrum*, *Ch. polyspermum*, *Arctiun* sp., *Galeopsis* sp., *Sonchus* sp., *Urtica dioica*, *Polygonum aviculare* etc.), xeromesophyte seeds (*Fragaria viridis*, *Lappula* sp., *Cotoneaster* sp., *Dracocephalum thymiflorum*, *Potentilla argentea*, *Teloxys aristata* etc.), hygrophyte seeds (*Eleocharis palustris*, *Lycopus europaeus*, *Bidens* sp.), mesohygrophyte seeds (*Persicaria lapathifolium*), hygromesophyte seeds (*Stachys palustris*) and hydrohygrophyte seeds (*Scirpus lacustris*) occur among the macrofossil taxa. Plant macrofossils of different phytocoenotic groups have been found: forest plants (*Betula pendula*), meadow plants (*Amoria repens*, *Medicago lupulina*, *Oberna behen*, *Potentilla argentea*), steppe meadow plants (*Lithospermum officinale*, *Cotoneaster* sp., *Fragaria viridis*, *Dracocephalum thymiflorum*) and water-swamp plants (*Bidens* sp., *Eleocharis palustris*, *Lycopus europaeus*, *Mentha* sp., *Persicaria lapathifolium*, *Scirpus lacustris*, *Solanum* sp. etc.).

Plant macrofossils belong to 30 taxa of indigenous flora and to 19 taxa of adventive flora of the Southern Trans-Urals. Plant macrofossils of 15 taxa of indigenous Southern Trans-Urals flora belong to ruderal plant species (*Amoria repens*, *Arctium* sp., *Bidens* sp., *Chenopodium polyspermum*, *Dracocephalum thymiflorum*, *Lithospermum officinale*, *Lycopus europaeus*, *Medicago lupulina, Potentilla argentea*, *Stachys palustris*, *Urtica dioica*) and ruderal-segetal plant species (*Chenopodium album*, *Oberna behen*, *Persicaria lapathifolium*).

Plant remains of adventive Southern Trans-Urals species are divided into deliberately imported taxa (cultivated plants) and taxa imported by chance (xenophytes). The xenophytes are divided into two groups: archaeophytes and kenophytes.

Archaeophytes are plant species that were imported to the Southern Trans-Urals flora before the 17th century and are dominated by plant macrofossils of ruderal plant species (*Amarantus retroflexus*, *Atriplex patula*, *Chenopodium hybridum*, *Chenopodium rubrum*, *Cannabis ruderalis*, *Cynoglossum officinalis*, *Polygonum aviculare*, *Solanum* sp., *Thlaspi arvense*) and segetal plant species (*Galeopsis* sp., *Lappula squarrosa*, *Sonchus* sp., *Neslia paniculata*, *Viola* sp., *Fallopia convolvulus*). The kenophytes brought to the Southern Trans-Urals flora in the 17th century include plant macrofossils of segetal-ruderal plant species of *Teloxys aristata* (Fig. 8c). Despite the fact that *Amaranthus retroflexus* (Fig. 8d) spread under anthropogenic influence from North and South America to the whole of

Table 6 Composition of plant macrofossil complexes from the Sukharysh cave (*—fragment of macrofossils)

Plant macrofossil complexes			I					II				III
Depth, cm			60-55	55-50	50-40	45-35	35-30	25-20	20-15	15-10	10-5	5-0
Genus/species	Ecological-coenotical groups	Remains										
Panicum miliaceum	Xeromesophyte, cultivated	caryopsis										1
Triticum aestivum	Mesophyte, cultivated	caryopsis						2	64*	12	13+12*	70+230*
Poaceae gen. indet.	Polyzonal	caryopsis										3
Carex sp.	Polyzonal	nuts										7+2*
Eleocharis palustris	Hygrophyte, water-swamp	fruits										2
Scirpus lacustris	Hydrohygrophyte, water-swamp	fruits							2			28+73*
Betula pendula	Mesophyte, boreal	fruits										4
Cannabis ruderalis	Mesophyte, ruderal	nuts										6*
Urtica dioica	Mesophyte, ruderal	seeds										260
Fallopia convolvulus	Mesophyte, segetal	fruits				1+1*						9*
Polygonum aviculare	Mesophyte, ruderal	fruits									4	10
Polygonum sp.	Polyzonal	fruits			1							8*
Persicaria lapathifolium	Mesohygrophyte, ruderal-segetal	fruits										1+2*
Atriplex patula	Mesophyte, ruderal	seeds										1
Chenopodium album	Mesophyte, ruderal-segetal	seeds		2	5+2*	2+1*	1		10+2*	1	5+1*	60+110*
Chenopodium hybridum	Mesophyte, ruderal	seeds	1+1*			1+1*		1*	16+6*	2+4*	11+4*	197+296*
Chenopodium polyspermum	Mesophyte, ruderal	seeds				2						18+4*
Chenopodium rubrum	Mesophyte, ruderal	seeds							1	1		12
Chenopodium sp.	Polyzonal	seeds			2	1						70
Teloxys aristata	Xeromesophyte, segetal-ruderal	seeds										5
Chenopodiaceae gen. indet.	Polyzonal	seeds									1	2
Amaranthus retroflexus	Mesophyte, ruderal	seeds										24
Oberna behen	Mesophyte, ruderal-segetal	seeds										13
Caryophyllaceae gen. indet.	Polyzonal	seeds										20
Papaver sp.	Mesophyte, cultivated	seeds										1
Neslia paniculata	Mesophyte, segetal	seeds										4*
Thlaspi arvense	Mesophyte, ruderal	seeds										2*
Cotoneaster sp.	Xeromesophyte, steppe meadow	fruits									1*	
Fragaria viridis	Xeromesophyte, steppe meadow	fruits						1*		1		2
Potentilla argentea	Xeromesophyte, ruderal	fruits										8
Potentilla spp.	Polyzonal	fruits										12
Rosaceae gen. indet.	Polyzonal	fruits				5						
Amoria repens	Mesophyte, ruderal	seeds										3
Medicago lupulina	Mesophyte, ruderal	seeds							1		2*	
Trifolium sp.	Polyzonal	seeds										7
Viola sp.	Polyzonal, segetal	seeds										11+8*
Apiaceae gen. indet.	Polyzonal	fruit				1						1+3*
Cynoglossum officinalis	Xeromesophyte, ruderal	seeds										1
Lappula squarrosa	Xeromesophyte, segetal	nutlets		4							1	4
Lithospermum officinale	Xeromesophyte, ruderal	nutlets										1
Dracocephalum thymiflorum	Xeromesophyte, ruderal	nutlets										5
Galeopsis sp.	Mesophyte, segetal	nutlets										2+5*
Lycopus europaeus	Hygrophyte, ruderal	nutlets										1
Mentha sp.	Mesophyte, water-swamp	nutlets										1
Stachys palustris	Hygromesophyte, ruderal	nutlets										2+1*
Solanum sp.	Polyzonal, ruderal	seeds							1			
Arctium sp.	Mesophyte, ruderal	achenes		1								1*
Bidens sp.	Hygrophyte, ruderal	achene										1*
Sonchus sp.	Mesophyte, segetal	achenes										2*
Number of taxa			1	3	3	7	1	3	7	5	8	45
Number of macrofossils			2	7	10	16	1	4	103	21	55	1,637

Europe and Asia after the Age of Discovery, we place this species in the archaeophytes. This is confirmed by the fact that its seeds have been found in the territory of Northern Eurasia in Pleistocene and Holocene sediments. For example, amaranth seeds have been found in the Holocene sediments of Voronezhskaya oblast (Nikitin 1957), in the lower layers of the Holocene peat bog near the village of Bolshoy Karagay on the Irtysh River (Krivonogov et al. 1985), in the Bashkir Pleistocene sediments (Kolesnikova 1957) and in the Kargian flora of the Irtysh River within the territory of Western Siberia (Krivonogov 1988).

Deliberately imported taxa include macrofossils of plants cultivated in this area such as millet (*Panicum miliaceum*), poppy (*Papaver* sp.) and wheat (*Triticum aestivum*). Millet is an archaeophyte that was widely cultivated, but at present grows as a segetal-ruderal plant (Kulikov 2005; Naumenko 2008). Poppy and wheat are kenophytes as they were brought to the Southern Trans-Urals after the Russian population arrived at the beginning of the 17th century (Naumenko 2008). Up to the present wheat has been grown as grain everywhere in the fields, although it is quite often self-seeding and can be found as an undesirable plant around wheat storage and transportation areas. Poppy species (*Papaver rhoeas*, *P. somniferum*) are cultivated as ornamental plants; sometimes they occur as ruderals growing along the roads and in urban areas (Naumenko 2008).

No plant macrofossils were found at the depths of 70–65 cm, 65–60 cm, and 30–25 cm (15 samples were studied). All the detected plant macrofossils represent three plant macrofossil complexes (Table 6).

Plant macrofossil complex 1 (60–30 cm depth) includes occasional macrofossils of *Chenopodium album*, *Ch. hybridum*, *Ch. polyspermum*, *Arctium* sp. etc. from 6 lower samples. These taxa are characteristic of forest-steppe and steppe meadow plant communities. The majority of taxa are mesophytes.

No macrofossils have been found in sediments at the depth of 30 cm. However, the composition of overlying plant macrofossil complexes stands in marked contrast to that of the underlying complexes. The former are characterized by a substantial rise in weed plant remains together with the presence of cultivated plant remains (*Triticum aestivum*). This could indicate a non-depositional hiatus in Sykharysh cave at this depth.

Plant macrofossil complex 2 (25–5 cm depth) is characterized by increased taxonomic diversity and abundance of plant macrofossils. A fragment of *Cotoneaster* sp. fruit was found here. Species of *Cotoneaster melanocarpa* and *C. integerrimus* are widely spread in the Southern Trans-Urals forest-steppe zone. Fruits and seeds of such meadow herbs of the forest-steppe and steppe as *Fragaria viridis*, *Chenopodium album*, *Ch. rubrum*, *Ch. hybridum*, *Medicago lupulina* and *Lappula squarrosa* occur among the herbaceous plant macrofossils. Mesophyte and xeromesophyte taxa prevail among the meadow herbs. Also fruits of the water-swamp plant *Scirpus lacustris* were found here. However, charred caryopsides of *Triticum aestivum* dominate this complex.

Plant macrofossil complex 3 (5–0 cm depth) is characterized by the richest species diversity. Sporadic birch fruits (*Betula pendula*) occur. Plant remains of meadow communities, such as *Fragaria viridis*, *Galeopsis* sp., *Lithospermum officinale*, *Medicago lupulina*, *Chenopodium hybridum*, *Ch. polyspermum*, *Fallopia convolvulus*, *Oberna behen*, *Trifolium repens* etc. are abundant. Mesophytes and xeromesophytes are predominant. Water-swamp plant remains occur (*Carex* sp., *Eleocharis palustris*, *Scirpus lacustris* etc.). Fragments and whole caryopses of *Triticum aestivum* are abundant. A caryopsis of *Panicum miliaceum* was found here (Fig. 8b).

Discussion

The palaeobotanical data from the Sukharysh cave and their comparison with other data available for the Southern Trans-Urals enable reconstruction of the vegetation history in the region. Pollen data and the results of the plant macrofossil analysis correlate well and complement each other. On the whole, the pollen spectra reflect regional vegetation at a sub-zonal formation level; data from plant macrofossil analysis mainly characterize local vegetation and its growth conditions.

The pollen spectra of PZ 1 from the Sukharysh cave in their composition and content of components are close to modern pollen spectra of the meadow communities of the Southern Trans-Urals forest-steppe. The AP-NAP ratio

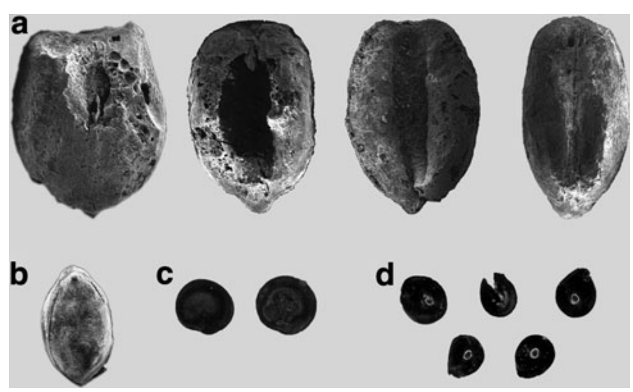

Fig. 8 Examples of plant macrofossils excavated from the sediments of the Sukharysh cave **a** caryopsis of *Triticum aestivum* (3.5–4 × 3 mm), charred; **b** caryopsis of *Panicum miliaceum* (3 × 1.6 mm), subfossil; **c** seeds of *Teloxys aristata* (0.5 mm), subfossil; **d** seeds of *Amaranthus retroflexus* (1 mm), subfossil

shows approximately equal proportions of arboreal and non-arboreal components of vegetation throughout the forest-steppe pollen spectra (Fig. 7). Forbs-and-*Artemisia* communities were widely spread. At the same time the pollen spectra of PZ 1 also reflect the existence of small woodland stands in the region. Birch is likely to have formed such woodland stands.

PZ 2 shows expansion of forest areas. High frequencies of pine pollen and the increase in spruce pollen concentration are explained by expansion of light- and dark-coniferous forests both in the Southern Ural Mountains and on the plain territories of the Southern Trans-Urals. Forest expansion occurred due to an increase in humidity.

As no absolute age determination data are available for the pollen zones no precise conclusions on the timing of the palaeoecological events they reflect could be made. However, the pollen spectra of PZ 1 and PZ 2 are comparable to pollen spectra from Lake Uvildy which correspond to the Boreal period (9300–8000 yr B.P.). Lake Uvildy pollen spectra (Fig. 1) corresponding to this period are characterized by practically equal concentrations of birch and pine pollen and the presence of spruce and broad-leaved species pollen. Thus they reflect the expansion of pine-birch forests across the meadow communities on the north of the Southern Trans-Urals forest-steppe zone (Khomutova et al. 1995; Subetto et al. 2004). However, the pollen spectra of these pollen zones differ from modern pollen spectra of the Southern Trans-Urals forest-steppe in having a high *Picea* pollen content. Generally, the high concentration of coniferous plant pollen in this pollen zone could reflect the expansion of pine forest outliers among birch woodland stands or light-coniferous forests on the east foothills of the Southern Urals and dark-coniferous forests in the South Ural Mountains. This correlates with vegetation reconstructions carried out on the basis of pollen spectra from the Southern Urals peat bogs (Table 1). Birch, spruce and pine forests with small quantities of larch, Siberian pine and broad-leaved species were typical of the central mountain part of the Southern Urals in the Boreal period. The eastern slope was dominated by birch and pine forests with small quantities of larch and spruce (Panova 1982).

According to the archaeological data (Mosin 2000), some isolated Mesolithic settlements existed on the Southern Trans-Urals territory until the end of the Boreal period (about 8000 year B.P., Fig. 2). The Mesolithic cultures inhabited the forest zone along the eastern slope of the Southern Urals, as well as the forest-steppe zone of the Southern Trans-Urals plains. No palaeobotanical studies in relation to the Mesolithic sites in the territory under study have ever been conducted. This does not permit the assessment of anthropogenic influence on the vegetation in the surroundings of the settlements. At the same time, PZ 1 of Sykharysh cave (Fig. 7) is characterized by the high concentration of pollen of different apophytic plant taxa, such as Apiaceae, Poaceae, Fabaceae, Asteroideae (*Senecio*-type) and Cichorioideae (*Scorzonera*-type). The presence of this pollen shows the development of the meadows in this area, as the plants of these taxa grow mainly in natural meadow communities of the forest-steppe and steppe zones. Pollen of Chenopodiaceae, *Polygonum aviculare*-type, *Plantago* and *Convolvulus arvensis*-type indicates the existence of ruderal habitats, paths and roads. As the Southern Trans-Urals people in the Mesolithic period were mostly hunter-gatherers, such a life style and low population density did not cause dramatic changes in the vegetation at the perimeter of their activity.

According to the radiocarbon date of 6800 ± 760 year B.P. and the Blytt-Sernander stratigraphical scale, the lower part of the grey loam in Sykharysh cave accumulated in the first half of the Atlantic period. The pollen spectra of PZ 3 reflect significant changes in the vegetation that occurred in that period. The pollen spectra show the increase of herbaceous pollen concentration, which reflects the expansion of open meadows (Fig. 7). The *Artemisia* content in the plant communities has increased. The decrease of tree species pollen indicates the decline of spruce and a reduction in the area occupied by birch woodland stands and pine forest outliers. Pollen grains of broad-leaved species *Ulmus*, *Quercus robur*-type and *Tilia cordata*-type become the permanent component of the pollen spectra. However, sporadic occurrence of this pollen does not indicate the expansion of broad-leaved species within forest formations on the Southern Trans-Urals plain territory, as modern pollen spectra of the Southern Trans-Urals forest-steppe contain sporadic pollen of the broad-leaved species, although these do not grow in natural forest communities. PZ 3 correlates with the pollen data from Lake Uvildy (Fig. 1) which reflect the existence of forest-steppe meadow communities and birch and pine forests with small quantities of broad-leaved species in the north of the forest-steppe in the Atlantic period (Khomutova et al. 1995; Subetto et al. 2004). In the central mountain regions of the Southern Urals spruce forest gave way to pine forest as the dominant tree species shifting to the higher levels (Table 1). The content of broad-leaved species in the forests has increased (Panova 1982).

At the turn of the Boreal and Atlantic periods, Neolithic culture settlements appeared on the Southern Trans-Urals territory (Mosin 2000). No radiocarbon dates are available for an absolute chronology of the Southern Trans-Urals Neolithic period. The dating of Middle Trans-Urals Neolithic artifacts and the proximity of the Southern Urals and Middle Urals Neolithic complexes show that the Neolithic period in the South Trans-Urals occurred during the period 5000–4000 B.C. The artifacts are mostly located along the banks of the rivers and the shores of lakes in the northern parts of the forest-steppe zone where forest formations prevail (Fig. 2). At the same time it was found that Neolithic cultures of the Southern Trans-Urals were close to those of Middle Trans-Urals, which could indicate that the population of the North and South regions were connected to each other, and that migration of people from the South to the North might have taken place (Mosin 2000). No palaeobotanical studies on Neolithic sites in the Southern Trans-Urals forest-steppe territory under study have been conducted as yet. However, the palynological profile from the Sukharysh cave provides some information on the human impact in the area. The pollen spectra of PZ 3 are characterized by high pollen concentration of such ruderal taxa as Cichorioideae, Chenopodiaceae, Brassicaceae, *Convolvulus arvensis*-type, *Chamaenerion angustifolium* and *Polygonum aviculare*-type (Fig. 7). Plant macrofossils consist of macro-remains of such ruderal plant species archaeophytes as *Chenopodium hybridum*, *Ch. rubrum*, *Medicago lupulina* and *Polygonum aviculare*, and ruderal-segetal and segetal plant species of cultivated land (*Ch. album* and *Fallopia convolvulus*) (Table 6). This could indicate the expansion of ruderal communities, paths and roads in the vicinity of the Sukharysh cave, as it is situated near Neolithic settlements.

On the whole, the palaeobotanical data from the Sukharysh cave show that no dramatic changes in the vegetation of the Southern Trans-Urals forest-steppe occurred under anthropogenic influence for both the periods under consideration. This correlates with the fact that during studies of the Mesolithic and Early Neolithic artifacts in Europe no evidence of significant anthropogenic influence on the vegetation has been found (Kalis et al. 2003).

It must be noted that the pollen diagram of the Sukharysh cave sediments shows sharp changes in practically all the taxa curves at the depth of 30 cm. Sharp changes in the composition of the macrofossil complexes were also noticed. This could indicate a non-depositional hiatus in the Sykharysh cave. A part of the sediments might have been washed out by stream water through a channel to the river.

PZ 4 is distinguished by the absolute dominance of herbaceous pollen that is characterized by the diversity of pollen grains of meadow forbs (Fig. 7). The pollen spectra of this zone are similar in their composition and content to those of modern meadow communities of the Southern Trans-Urals forest-steppe. Meadow herb fruits and seeds prevail in the plant macrofossil complex, which indicates the expansion of meadow communities in the surroundings of the Sukharysh cave. Forest outliers were formed by birch. The presence of pine pollen points to the fact that pine forests might have grown in the submontane and central mountain parts of the eastern slope of the Southern Urals. According to the macrofossil AMS date of 290 ± 30 years B.P., PZ 4 and plant macrofossil complex 2 characterize the plant communities of the southern forest-steppe of the Southern Trans-Urals in cal. A.D. 1500–1600, which corresponds to the final phase of the Subatlantic period. The pollen spectra from Lake Uvildy of the bottom sediments of the final phase of the Subatlantic period are also similar in their composition to modern ones (Fig. 1). They are characterized by birch pollen with small quantities of broad-leaved species (Khomutova et al. 1995; Subetto et al. 2004). Pollen data from the Southern Urals peat bogs indicate the expansion of the birch and pine forests in the central part and on the eastern slope of the Southern Urals (Panova 1982).

The high concentration of meadow plant pollen in PZ 4 indicates the existence of pastures and grazing lands within natural communities of forest-steppe landscapes. This correlates with archeological data which show that farming by nomadic tribes was of a hunter-gathering nature with elements of cattle-breeding and existed in this way in the Southern Trans-Urals territory until the 17th century (Botalov 2000). The concentration of pollen from ruderal communities is also significant. Pollen of *Plantago*, *Convolvulus arvensis*-type and *Polygonum aviculare*-type has become a permanent component of the pollen spectra (Fig. 7). *Fagopyrum* (a cultivated land weed) pollen occurs sporadically. Ruderal plants (*Polygonum aviculare, Chenopodium hybridum*, *Ch. album*) prevail among the plant macrofossils. Segetal plant seeds (*Lappula squarrosa*) also occur (Table 6). The predominance of pollen and macrofossils of ruderal plants indicates a significant spread of waste sites near habitations, roads and paths.

At the same time, PZ 4 and plant macrofossil complex 2 characterize the early farming of the Russian population on the Southern Trans-Urals forest-steppe territory. The presence of wheat caryopsides (*Triticum aestivum*) in complexes starting from the depth of 25–20 cm indicates farming activity by the Russian population in the vicinity of the Sukharysh cave (Table 6). Before the Russians came to the Southern Trans-Urals and Siberia, the nomadic tribes had cultivated land with primitive tools (hoes) and had cultivated barley. The Russians used ploughs, harrows, three-course rotation and fertilizers, so they started to cultivate wheat, rye, oats, barley, pea, buckwheat, millet and hemp. Arable farming in the Urals and Trans-Urals started to spread widely in the 16th–18th centuries due to the development of the mining industry and the exploration of western and eastern slopes of the Urals mountain range and Trans-Urals territories by the Russians (Tataurov 2008). This period is connected with the increase in the weed concentration and the penetration of cultivated cereals into the Southern Trans-Urals flora (Kulikov 2005; Naumenko 2008).

PZ 5 characterizes modern vegetation in the surroundings of the Sukharysh cave. The pollen spectrum is close in its composition and the content of its components to that of modern meadow communities of the Southern Trans-Urals forest-steppe. In the vicinity of the Sukharysh cave, birch woodland stands are widely spread across the meadows. Pine forests are typical of the Southern Urals foothills. At the same time, the pollen spectra and plant macrofossils at the depth of 5-0 cm characterize the farming of the population living in the Southern Trans-Urals forest-steppe from the 17th century till the present time. The pollen of ruderal taxa prevails in the pollen spectra of this pollen zone; macrofossils of archaeophytes belonging to different habitats are predominant in the plant macrofossil complex (Fig. 7, Table 6). At the same time, kenophyte macrofossils (*Teloxys aristata*) and those of cultivated plants (*Triticum aestivum*, *Panicum miliaceum*, *Papaver* sp.) occur here. The presence of kenophyte macrofossils permit the dating of this complex as the late farming period (after the 17th century), especially considering the fact that nowadays, vast territories of the Southern Trans-Urals, the surroundings of the Sukharysh cave in particular, are cropland and cultivated fields.

Conclusion

Palaeobotanical investigation of the sediments from the Sukharysh cave, situated in the Southern forest-steppe zone of the Southern Trans-Urals, recorded significant changes in the vegetation caused by anthropogenic influence (among other factors) during certain Holocene periods.

In the Early Holocene, most probably before the Atlantic period, this territory was occupied by forest-steppe. Forbs-and-*Artemisia* communities and birch woodland stands were widespread. Pine stands occurred sporadically. In the Boreal period, forest formations spread over the area due to the humidity increase. This period correlates with expansion of spruce forest in the Southern Urals mountains. In the Early Atlantic period, approximately at 8-6 ka B.P., probably due to climate aridification, the expansion of open spaces took place with the spread of meadow-steppe forbs to the north. No evidence was found of significant anthropogenic influence on the vegetation of the Southern Trans-Urals in the surroundings of the Sukharysh cave in this period.

The Late Holocene is characterized by significant changes in the vegetation in this territory. Fields, tilled fields and pastures penetrated the natural forest-steppe meadows. Pollen and plant macrofossil taxa typical of ruderal communities and pastures indicate the existence of these at that time. Plant micro and macrofossils of cultivated land weeds and the high concentration of wheat caryopses indicate the development of farming in the forest-steppe Southern Trans-Urals in the Late Sub-Atlantic period after the arrival of the Russian population in this territory in the 17th–18th centuries.

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References

Behre K-E (1981) Anthropogenic indicators in pollen diagrams. Pollen Spores 23:225–245

Botalov SG (2000) Pozdnyaya drevnost' i srednevekov'e [The Late Antiquity and Middle Ages]. In: Ivanova NO (ed) Drevnyaya istotiya Yuzhnogo Zaural'ya [Ancient History of the Southern Trans-Urals. Vol. II. Early Iron Age and the Middle Ages]. South-Urals University Press, Chelyabinsk, pp 207–430 (in Russian)

Coles GM, Gilbertson DD, Hunt CO, Jenkinson RDS (1989) Taphonomy and the palynology of cave deposits. Cave Sci 16: 83–88

Dobrokhotov VN (1961) Semena sornyh rastenii [Seed of weeds]. Selhozizdat, Moskow (in Russian)

Faegri K, Iversen J (1989) Textbook of pollen analysis. Blackburn Press, London

Fernández S, Fuentes N, Carrión JS, González-Sampériz P, Montoya E, Gil G, Vega-Toscano G, Riquelme JA (2007) The Holocene and Upper Pleistocene pollen sequence of Carihuela Cave, southern Spain. Geobios 40:75–90

Gaillard M-J (2007) Archaeological applications. In: Elias SA (ed) Encyclopedia of quaternary science. Elsevier, Amsterdam, pp 2,570–2,595

Gorchakovsky PL (1968) Rasteniya evropeiskikh shirokolistvennykh lesov na vostochnom predele ich areala [The European broad-leaved forest plants at their eastern distribution limits]. Academy of Science USSR, Sverdlovsk (in Russian)

Gorchakovsky PL (1975) Rastitel'nyi mir vysokogornogo Urala [Alpine flora of the Urals]. Nauka, Moscow (in Russian)

Grimm EC (1987) CONISS: a FORTRAN 77 program for stratigraphically constrained cluster analysis by the methods of incremental sum of squares. Comput Geosci 13:13–15

Grimm EC (1991) TILIA and TILIAGRAPH. Illinois State Museum, Springfield

Kalis AJ, Merkt J, Wunderlich J (2003) Environmental changes during the Holocene climatic optimum in central Europe—human impact and natural causes. Quat Sci Rev 20:33–79

Khomutova VI (1978) Sporovo-pylcevoy analiz donnykh otlozheny [Pollen analysis of bottom sediments]. In: Pazarov GV (ed) Landshaftny factor v formirovanii gidrologii ozer Yuzhnogo Urala. Nauka, Leningrad, pp 222–225 (in Russian)

Khomutova VI, Andreeva MA, Davydova NN et al (1995) Southern Ural. Lake Uvildy. In: Davydova NN (ed) The history of lakes of Northern Asia. Nauka, St.-Peterburg (in Russian)

Kolesnikova TD (1957) Chetvertichnye flory Bachkirii [Quaternary flora of Bashkortostan]. Bot J 42:878–889 (in Russian)

Komar IV, Chikishev AG (eds) (1968) Ural I Priural'e [Ural and pre-Urals]. Nauka, Moscow (in Russian)

Krasheninnikov IM (1937) Analis reliktovoy flory Yuzhnogo Urala v svyazi s istoriei rastitel'nosti i paleogeografiei Pleistocena [Analysis of the Southern Urals relict flora in connection with the Pleistocene vegetation history and paleogeography]. Sovetskaya botanica 4:16–45 (in Russian)
Krasheninnikov IM (1939) Osnovnye pyti razvitiya rastitel'nosti Yuzhnogo Urala v svyazi s paleogeografiey Severnoy Evrazii v Pleistocene i Gilotsene [The main ways of vegetation development of the Southern Urals in relation to the paleogeography of Northern Eurasia during the Pleistocene and Holocene]. Sovetskaya botanica 6-7:18–26 (in Russian)
Krivonogov SK (1988) Stratigrafiya i paleogeografiya Nizhnego Priirtyshya v epohu poslednego oledeneniya [Stratigraphy and palaeogeography of the Lower Irtysh in the era of the last glaciation]. Nauka, Novosibirsk (in Russian)
Krivonogov SK, Orlova LA, Panychev VA (1985) Semennye flory i absolutnyi vozrast opornogo razreza I nadpoimennoi terrasy Srednego Irtysha [Seminal flora and absolute age of the reference section I first terrace of the Middle Irtysh] In: Volkova VS (ed) Palinostratigrafiya Mesozoic and Cenozoic of Siberia. Nauka, Novosibirsk, pp 99–115 (in Russian)
Kulikov PV (2005) Konspekt flory Chelyabinskoy oblasti (cocudistye rasteniya) [Conspectus florae provinciae Czeljabiskiensis (plantae vasculares)] Geotur, Yekaterinburg-Miass (in Russian)
Kuprianova LA (1965) The palynology of the Amentiferae. Nauka, Moscow-Leningrad (in Russian)
Kuprianova LA, Alyoshina LA (1972) Pollen and spores of plants from the flora of European part of the USSR. Nauka, Leningrad (in Russian)
Kuzmina EA (2009) Late Pleistocene and Holocene small mammal faunas from the South Trans-Urals. Quat Int 201:25–30
Matyushin GN (1976) Mezolit Yuzhnogo Urala [The Metholitic of the Southern Urals]. Nauka, Moscow (in Russian)
Matyushin GN (1982) Eneolit Yuzhnogo Urala [The Chalcolithic of the Southern Urals]. Nauka, Moscow (in Russian)
Milkov FN, Berezhnoy AV, Mikhno VB (1993) Terminologicheski slovar' po fizicheskoi geografii [Terminological dictionary of physical geography] Vysshaya shkola, Moscow (in Russian)
Mosin VS (2000) Kamennyi vek [The Stone Age]. In: Ivanova NO (ed) Drevnyaya istotiya Yuzhnogo Zaural'ya [Ancient History of the Southern Trans-Urals.Vol. I. The Stone Age. The Bronze Age. South-Ural University Press, Chelyabinsk, pp 21–240 (in Russian)
Naumenko NI (2008) Flora i rastitel'nost' Yuzhnogo Zaural'ya [On the flora and vegetative cover of the Southern Trans-Urals]. Kurgan University Press, Kurgan (in Russian)
Navarro Camacho C, Carrion JS, Navarro J, Munuera M, Prieto AR (2000) An experimental approach to the palynology of cave deposits. J Quat Sci 15:603–619
Nikitin PA (1957) Pliocenovye i chetvertichnye flory Voronezhskoi oblasti [Pliocene and Quaternary flora of the Voronezh region]. Academy of Science of USSR, Moscow-Leningrad (in Russian)
Nikitin VP (1969) Paleokarpologicheskyi metod [Plant macrofossil analysis]. Tomsk University Press, Tomsk (in Russian)
Nikitin VV (1983) Sornye rasteniya flory SSSR [Weeds of the USSR flora]. Nauka, Leningrad (in Russian)
NJa Katz, Katz SV (1978) O smenax rastitel'nosti na vostochnykh predgor'yakh Yuzhnogo Urala v poslelednikovoe vremya [On the changes of vegetation in the eastern foothills of the Southern Urals during the Poastglacial period]. Bull Moscow Soc Nat Biol Ser 83:97–106 (in Russian)
NJa Katz, Katz SV, Kipiani MG (1965) Atlas i opredelitel' plodov i semyan, vstrechayushchihsya v chetvertichnyh otlozheniyah SSSR [Atlas and the identification keys of the fruits and seeds occurring in the Quaternary deposits of the USSR]. Nauka, Moscow (in Russian)
Panova NK (1981) Formirovanie pastitel'nogo pokrova srednegornogo vysotnogo poyasa Yuzhnogo Urala s izmeneniyami klimata v golotsene [Formation of vegetative cover of the medium-altitude zone of the Southern Urals due to climate change in the Holocene]. Interconnection of environment and forest vegetation in the Urals. Sverdlovsk, pp 40–57 (in Russian)
Panova NK (1982) Istoriya gornykh lesov centralnoy chasti Yuzhnogo Urala v golocene [History of moumtain forests in the Southern Urals crntral part in Holocene]. Lesovedenie 1:26–34 (in Russian)
Panova NK (1990) Istoriya razvitiya rastitel'nosti gornoi chasti Yuzhnogo Urala v pozdnem plyeistotsene i golotsene, po palinologicheskim dannym [History of vegetation development of mountain part of the Southern Urals during the Late Pleistocene and Holocene based on pollen data]. In: Smirnov NG (ed) Istoricheslaya ekologiya zhivotnych gor Yuzhnogo Urala [History ecology of animal of the Southern Ural Mountains]. UB RAS USSR, Sverdlovsk, pp 144–158 (in Russian)
Panova NK, Makovsky BI (1987) O golocenovoy dinamike rastitel'nosti I vozraste bolot v verkhnem lesnom poyase gory Yaman-Tau [On the Holocene vegetation dynamics and the age of bogs in the upper forest belt of Yaman-Tau Mountain]. In: Zubareva RS, Smolonogov EP (eds) Vostanovitel'naya i vozrastnaya dinamica tayezhnykh lesov Srednego Urala. IPAE, Sverdlovsk, pp 95–102 (in Russian)
Poska A, Saarse L, Veski S (2004) Reflections of pre- and early-agrarian human impact in the pollen diagrams of Estonia. Palaeogeogr Palaeoclim Palaeoecol 209:37–50
Reille M (1995) Pollen et spores d'Europe et d'Afrique du nord Supplement 1. Laboratoire de botanique historigue et palynologie. URA CNRS, Marseille
Reille M (1998) Pollen et spores d'Europe et d'Afrique du nord Supplement 2. Laboratoire de botanique historigue et palynologie. URA CNRS, Marseille
Smirnov NG (ed) (1990) Istoricheslaya ekologiya zhivotnych gor Yuzhnogo Urala [History ecology of animal of the Southern Ural Mountains]. UB RAS USSR, Sverdlovsk (in Russian)
Stockmarr J (1971) Tablets with spores used in absolute pollen analysis. Pollen Spores 13:615–621
Subetto DA, Davydova NN, Sapelko TV, Heustrueva IY (2004) Paleogeografiya ozera Uvildy, Yuzhny Ural [Palaeogiography of Lake Uvildy]. In: Deryagin VV (ed) Problemy geografii Urala I sopredel'nykh territory. Proceedings of conference. Chelyabinsk Pedagogical University Press, Chelyabinsk, pp 94–96 (in Russian)
Tataurov SF (2008) The influence of Russian immigrants on the life of Siberian Tatars (based on Tarski Irtysh). Russian Culture in archaeological research. Apelsin, Omsk, pp 384–395 (in Russian)
Usoltsev VA (2001) Fitomassa lesov Severnoy Evrasii [Forest biomass of Northern Eurasia]. Ural Brunch Press of Russian Academy of Sciences, Yekaterinburg (in Russian)
van Geel B (2001) Non-pollen palynomorphs. In: Smol JP, Birks HJB, Last WM (eds) Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators. Kluwer, Dordrecht, pp 99–119
van Geel B, Buurman J, Brinkkemper O, Schelvis J, Aptroot A, Van Reenen G, Hakbijl T (2003) Environmental reconstruction of a Roman Period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi. J Archaeol Sci 30: 873–883
Velichkevich FY, Zastawniak E (2009) Atlas of the Pleistocene vascular plant macrofossils of Central and Eastern Europe Part 2W. Szafer Institute of Botany. Polish Academy of Sciences, Krakow
Weninger B, Jöris O, Danzeglocke U (2006) http://www.calpal.de