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Supra-regional correlations of the most ancient paleosols and Paleolithic layers of Kostenki-Borschevo region (Russian Plain)

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ABSTRACT

The archaeological site Kostenki12, located on the Middle Don River, provides a key stratigraphic profile for regional paleopedological, paleoenvironmental, geological and cultural sequences, containing the oldest known cultural layers of the region (layer V – Paleolithic, layer IV – Upper Paleolithic, layer III – Kostenki-Strelets culture early phase) dating to the early part of MIS3, or, in chronometric terms, to 54–42 ka. Kostenki12 complements Kostenki14 (Markina Gora), which is a key profile for the interval 42–27 ka. The new data from Kostenki12 show that the East European Upper Paleolithic began ~45 ka. The stratigraphy exhibits similarities to that of Borschevo5. The Kostenki12 pollen diagram is correlated with: 1) other pollen diagrams from Kostenki-Borschevo region; 2) the most detailed climatostratigraphical scale of the Russian Plain Late Pleistocene; 3) $^{16}O/^{18}O$ Greenland GISP2 scale; 4) $^{13}C/^{14}C$ record from stalagmite at Villars Cave (France), as well as with pollen records (5–7) from: 5) Lake Monticchio (Italy), 6) southern Black Sea (M72/5-25-GC1) and 7) Glinde and Moershoofd (northern Germany). The results of the supra-regional paleoenvironmental correlations demonstrate that the lowest Paleolithic layer V and paleosol D, characterized by elm dominance, correlate to the second half of the optimum of the Glinde interstadial at 51–48 ka, corresponding to DO 14. The earliest Upper Paleolithic layer IV and paleosol B, characterized by coexistence of elm forests and wet meadows, began to form during the second part of the Moershoofd interstadial optimum at 46–44 ka, correlating with DO 12. Paleosol A and layer III (Kostenki-Strelets culture) began to form after the abrupt end of the Moershoofd interstadial ~43.5 ka, during unstable conditions, according to pollen and paleozoological data (steppe with horse dominance and later spruce forest tundra with reindeer dominance in paleozoological complex). These correlations provide more accurate dating of the Paleolithic layers and paleosols at Kostenki-Borschevo, suggesting that previously reported radiocarbon dates on units below CI tephra layer are too young, but that the OSL chronology is generally accurate.

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1. Introduction

The Kostenki-Borschevo region of the Russian Plain contains a concentration of nearly 30 buried Upper Paleolithic sites, 10 of which are multilayered. It is located in the modern forest-steppe zone on the Middle Don River basin near Voronezh (Fig. 1) and represents a key study area for the Eurasian Upper Paleolithic.

Paleolithic cultures existed in the region during 53–12 ka, allowing study of various archaeological cultures of Eurasia in the context of the long regional paleoenvironmental dynamics and correlation of the specific archeological complexes with supra-regional paleoenvironmental events. In the Kostenki region, there are some archeological sites dated to more than 40 ka (Praslov and Rogachev, 1982; Anikovich, 2004, 2006; Anikovich et al., 2004, 2005, 2007a, 2007b, 2008, 2012; Hoffecker et al., 2005, 2008, 2010; Holliday et al., 2006, 2007; Levkovskaya et al., 2005; Lisitsyn, 2006; Sedov et al., 2010a,b; Sinitsyn, 2006, 2012, 2013, 2014; Sinitsyn et al., 2013; Pietsch et al., 2014). For example, some layers at Kostenki1 and Kostenki12 (excavated by A.N. Rogachev and M.V. Anikovich), Kostenki14 and Kostenki17 (excavated by A.N. Rogachev, P.I. Boriskovskiy, and A.A. Sinitsyn), and Borschevo5 (excavated by S.A. Lisitsyn) (Fig. 1) were formed before the Laschamp excursion of about 41 ka (Guillou et al., 2004; Nowaczyk et al., 2012) and the CI eruption in Italy of about 40 ka (Melekeszev et al., 1984; De Vivo et al., 2001; Fedele et al., 2003; Pyle et al., 2006; Douka et al., 2010).

New Paleolithic layers (V, IV, III) and paleosols (D, C, B and A) were discovered by M.V. Anikovich at Kostenki12 site under the sediments with CI/Y5 tephra and Laschamp excursion during the excavations in 1999–2004 (Figs. 2 and 3). They represent the oldest known Paleolithic layers and associated paleosols of Kostenki-Borschevo region (Anikovich et al., 2005, 2007a,b, 2008; Hoffecker, 2005; Levkovskaya et al., 2005), some analogs of which are found in the region only at the Borschevo5 site (Fig. 3). However, the exact age of their formation is uncertain because of discrepancies of 2000–10,000 years (Table 1) between the OSL (Anikovich et al., 2005, 2007a,b, 2008; Forman, 2006; Hoffecker et al., 2006, 2008) and the radiocarbon dates (Anikovich et al., 2005; Housley et al., 2006). New multidisciplinary approaches were used in order to ascertain the age of these layers (Anikovich et al., 2005; Levkovskaya et al., 2005; Pospelova et al., 2005; Hoffecker et al., 2006, 2008, 2010; Holliday et al., 2006, 2007). The pollen data from the Kostenki12 sediments below Laschamp geomagnetic excursion and CI/Y5 tephra correlated well with OSL chronology and global paleoenvironmental events based on well-dated pollen and stable isotope records (Levkovskaya et al., 2005). The new well-dated pollen record M72/5-25-GC1 from the neighbouring Black Sea (Shumilovskikh et al., 2012, 2014; Shumilovskikh and Levkovskaya, 2013) permits identification of the new paleoenvironmental markers for supra-regional

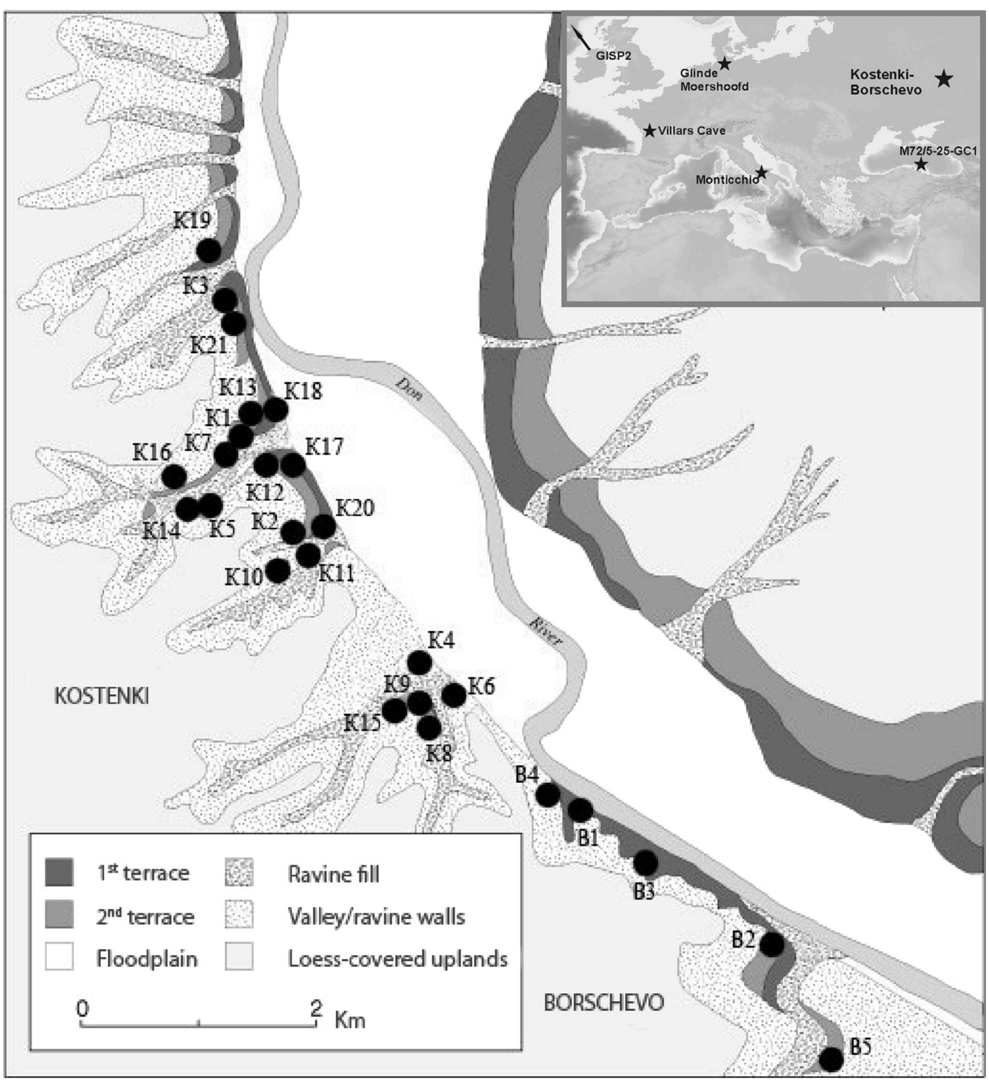

Fig. 1. Map of Kostenki with location of all archeological sites (based on Anikovich et al., 2007a,b). Inset: location of Kostenki12 and records used for supra-regional correlations, discussed in the text.

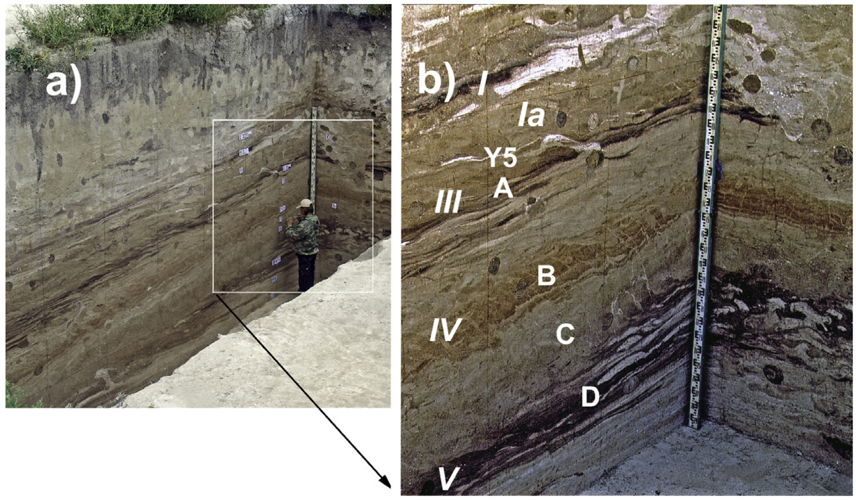

Fig. 2. Photographs of sections in Kostenki12: a) eastern wall and south-eastern corner (line «ь», squares 86–91, 2004); b) stratigraphical details of the south-eastern corner – with locations of paleosols A, B, C and D, Upper Paleolithic cultural layers I, Ia, III, IV and Mousterian? or Upper Palelithic? layer V, and tephra layer CI(Y5).

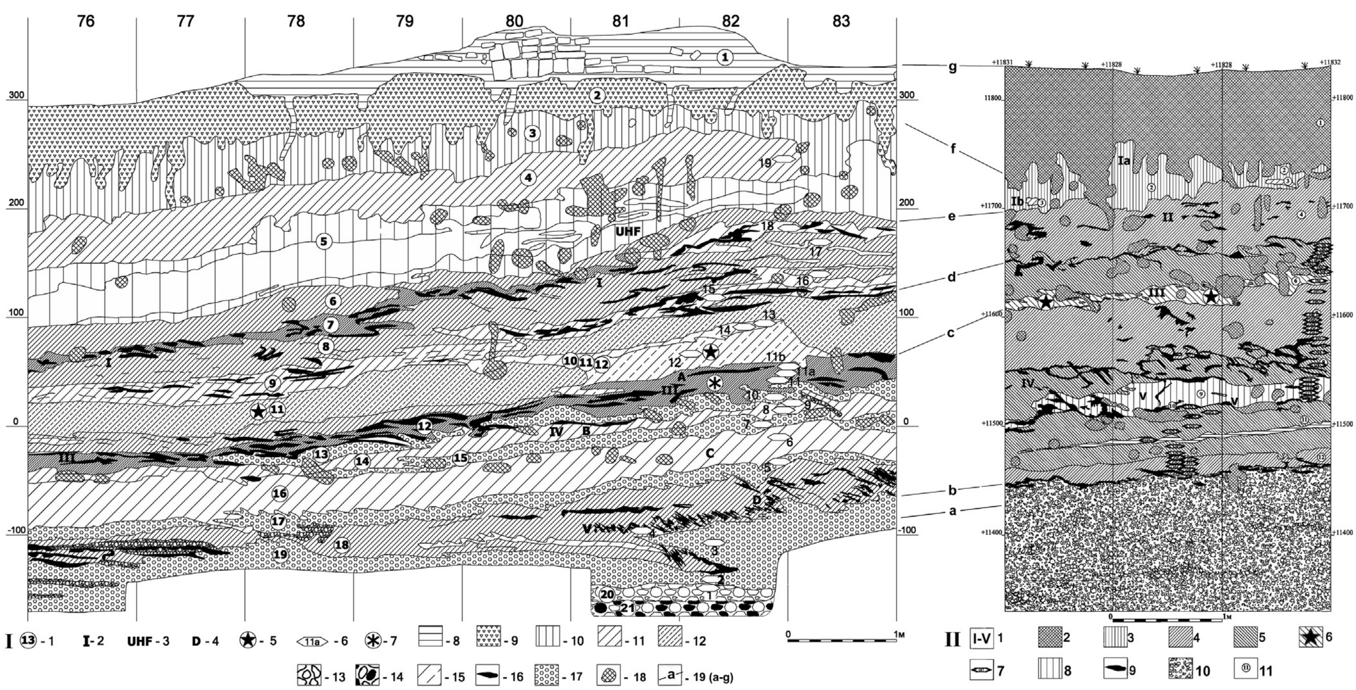

Fig. 3. Correlation of: I. Kostenki12 (excavations of M.V. Anikovich) and II. Borschevo5 (excavations of S.A. Lisitsyn) sediments. I. Kostenki12 schematic profile of the eastern wall (line «ы», squares 76–83, 2003): 1) lithological horizons (description and numerical dates in Table 1); 2) cultural layers I, III, IV and V; 3) upper horizon of archeological finds; 4) paleosols A, B, C and D; 5) samples of tephra; 6) pollen samples; 7) presumptive level of paleomagnetic excursion Laschamp-Kargapolovo; 8) building horizon, XX cent.; 9) recent chernozem soil; 10) loess-like loam (the frequency of hatching depends on the color intensity); 11) humified loam (the frequency of hatching depends on the color intensity); 12) partly washout humified loam with admixture of volcanic ash; 13) diluvium with chalk gravel loam 14) channel ravine alluvium: pale loam with about 40% of small (2 cm) rolled chalky pebbles and gravels; 15) strongly mixed horizon: washout particles of lit. hor. 10, 11, 12; 16) lenses of intensively humified loam; 17) pale non-humified loam; 18) ancient rodent burrows (krotovinas); 19) levels of K12 correlated with Borschevo5 sediments: a – chalk gravel loam; b – Kostenki paleosol D and its B5 analogy (with maxima of elm pollen in both cases); c – sediments with CI/Y5 tephra; d – basis of upper humic bed; e – basis of loess horizon under Holocene sediments; f, g – Holocene sediments. II. Borschevo5 schematic south-east profile of testpit 4 (2006): 1) Upper Paleolithic layers: V, IV, III, II, Ib, Ia (they repeat the numbers of K12 archeological layers though they contain non-similar archeological complexes); 2) chernozem/krotovinae; 3) loess loam; 4) humus loam; 5) carbonized loam; 6) carbonized loam with CI/Y5 ash; 7) samples collected for pollen analysis; 8) dense reddish-brown loam; 9) lenses of black humus; 10) chalk-gravel basement loam; 11) numbers of geological layers.

correlations and for more accurate dating of Paleolithic layers and paleosols.

The present article addresses paleoenvironmental and chronological issues of the Paleolithic layers V, IV and III which are the oldest known in the region and paleosols D, C, B and A of Kostenki12. For the first time, these problems are discussed in the context of supra-regional correlations with paleoenvironmental stages. The aims of the present article are:

1. to present climatostratigraphic and chronological data analyzed from the lowest Paleolithic layers and paleosols of Kostenki region;

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Table 1
Kostenki-12 (2003 year excavation of M.V. Anikovich). Sediments of the eastern wall, their absolute dates (ka BP), and chronology based on supra-regional correlations.

Pollen zones	Layer	Litological horizons description (Anikovich et al., 2005, 2008)	Cultural layer (Anikovich et al., 2005)	^{14}C/**$^{14}C_{AMS}$ (Hoffecker et al., 2005, 2008, 2010; Holliday et al., 2007)	$^{14}C_{cal}$ (calendar) F – Fairbanks et al., 2005; C – Calpal, 2005 (Hoffecker et al., 2008)	IRSL/OSL (calendar) (Holliday et al., 2007; Hoffecker et al., 2008)	Supra-regional correlation chronology (references see Table 1)	Russian Plain stratigraphy (Zarrina et al., 1980; Spiridonova, 1991)
	1	Building horizon, XX cent.					Holocene	
	2	Recent soil (chernozem)						
	3	Brown loess-like stratified loam with chalk gravel				UIC-1418: 19.890 ± 1730		
18	4	Greyish-brown humified loam. Gmelin (?) paleosol. The bottom part is distinguished clearly by more intense coloration					Gmelinsky interstadial	Late Valdai: glaciation
								23.500
?	5	Light-grey-brownish, stratified carbonized loam. Its bottom part contains some isolated finds which corresponds now to "upper horizon of finds" (UHF)	UHF			UIC-1419: 25.770 ± 2.250 UIC-1419Q: 24.020 ± 2.120 UIC-1419Q-IR: 24.740 ± 2.190		
?	6	Greyish-brown humified streaky loam. Buried soil (?), the top of upper humus bed						
17	7	Stratified horizon – black lenses of humified loam, alternating with light-brown and whitish lenses. Contains the upper part of cultural layer K12/I (Gorodtsovian culture).	I					
16 15	8	Gray-brownish, stratified humified loam. Contains the main part of cultural layer K12/I (Gorodtsovian culture).	I	23.600 ± 300 (ГИН-89); 24.000 ± 800 (ГИН-019); 26.300 ± 300 (ГИН-8574)		UIC-916: 27.360 ± 2.360& 30.030 ± 2.210		
14 13	9	Black lenses of medium humified loam, alternating with light-brown and whitish lenses. The bottom of upper humus bed. Contains the cultural layer K12/Ia (Strelets culture, stage II (according to M. Anikovich).	Ia	28.500 ± 140 (GrA-5552); 28.700 ± 400 (ЛЕ-1428а); 30.240 ± 400 (ЛЕ-1428б); 31.150 ± 150 (ЛЕ-1428в); 31.900 ± 200 (ЛЕ-1428г); 32.700 ± 700 (GrN-7758)	GrA-5552 33.136 ± 171 cal F & 33.200 ± 666 cal C; GrN-7758 37.614 ± 843 cal F & 38.019 ± 900 cal C			
13b	10	Washed out whitish horizon						
13a	11	Gray light-humified streaky loam with chalk gravel. Contains the washed out deposits of ash.	II (absent at southern part)				CI/Y5 eruption: ~40.0	
12 11 10	12	Streaky humus, lenses of black loam – buried soil "A". Contains the cultural layer K12/III as more or less located conglomerations of cultural remains, partly *in situ* (Strelets culture, stage I (according to M. Anikovich). Hiatus at the upper contact.	III	>31.000 (ГИН-8021); 36.280 ± 360/350 (GrA-5551) **31.760 ± 230 (OxA-X-2158-14); **35.820 ± 230 (OxA-15482)	OxA-X-2158-14 36.734 ± 177 cal F & 36.720 ± 279 cal C; OxA-15482 41.263 ± 161 cal F 41.732 ± 190 cal C; GrA-5551 41.535 ± 225 cal F & 41.909 ± 218 cal C		Laschamp: ~41.0 (Nowaczyk et al., 2012)	
9a, 9b	13	Pale yellow loam.					Interstadial Moershoofd: 47.500–43.500	Middle Valdai: megainterstadial Grazhdanskiy with two optima (50.000–40.000)
8 7	14	Light gray-brownish, humified loam. Paleosol "B". Contains cultural remains – bones and stone tools. Cultural layer K12/IV.	IV	**35.540 ± 260 (OxA-15555)	OxA-15555 41.079 ± 212 cal F & 41.240 ± 550 cal C		Optimum: 46.300–45.400 (data on C^{13}/C^{14} Villars scale)	Kostenki « elm » megastage (52,440–43,470) with two optima (51,000–50,000 and 46,300–45,400)
6	15	Pale grey loam.				UIC-915: 43.990 ± 3.670& 44.620 ± 3820& 48.870 ± 3.620 UIC-946: 43.470 ± 3.670&		

Table 1 (*continued*)

Pollen zones	Layer	Litological horizons description (Anikovich et al., 2005, 2008)	Cultural layer (Anikovich et al., 2005)	$^{14}C/^{**14}C_{AMS}$ (Hoffecker et al., 2005, 2008, 2010; Holliday et al., 2007)	$^{14}C_{cal}$ (calendar) F – Fairbanks et al., 2005; C – Calpal, 2005 (Hoffecker et al., 2008)	IRSL/OSL (calendar) (Holliday et al., 2007; Hoffecker et al., 2008)	Supra-regional correlation chronology (references see Table 1)	Russian Plain stratigraphy (Zarrina et al., 1980; Spiridonova, 1991)
						43.870 ± 3740& 47.390 ± 3.470 ^{X} UIC-945: 44.150 ± 3.780 & 44.650 ± 3.800 & 45.200 ± 3.260 (?)UIC-947: 46.910 ± 3.860 & 47.380 ± 3930 & 50.120 ± 3.630		
5	16	Medium humified streaky loam – paleosol "C".						
4	17	Pale yellow loam (ACb6, after Holliday et al., 2006).	V				Endotherm	
3b	18	Dark-brownish, partly nearly black streaky loam – paleosol "D". Contains cultural remains – bones and stone tools. Cultural layer K12/V.		**34.710 ± 330 (OxA-X-2158-15); **41.300 ± 450 (OxA-15556); **38.410 ± 300 (OxA-15902);		(?)UIC-945: 44.150 ± 3.780 & 44.650 ± 3.800 & 45.200 ± 3.260 ^{X} UIC-947: 46.910 ± 3.860 & 47.380 ± 3930 & 50.120 ± 3.630	Interstadial Glinde: 53.900–47.000 Optimum: 51.000–50.000 (data on C^{13}/C^{14} Villars scale)	
3a	19	Pale grey marlaceous loam				UIC-917 PZ 3a: 50.520 ± 4.380 & 51.330 ± 4.950 & 52.440 ± 3.850		
							53,9	
2								
1	20	Chalky deluvium						Early Valdai glaciation: final advance (~60.000)
1	21	Alluvium: whitish loam, and 40% of small rolled pebbles and gravels						

^{X} The places of collection of the samples UIC-945 and UIC-947 might be unclear in context of supra-regional correlations (chapter 3.4).
Therefore we show the samples from Glinde (zone 3a, palaeosol D) or Moershoofd (zone 6, sediments under B palaeosol) age sediments at both levels simultaneously. But used for interpretation only the dates which agree with reconstructed global interstadials chronology and their Kostenki IRSL/OSL dates.

2. to develop a general paleoenvironmental framework for the Kostenki region;
3. to correlate paleoenvironmental markers of the Kostenki region with global thermomers and cryomers established in other regions as an additional chronological tool.

2. Methods

The environmental reconstructions of the Kostenki region are based on multidisciplinary data from Kostenki12. These data were obtained by archeological (Anikovich et al., 2004, 2005, 2008), traditional paleopedological and detailed micromorphological (Holliday et al., 2006, 2007; Aparin and Platonova, 2013), traditional paleozoological and detailed taphonomical (Anikovich et al., 2005; Hoffecker et al., 2005, 2010), geomagnetic (Pospelova, 2003, 2005, 2008; Pospelova et al., 2005) and pollen studies, including traditional palynological, and statistical palynoteratical methods (Levkovskaya, 1977; Levkovskaya et al., 2005, 2011, 2013). IRSL/OSL dates (Table 1) were obtained by S. L. Forman at the University of Illinois at Chicago (Forman, 2006; Holliday et al., 2007). The ages of ^{14}C dates were calibrated (Table 1) on the basis of two calibration curves (Fairbanks et al., 2005; CalPal, 2005). Molluscs were studied by A.F. Sanko (Sanko and Sinitsyn, 2004; Sanko, 2007).

In order to establish the regional vegetation and paleoenvironmental history of Kostenki, all published pollen diagrams were analyzed. The pollen diagrams are stored in the Archeology–Paleobotany–Palynology Database for the former USSR area/BARPP (Levkovskaya, 1999; Stepanov et al., 2002; www.gml.spb.ru). Reconstructions of the zonal types of the vegetation and paleoclimate are based on the results of the subfossil pollen spectra studies from all geobotanical subzones of European Russia (Gritchouk, 1941; Gritchouk and Zaklinskaya, 1948) and Western Siberia (Levkovskaya, 1973) and various methods of paleoclimatic reconstructions based on pollen data (Bukreeva and Levkovskaya, 2000; Ukraintseva, 2013). For these studies, only sites without obvious anthropogenic impact on the vegetation have been chosen.

The SEM-micrographs of the palynoteratical complexes (Fig. 4) were obtained using the original method of preparation of SEM "tables" for research (Levkovskaya et al., 2005). For reconstruction of geobotanical stresses in the past and present with palynoteratical method (Levkovskaya, 1999, 2012; Levkovskaya and Bogolyubova, 2011; Levkovskaya et al., 2011), statistics on normal and abnormal morphology pollen grains of all taxa were collected for each pollen complex. A palynoteratical diagram was prepared for Kostenki12 on the basis of these statistics (Levkovskaya et al., 2005). It shows the percentages of all pollen grains and spores: 1) with normal morphology of all taxa forms; 2) underdeveloped

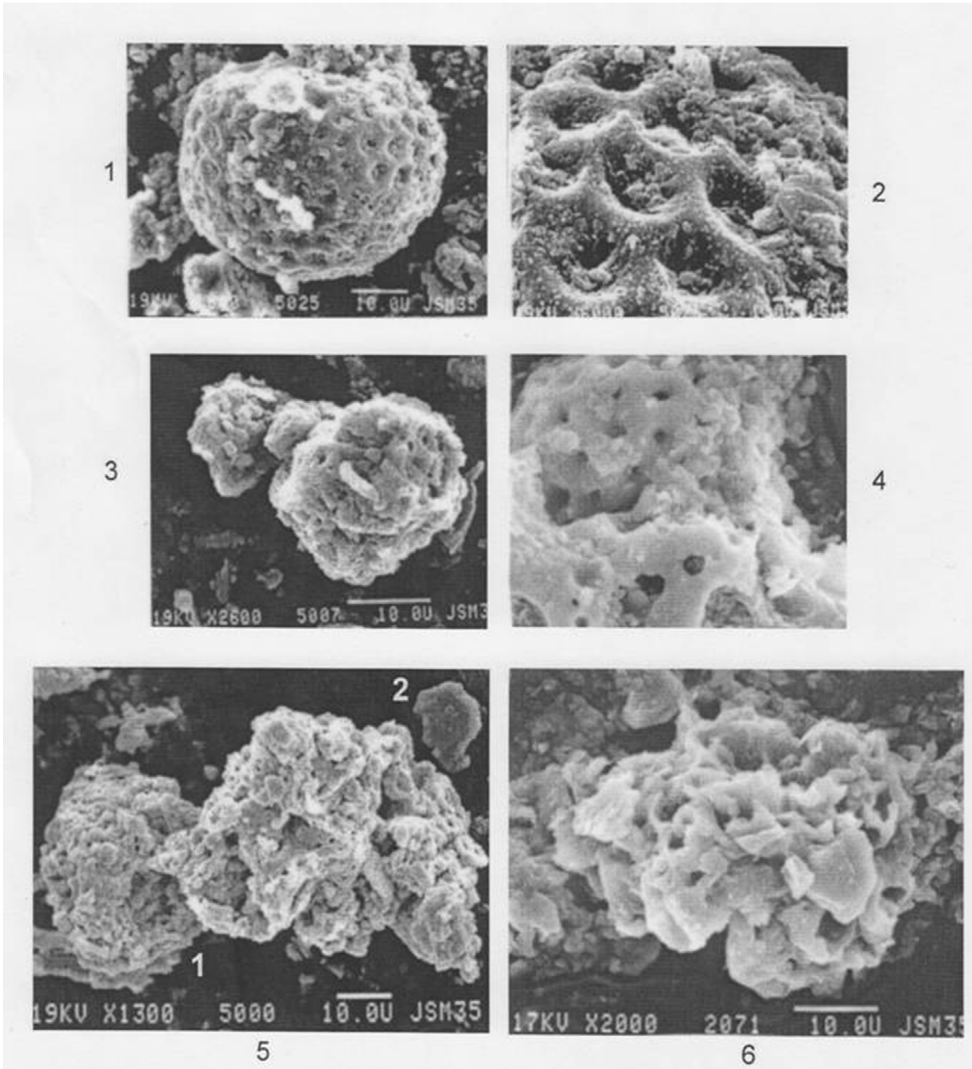

Fig. 4. Kostenki12 SEM-micrographs of underdeveloped and dwarf pollen grains of *Chenopodiaceae* from layer III of Kostenki Strelets culture first phase as an indicator of the regional geobotanical stress. 1,2) Pollen grain of *Chenopodiaceae*: 1. general view (×1800); 2. sculpture detail (×6000). 3–6) Conglomerates (polyades) of about 100 grains, each of them is simultaneously dwarf and underdeveloped (loss of sculpture, etc.): 3. ×2600; 4. ×2000; 5. ×1300; 6. ×2000.

("abortive") differentiated on the basis of 7 signs of Ananova (1966); 3) dwarf; 4) "ugly" with various morphological pathologies; 5) simultaneously underdeveloped and dwarf and "ugly" (Fig. 4). This graph is used for differentiation of stages with normal, transitional or stressed states of reproductive spheres of most plants of the area, clearly indicating periods of geobotanical stresses and more accurate differentiations of climatic optima, most extreme climatic phases, and transitions between them.

The basis of the supra-regional correlations is regional archeological, pollen, paleosol and IRSL/OSL data on Kostenki12 site. They were correlated with the most detailed (based on pollen data) climatostratigraphical scale of Russian Plain Late Pleistocene (Zarrina et al., 1980; Nalivkin and Sokolov, 1984; Spiridonova, 1991). For supra-regional correlation of Kostenki-Borschevo region (Fig. 5, Table 2), we have chosen several well-dated records: 1) oxygen isotope records GISP2 from Greenland (Grootes et al., 1993; Johnsen et al., 2001); 2) carbon isotope record from stalagmite in Villars cave (Genty et al., 2003); 3) pollen record of lake Monticchio from Italy (Watts et al., 1996, 2000); 4) pollen record from the Black Sea core M72/5-25-GC1 (Shumilovskikh et al., 2012, 2014); 5) different dates (14C, 14CAMS and others) of the sediments from the key sections of Glinde and Moershoofd interstadials in Netherlands and northern Germany (Zagwijn, 1961; Van der Hammen et al., 1967; Kolstrup and Wijmstra, 1977; Behre and van der Plicht, 1992).

3. Results and discussion

3.1. Kostenki region paleoenvironmental patterns

3.1.1. Vegetation dynamics in Kostenki region during 53–12 ka

Many pollen diagrams have been published for the Upper Paleolithic geological and archeological sections of the Kostenki region (Lazukov, 1957; Velichko, 1961; Fedorova, 1963; Gritchouk, 1969; Klein, 1969; Levkovskaya, 1977, 1999; Malyasova and Spiridonova, 1982; Levkovskaya et al., 1983, 2005; Spiridonova, 1989, 1991, 2002; Velichko et al., 2009; Oshurkova, 2013). There are some unpublished diagrams of G.M. Levkovskaya on archeological sites Kostenki1, Kostenki12, Kostenki14, Kostenki21, Borschevo5, sections of cores drilled in Kostenki1, Kostenki14, Kostenki21, and buried terraces. In spite of the large quantity of pollen diagrams, the general paleoenvironmental pattern had not been worked out for the Kostenki region due to several reasons.

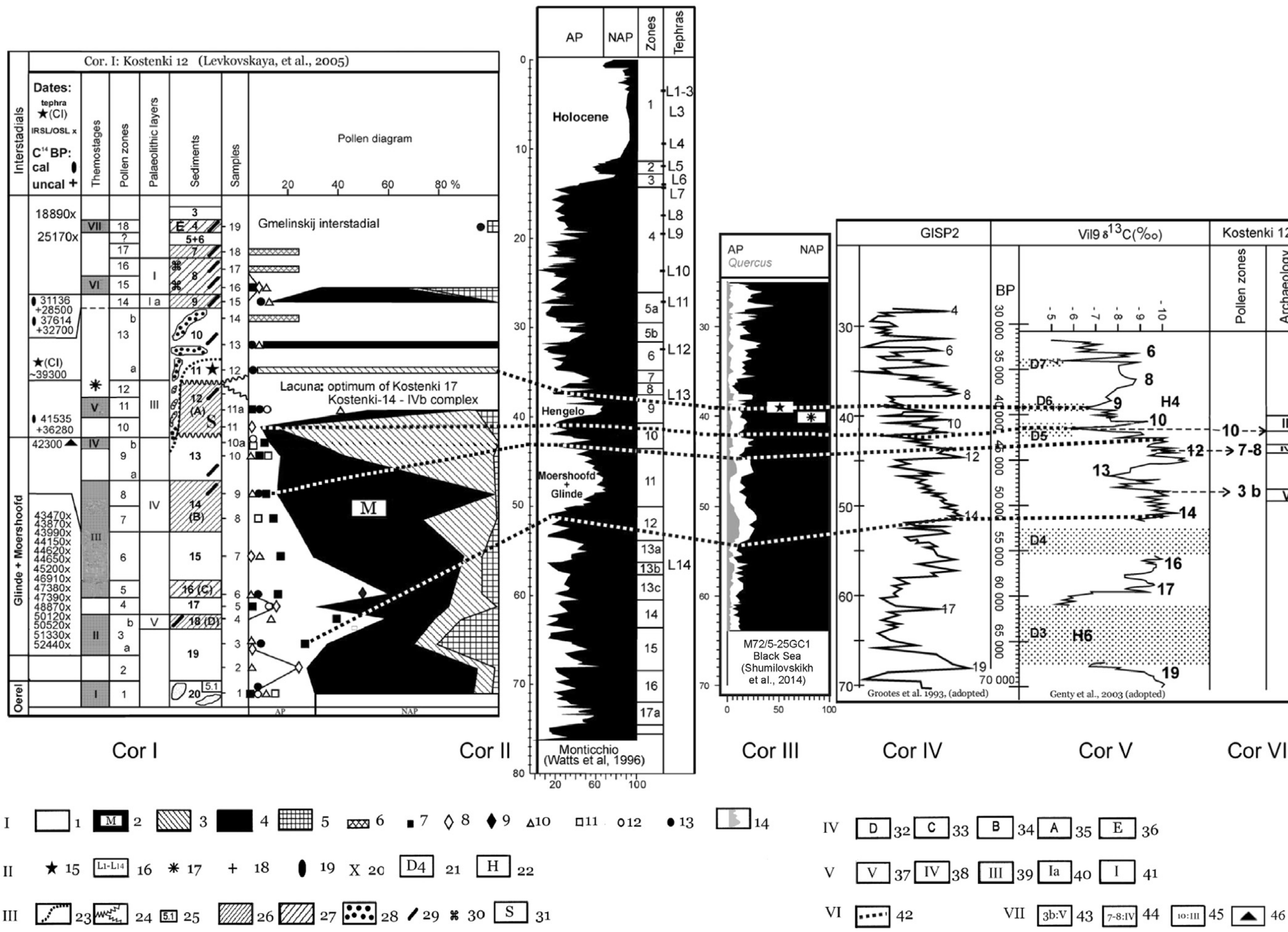

Fig. 5. Supra-regional correlations of Kostenki12 pollen diagram with pollen diagrams of Monticchio Lake and Black Sea core M72/5-25-GC1, oxygen isotope record GISP2 and carbon isotope record from Villars cave. CorI – pollen diagram of K12 site (Levkovskaya et al., 2005), CorII – pollen diagram of Monticchio Lake sediments (Watts et al., 1996), CorIII – pollen diagram of the Black Sea sediments from the core M72/5-25-GC1 (Shumilovskikh et al., 2014), CorIV – isotope $^{16}O/^{18}O$ glacial Greenland scale (Grootes et al., 1993; Johnsen et al., 2001), CorV – isotope $^{13}C/^{14}C$ scale of stalagmite Vil.9 from Villars cave in France (Genty et al., 2003), CorVI – climatostratigraphical positions of the most ancient Kostenki Paleolithic layers, paleosols and pollen zones in context of their supra-regional correlations. *I. Palynological Symbols*: 1. AP – arboreal pollen + shrubs; 2. non-arboreal pollen – mesophilous (M); 3. non-arboreal pollen – xerophilous; 4. total quantity of non-arboreal pollen (NAP); 5. spores (dominant – *Botrychium* sp.); 6. levels with isolated pollen grains; 7. sum of broad-leaved trees pollen (dominant – *Ulmus laevis*, rare *Quercus*, *Carpinus betulus*, *Tilia platyphillos* and *T. cordata*, *Fraxinus*, *Corylus*) – pollen indicator of warm conditions; 8. sum of microtherm mesophilous shrub pollen (*Alnaster* sp., *Betula nana*, *B. humilis*) – pollen indicator of wet and cold conditions; 9. sum of xerophilous and mesothermophilous bushes or trees pollen (*Ephedra distachya, Ephedra sp., Carpinus orientalis, Hippophae rhamnoides*) – pollen indicator of dry conditions; 10–13. arboreal pollen: 10. spruce (*Picea* sp.); 11. alder (*Alnus incana* + *A. glutinosa*); 12. birch trees (*Betula sect. Albae*; *Betula verucosa*, *B. pubescens*); 13. pine (*Pinus sylvestris*); 14. oak (*Quercus*). *II Geological and Chronological Markers and Dates*: 15. tephra of Campanian Ignimbrite (CI/Y5) eruption in Italy (39,28 ± 0,1 ka BP; Fedele et al., 2003; Pyle et al., 2006; Douka et al., 2010) found in K12 (Cor.I) and Black Sea core 25-GCI (Cor.II); 16. tephra horizons in Monticchio palaeolake section from the volcanic caldera (Cor.II); 17. geomagnetic excursion Laschamp (40,70 ± 0,95 ka BP; Nowaczyk et al., 2012); 18. uncalibrated ^{14}C dates (their laboratory numbers and confidence intervals are given in Table 1); 19. calibrated ^{14}C dates (their laboratory numbers and confidence intervals are given in Table 1); 20. IRSL/OSL dates (Hoffecker et al., 2008) (their laboratory numbers and confidence intervals are given in Table 1); 21. D3–D7 discontinuities in the growing of the Villars cave stalagmite (Cor.V) (Genty et al., 2003); 22. Heinrich events 6 and 4.*III Sediments:* 23–31: 23. erosional contact between the sediments of the lower (under CI/Y5 tephra) and upper humic beds; 24. the level of stratigraphical hiatus in K12 which corresponds to the time formation of the sediments of lower level of the second terrace buried under CI/Y5 tephra with Upper Paleolithic layers II of K17 site, and IVb, IVa, and layer in tephra of Kostenki14; 25. depth of sediments (meters); 26. very dark humus horizon; 27. dark humus horizon; 28. chalk gravel lenses; 29. charcoal micro-remains; 30. plant micro-remains; 31. solifluction. *IV Palaeopedological Symbols of Flood Terrace Paleosols*: 32. paleosol D; 33. paleosol C; 34. paleosol B; 35. paleosol A; 36. Gmelinsky paleosol E. *V. Archaeological Layers of K12:* 37. layer V – the most ancient Paleolithic layer of Kostenki-Borschevo region (Mousterian? or Upper Paleolithic?); 38. layer IV – definitely Upper Paleolithic layer; 39. layer III – the first phase of Kostenki-Strelets culture; 40. layer Ia – the third phase of Kostenki-Strelets culture; 41. layer I – Gorodtsovian culture.*VI. Correlations*: 42. correlated levels; VII. Results of supra-regional correlations: chronostratigraphical and climatostratigraphical positions of simultaneously pollen zones, paleosols, and connected with them Paleolithic layers: 43. zone 3b – paleosol D – Paleolithic layer V; 44. zone 7–8-paleosol B – definitely Upper Paeolthic layer IV; 45. zone 10 – lower part of paleosol A – lower part of layer III of the first phase of Kostenki-Strelets culture; 46. the abrupt end of Moershoofd interstadial and upper borders of oscillations 12 at GISP2 $^{16}O/^{18}O$ and Vil.9 $^{13}C/^{14}C$ scales: 43.5 ka BP. Characteristics of correlated levels: Correlated level A (~54–51 ka BP is the beginning of the warmest (within MIS3 and MIS2) thermomer – Glinde interstadial. This thermomer is registered at CorI and CorIII as the largest maxima of broad-leaved trees (*Ulmus* is dominant in Kostenki12, but *Quercus* in the area of Black Sea). At CorII, it is the first half of the MIS3/MIS2 longest and largest maximum of arboreal pollen (AP) of Glinde + Moershoofd time. It is synchronous with the lower borders of the stage 14 of GISP2 $^{16}O/^{18}O$ scale and stage 14 of $^{13}C/^{14}C$ Villars stalagmite scale. Correlated level B (~44.5 ka BP) is the end of the second (within MIS3 and MIS2) warm thermomer (Moershoofd interstadial) of the same environmental megastage as level A. This thermomer is differentiated at CorI and Cor III by the optimum of the second maximum of broad-leaved trees (AP). *Ulmus* dominates in Kostenki12, but *Quercus* in the area of the Black Sea, although the quantity of broad-leaved trees is less than in the Glinde. At CorII it is the second half of the MIS3/MIS2 longest and largest maximum of arboreal pollen (AP) of Glinde + Moershoofd time. It is synchronous with the upper border of stage 12 of GISP2 $^{16}O/^{18}O$ scale and stage 12 of $^{13}C/^{14}C$ Villars stalagmite scale. Correlated level C (~43 ka BP) is the most extreme climatic phase of the cryomer that followed the Moershoofd interstadial. In Kostenki12, it is characterized by practically the entire disappearance of most tree pollen, domination of xerophilous NAP, and horse in the paleozoological complex. At CorII and Cor III it is an abrupt lower border of the first NAP maximum after the end of Glinde + Moershoofd megastage. Correlated level D (~40 ka BP) is the level of finds of CI/Y5 tephra (~40 ka BP) in Kostenki12 and in the Black Sea core M72/5-25-GC1.

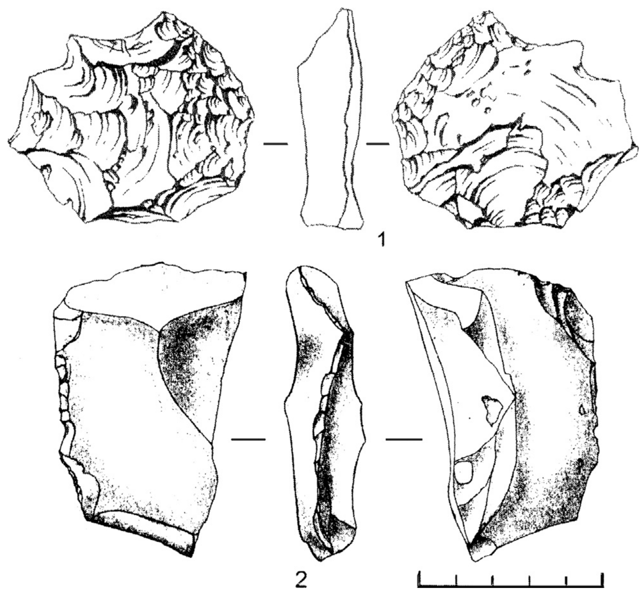

Fig. 6. Stone tools from Kostenki12, layer V: 1) denticulate on a flake; 2) endscraper-like tool made on a massive piece.

First, most published Kostenki diagrams, except for Kostenki12 (Levkovskaya et al., 2005) and Kostenki14 (Velichko et al., 2009), characterize sections with many sedimentation gaps. For example, the Kostenki17 optimum under tephra, discovered within the coniferous megastage (Fedorova, 1963), is not found in other sections of the region. Second, some diagrams were not dated, and therefore, many radiocarbon dates obtained for these sections cannot be related to pollen zones. Third, only in individual cases were the positions of archeological layers shown on diagrams (Gritchouk, 1969; Levkovskaya, 1977; Levkovskaya et al., 2005), whereas in most cases, they are not indicated (Lazukov, 1957; Fedorova, 1963; Malyasova and Spiridonova, 1982, 2002; Velichko et al., 2009). Fourth, some palynologists excluded the morphologically abnormal pollen grains of coniferous plants (Fig. 8) from Quaternary complexes, precluding correlation of their diagrams with those of other palynologists (see discussion on Kostenki14 in Levkovskaya et al. (1983)).

In recent years, full pollen diagrams of two levels of the second buried terraces under CI/Y5 tephra have appeared. These are the diagrams of Kostenki12 of upper level of the second buried terrace (Levkovskaya et al., 2005), and Kostenki14 (Velichko et al., 2009) of lower level of the second terrace. There are pollen diagrams of two levels of the first buried terraces (unpublished matireals of G.M. Levkovskaya). These diagrams supplement each other. Moreover, new results of multidisciplinary studies of the lowest Paleolithic layers at sites Kostenki1, Kostenki12, Kostenki14, and Borschevo5 (e.g. Anikovich et al., 2004, 2005a,b; Lisitsyn, 2004, 2005, 2006; Hoffecker et al., 2005, 2010; Levkovskaya et al., 2005; Douka et al., 2010; Sedov et al., 2010a,b; Sinitsyn, 2012, 2013; Haesaerts et al., 2013; Pietsch et al., 2014) have appeared. These materials allow determination of the general pattern of the paleoenvironmental dynamics in the Kostenki-Borschevo region for the entire period of Paleolithic cultures between 53 and 12 ka BP.

The paleoenvironmental reconstructions presented here reflect the phenomenon of ravine terrace refugium, in which flora and fauna enjoyed more favorable conditions than on the watersheds. For example, during the "coniferous" megastage only pine coniferous forests grew at Strelitsa watershed (Bolikhovskaya, 1995), whereas spruce or pine spruce forests occurred at Kostenki; mesophilous *Carpinus betulus* appeared at Kostenki refugium during the warmest "elm" megastage, whereas more xerophilous *Carpinus orientalis* occurred at Strelitsa watershed.

Based on pollen data, the following paleoenvironmental megastages have been identified in Kostenki region for Paleolithic time:

Megastage A includes zone 2 of the Kostenki12 pollen diagram (Fig. 5: CorI, lower part of layer 19) and corresponds to an interval of shrub tundra conditions in the region. It is characterized by a maximum of microtherm shrubs and dominance of wet meadows. It correlates with a stadial in Northern Europe at 50–60 ka (Mangerud et al., 2004) and very wet cold D4 hiatus (55.7–51.7 ka BP) in the Villars Cave stalagmite record in France (Genty et al., 2003). The first Kostenki12 thermomer (zone 1) before this stadial correlates with the Oerel interstadial. The following ^{14}C dates are published for Oerel key section in Northern Germany (Behre and van der Plicht, 1992): 57.7 ± 1.3 ka, 57.3 + 1.9/−1.6 ka, 57.0 + 3.5/−2.5 ka, 55.9 + 4.0/−2.7 ka, 55.4 ± 9.0 ka, and 53.5 + 2.9/−2.1 ka.

Megastage B includes zones 3a-9b of Kostenki12 (Fig. 5: CorI; Table 2, upper part of layer 19, and layers 18–13). A megastage of elm (*Ulmus*) forests with admixture of alder (*Alnus*) and wet meadows (with isolated coniferous plants) suggests a complicated mega-interstadial with few optima. The paleoenvironmental reconstructions and IRSL/OSL dates for the period 52.44–43.47 ka (Table 1) allow correlation of the Kostenki12 complicated mega-interstadial with the Glinde and Moershoofd interstadials (Fig.5: CorII; Tables 1 and 2). Both correspond to the interval of 50–43.5 ka in the Monticchio pollen record (Watts et al., 1996, 2000; Allen et al., 2000).

Comparison of the pollen diagrams from K12 (Fig.5: CorI, zones 3a, 3b) and Black Sea core M72/5-25-GC1 (Zolitschka and Negendank, 1996; Shumilovskikh et al., 2014) (Fig.5: CorIII) shows that both regions are characterized by the largest MIS 3 pollen maximum of the broad-leaved trees with dominance of elm in Kostenki, but deciduous *Quercus* in the Black Sea core. This period spans 53.9–51 ka in the M72/5-25-GC1 and about 52.4–50.5 ka at Kostenki (Table 1). This was the first (Glinde) optimum of the Kostenki "elm" megainterstadial. Paleosol D and Paleolithic complex V are connected with this first optimum.

The second "elm" optimum of Kostenki megainterstadial is characterized by lower percentages of the broad-leaved arboreal pollen (18%) than during the first phase (38%) (Fig.5: CorI, zones 7, 8). It is correlated to the second maximum of broad-leaved trees (maximum of oak) in M72/5-25-GC1 and Moershoofd interstadial in Germany between 46.3 and 45.4 ka BP (Table 2).

Megastage C corresponds to zone 10 of the Kostenki12 pollen diagram (Fig. 5: CorI; Table 2, layer III: lower part). It reflects a period of periglacial steppe with occasional trees indicated by dominance of xerophilous NAP. According to Kostenki12 SEM-data, this period is characterized by geobotanical stress for reproduction of most plants of the area. All plants produced dwarf and immature pollen grains. In the SEM-micrographs (Fig. 4), the complex resembles a "cemetery" of conglomerates (polyades) of dwarf and immature pollen grains (often in polyads) of *Chenopodiaceae,* all underdeveloped.

The pollen diagram of the Kostenki14 (Velichko et al., 2009) shows that Upper Paleolithic layer IVb (geological layer 23) and sterile sediments under all archeological layers were formed during this megastage. In the Kostenki14 pollen diagram, it is the lowest pollen zone with dominance of NAP (*Cichoreaceae, Asteraceae*, *Artemisia*, and *Chenopodiaceae*, with *Poaceae* and mesophilous grasses) and single AP pollen grains.

Megastage D includes zone 11 of the Kostenki12 pollen diagram (Fig. 5: CorI; Table 2, layer III: upper part) and indicates predominance of coniferous forests (*Picea* at Kostenki12) and various types of meadows. Most of the Kostenki pollen diagrams belong to this "coniferous"-type, in which AP is represented mostly by pine

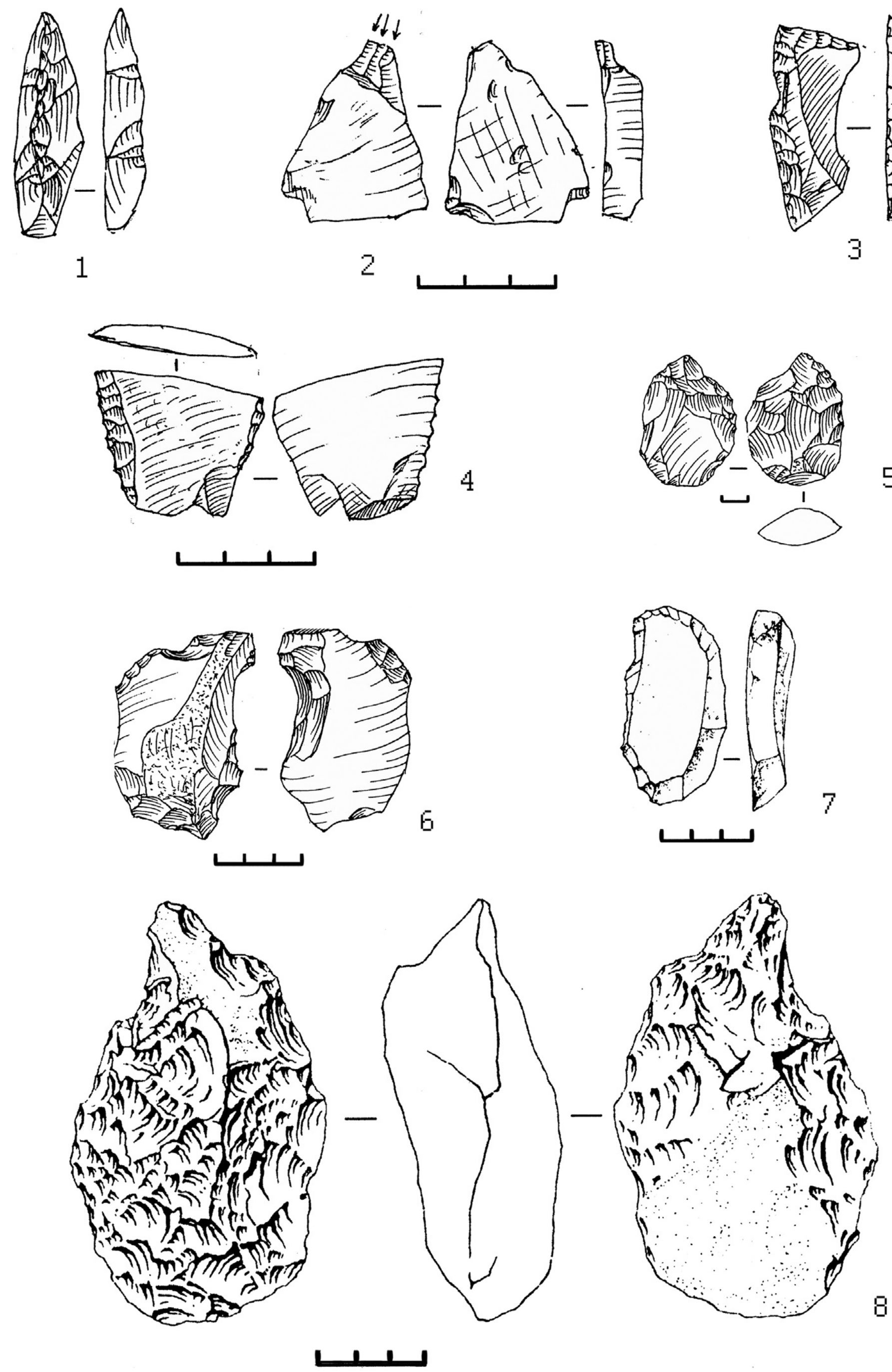

Fig. 7. Stone tools from Kostenki12, layer IV: 1) crested blade; 2) flat burin on a flake with additionally shaped point; 3) angled sidescraper; 4) straight sidescraper on a thin flake; 5) massive bifacially worked tool of oval shape; 6) combined tool on a flake; 7) sidescraper–endscraper of oval shape; 8) handaxe-like biface.

(*Pinus)* or spruce (*Picea)*. *Picea* charcoals have been identified at Kostenki by paleobotanists N.G. Blokhina, E.S. Chavchavadze, G.N. Lisitsyna, and L. Crowford (Blokhina, 1964; Klein, 1969; Levkovskaya et al., 2013).

Data from Kostenki1, Kostenki12, and Kostenki14 (Levkovskaya, 1999; Levkovskaya et al., 2005; and unpublished data) shows that the transition from periglacial steppe to Kostenki coniferous megastage is characterized by a pollen complex with the dominance of morphologically abnormal pollen grains of spruce (Fig. 9) or pine. They are similar to underdeveloped ("abortive") forms from the modern immature anthers of coniferous plants, which sometimes resemble Neogene or Cretaceous forms (Ananova, 1966). According to most palynologists, complexes with such forms of coniferous pollen are not redeposited (see Levkovskaya et al., 1983). They reflect poor conditions for most coniferous trees during their first appearance in the periglacial steppe zone.

Kostenki coniferous megastage began between 42 and 40 ka, which is younger than the abrupt end of the "elm" megastage B (~43.5 ka) and megastage C (periglacial steppes), but before the appearance of tephra about 40 ka (Table 2). Tephra was found within coniferous megastage sediments at Kostenki1, Kostenki12, Kostenki14, Kostenki17, and others. This megastage finished after maximal advance of the glacial sheet in Europe and America at

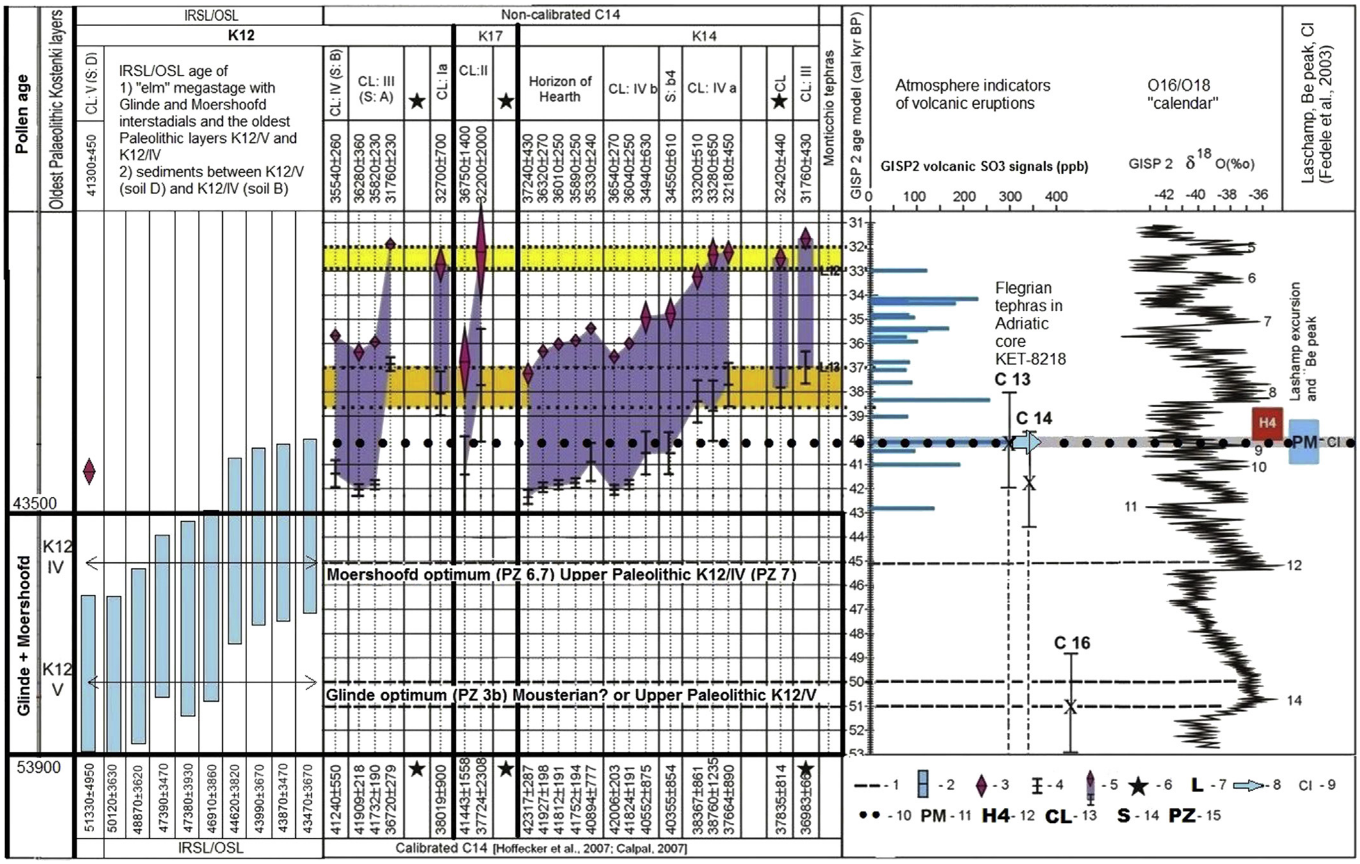

Fig. 8. Kostenki-Borschevo region of the Russian Plain. Comparison of the chronology of Paleolithic layers under CI/Y5 tephra from K12, K17 and K14 sites, based on different methods of dating. Legend: 1) optima of interstadials Glinde and Moershoofd; 2) IRL/OSL dates; 3) uncalibrated ^{14}C dates; 4) calibrated ^{14}C dates; 5) differencies between calibrated and uncalibrated ^{14}C dates; 6) CI/Y5 tephra; 7) levels of tephra in Monticchio Lake pollen standard (Watts et al., 1996); 8) GISP2 volcanic SO_3 signals in atmosphere (Zielinski et al., 1996); 9) dates of three layers of Flegrian tephra from Adriatic Sea core KET-8218; 10) level of correlation of: maximal SO_3 signal of volcanic eruptions in atmosphere, geomagnetic excursion Laschamp, and CI/Y5 eruption time; 11) geomagnetic excursion Laschamp; 12) H4 event; 13) cultural layers; 14) paleosols; 15) pollen zones; 16) variations of ^{14}C dates of charcoal pre-eruption time from K14 site: uncalibrated (upper level) and calibrated (Haesaerts et al., 2004; Hoffecker et al., 2008; Douka et al., 2010).

17 ka, when the cryoxerophilous stage of the Last Glacial Age began. Three thermomers and four cryomers are differentiated within 40–23 ka on the Russian Plain (Zarrina et al., 1980; Nalivkin and Sokolov, 1984; Spiridonova, 1991). Their significance in the Kostenki region is not clear because most diagrams characterize sediments with sedimentation gaps.

Only the brief Kostenki17 optimum, preceding deposition of the CI tephra in the region, was characterized by co-dominance of *Corylus*, *Alnus*, and maximum (20%) of various broad-leaved trees such as *Quercus*, *Ulmus*, and *Tilia* (Fedorova, 1963; Gritchouk, 1969). Analogies of the Kostenki17 interstadial are not found in other profiles of the Kostenki-Borschevo region. Possibly, it is the Hengelo interstadial, an especially favourable period for broad-leaved trees in the Strelitsa watershed (Bolikhovskaya, 1995). The Gmelinskiy interstadial, about 21 ka, is well differentiated at Kostenki12 (zone 18 with about 95% AP and pine), and at Kostenki21 (Levkovskaya et al., 2005; Levkovskaya, unpubl.).

Some stadials are differentiated within the coniferous megastage by low percentage of AP, dominance of NAP (*Artemisia*, *Chenopodiaceae* or mesophilous grasses) and appearance of microtherm shrubs (*Betula nana*, *B. humilis*, and *Alnaster*), although coniferous plants did not disappear from the Kostenki terrace refugium even during the stadials. During the extreme phases of stadials, palynoteratical complexes with dwarf and underdeveloped forms of all plant taxa were predominant.

Especially extreme conditions existed during deposition of the CI/Y5 tephra in the Kostenki region. The palynoteratical complexes of sediments with volcanic ash from Kostenki12 and Borschevo5 resemble "cemeteries" of the "contours" of unidentified palynomorphs of different taxa, most of which are both underdeveloped and dwarf. They indicate an abnormal state of reproductive sphere of most plants of the area. Some palynomorphs are sterile and have completely lost their shape and even protoplast in some cases. Most forms are covered by colloid, which possibly developed as a result of lowering of highly-mineralized ground water temperatures during a "volcanic winter". The colloided pollen grains resemble minerals, which were described in some Kostenki14 layers as drilled sand pieces (Velichko et al., 2009). However, there are variations in pollen characteristics of sediments with tephra collected from different places.

Megastage E is characterized by the dominance of xerophilous NAP (*Artemisia*, *Chenopodiaceae*). It is represented in pollen diagrams of Kostenki19 (Velichko, 1961b; Klein, 1969), and Kostenki21 upper archeological layers (Spiridonova, 1991; Malyasova, unpubl.; Levkovskaya, unpubl.). These archeological sites are located at the first terrace of Don River (Lazukov, 1957; Krasnov, 1982). It is the megastage of periglacial steppe dated to the second (cryoxerophilous) half of the glacial period and to the late glacial.

3.1.2. Oldest buried paleoterraces and subdivision of the Kostenki pollen diagrams

Most Paleolithic sites of the Kostenki-Borschevo region are connected with the second and first ravine of the Don River basin

Table 2
Supra-regional correlations of the most ancient paleosols and Paleolithic layers of Kostenki-12 (Russian Plain).

Kostenki-12 events	Supra-regional correlations		
	Region	Event	Age (ka BP)
Upper part of paleosol A with Strelets culture (first phase) layer III (zone 11) *Fauna complex*: reindeer dominance (Hoffecker et al., 2005) *Pollen zone 11*: The first "spruce" phase of K-12 Paleolithic time, beginning of the long megastage of coniferous forests domination at Kostenki flood terrace refugium (Levkovskaya et al., 2005)	Greenland GISP2 scale of glacial sediments (Grootes et al., 1993)	D–O event 11?	~42
	West France Stalagmite Vil.9 from Villars cave (Genty et al., 2003)	D–O event 11?	~42
	Russian Plain, Kostenki region, K-14 Upper Paleolithic layer IVb (Sinitsyn, 2002, 2012; Sedov et al., 2010a,b)	Transition from periglacial steppe to coniferous megastages (Velichko et al., 2009), and coniferous (spruce) megastage (Spiridonova, 2002). Domination of morphologically abnormal (Fig. 8) pollen (Levkovskaya et al., 1983; Levkovskaya, 1999)	After 42.3
Lower part of paleosol A with Strelets culture layer III (first phase) (zone 10) *Fauna complex*: horse dominance (Hoffecker et al., 2005) *Pollen zone 10*: Dominance of periglacial steppes with single trees. All plants produced only dwarf and immature pollen grains (Fig. 4), indicating geobotanical stress (Levkovskaya, 1999; Levkovskaya et al., 2005; Levkovskaya and Bogolyubova, 2011). C^{14} *dates, a BP* (Table 1): OxA-15482: 35,820 ± 230 (41,732 ± 190 cal) GrA-5551: 36,280 ± 360 (41,909 ± 218 cal) OxA-X-2158-14: 31,760 ± 230 (36,720 ± 279 cal) (Housley et al., 2006; Anikovich et al., 2008; Hoffecker et al., 2008)	Greenland GISP2 section of glacial sediments (Grootes et al., 1993)	Sharp minimum of $^{16}O/^{18}O$ after D–O event 12	~42.3
	West France, Stalagmite Vil.9 from Villars cave (Genty et al., 2003)	Sharp oscillation of $^{13}C/^{14}C$ after D–O event 12 at stalagmite scale Vil.9	~42.3
	Southern Italy, Monticchio paleolake pollen diagram (Watts et al., 1996)	Zone 10: small quantity of AP. Stadial after Glinde + Moershoofd megainterstadial (Watts et al., 2000)	~42.3 (abrupt beginning of stadial)
	Black Sea sediment core 25GC-1 (Shumilovskikh et al., 2014)	Spread of steppe	~44
	Russian Plain, Kostenki region, K-14 Upper Paleolithic layer IVb: its lower part: IVb2? (Sinitsyn, 2002, 2012; Sedov et al., 2010a,b)	End of periglacial steppe megastage. Top of K14 zone of layer 23 with NAP dominance (Velichko et al., 2009)	After 42.3
Paleosol B with Upper Paleolithic layer IV (zones 7,8) and sterile loam under it (zone 6) Moershoofd interstadial *Fauna complex of zones 7 and 8*: dominance of mammoths (Anikovich et al., 2005) *Pollen zone 8*: thermohydrophilous stage of interstadial; maximum of mesophilous NAP, in forests dominance of elm, admixture of pine and spruce *Pollen zone 7*: optimum of interstadial; the second maximum of broad-leaved trees pollen (18%) of Paleolithic time. Second Kostenki "elm" maximum *Pollen zone 6 (sterile)*: beginning of the second "elm" interstadial optimum (Levkovskaya et al., 2005) C^{14} *dates of zones 7 and 8, a BP* (Table 1): OxA-15555: 35,540 ± 260 (41,240 ± 550 cal) (Housley et al., 2006; Anikovich et al., 2008; Hoffecker et al., 2008) *IRSL/OSL dates of zone 6, a BP*(Table 1): UIC-915: 48,870 ± 3620(?); 44,620 ± 3820; 43,990 ± 3670 [a]UIC-945: 45,200 ± 3260; 44,650 ± 3800; 44,150 ± 3780 UIC-946: 47,390 ± 3470; 43,870 ± 3740; 43,470 ± 3670 [a]UIC-947(?): 50,120 ± 3630; 47,380 ± 3930; 46,910 ± 3860 (Anikovich et al., 2005, 2007a,b; Hoffecker et al., 2007, 2008)	Greenland GISP2 section of glacial sediments (Grootes et al., 1993)	D–O event 12 on $^{16}O/^{18}O$ scale GISP2	Optimum ~45.3
	West France, Stalagmite Vil.9 from Villars cave (Genty et al., 2003)	D–O event 12 at Vil.9 scale: A) thermohydrophilous and cryohydrophilous stages (time of stalagmite maximal growth rate); B) optimum	A) 45.4–42.3 B) 46.3–45.4
	Southern Italy, Monticchio paleolake pollen diagram (Watts et al., 1996; Zolitschka and Negendank, 1996)	Zone 11: dominance of AP (*Quercus* with *Pinus* and *Abies*). Glinde + Moershoofd megainterstadial (second half)	~50–43.6 (second half of span)
	Black Sea sediment core 25GC-1 (Shumilovskikh et al., 2014)	MIS-3 second maximum of broad-leaved trees pollen with dominant *Quercus*	46.3–45.4
	Central France, pollen diagram of pit-bog section Boushet-Proclaux (Reille and Beaulieu, 1995)	MIS-3 second AP maximum	~45
	Northern Europe, Moershoofd pollen diagrams (Zagwijn, 1961; Van der Hammen et al., 1967; Kolstrup, Wijmstra, 1977; Ran, 1990)	Optimum of the Moershoofd interstadial. Dominance of birch	Opt. ~46–44
	Russian Plain stratigraphical scheme (Zarrina et al., 1980; Spiridonova, 1991)	Grazhdanskiy megainterstadial with two optima	~50.0–40.0 (second half of span)
Paleosol D with Paleolithic Layer V (zones 3b) and upper part of sterile	Greenland GISP2 section of glacial sediments (Grootes et al., 1993)	D–O event 14 at $^{16}O/^{18}O$ scale GISP2	53–47 Optimum: 51–50

(*continued on next page*)

Table 2 (*continued*)

Kostenki-12 events	Supra-regional correlations		
	Region	Event	Age (ka BP)
layer 19 (zone 3a) Glinde interstadial	West France, Stalagmite Vil.9 from Villars cave (Genty et al., 2003)	D–O event 14 at stalagmite scale Vil.9 $^{13}C/^{14}C$	53–48
Fauna complex of zone 3b: dominance of red deer (Anikovich et al., 2005)	Southern Italy, Monticchio paleolake pollen diagram (Watts et al., 1996; Zolitschka and Negendank, 1996)	Zone 11: dominance of *Quercus*. Glinde + Moershoofd megainterstadial (first half)	50–43.5 (first half of span)
Zone 3b (layer V, paleosol D): the largest maximum of broad-leaved trees pollen. First "elm" interstadial optimum (Levkovskaya et al., 2005)	Black Sea sediment core 25GC-1 (Shumilovskikh et al., 2014)	Largest MIS2-3 maximum of AP with dominance of *Quercus*.	53.9–51
C^{14} *dates, a BP (uncal)* (Table 1): OxA-15902: 38,410 ± 300; OxA-15556: 41,300 ± 450 (Housley et al., 2006; Anikovich et al., 2008; Hoffecker et al., 2008)	Central France, pollen diagram of pit-bog section Boushet-Proclaux (Reille and Beaulieu, 1995)	AP maximum	~49
Zone 3a (under layer V, border of soil D and sterile layer 19): Beginning of the first and largest "elm" maximum (Levkovskaya et al., 2005) *IRSL/OSL of sterile layer 19, a BP* (Table 1): UIC-917: 50,520 ± 4380; 51,330 ± 4950; 52,440 ± 3850 [a]UIC-945 (?): 45,200 ± 3260; 44,650 ± 3800; 44,150 ± 3780 [a]UIC-947: 50,120 ± 3630; 47,380 ± 3930; 46,910 ± 3860 (Anikovich et al., 2005, 2007a,b; Hoffecker et al., 2007, 2008)	Northern Germany, Rugen Island Key diagram for interstadials Oerel and Glinde (Behre and van der Plicht, 1992)	Optimum of Interstadial Glinde	51.6–47

[a] The locations of the samples UIC-945 and UIC-947 might be unclear in context of supra-regional correlations (chapter 3.4). Therefore we show the samples from Glinde (zone 3a, palaeosol D) or Moershoofd (zone 6, sediments under B palaeosol) age sediments at both levels simultaneously. But used for interpretation only the dates which agree with reconstructed global interstadials chronology and their Kostenki IRSL/OSL dates.

terraces (Lazukov, 1957; Krasnov, 1982), which may be differentiated into upper and lower levels (Grischenko, 1974; Grischenko and Durnev, 1974; Durnev, 1974, 1979). The sediments of both levels of the second terrace are covered by tephra. The Kostenki12 "elm"-type pollen diagram characterizes the full sedimentary cycle of the older level of the second terrace covered by the CI/Y5 tephra, because the same "elm"-type was discovered in the sediments under tephra of the second "Deviza" Don River terrace (unpublished materials of F.A. Durnev), and the most ancient paleosols and Paleolithic layers of the region are correlative (Anikovich et al., 2005, 2007b, 2008; Hoffecker, 2005; Levkovskaya et al., 2005; Anikovich, 2005a,b; Hoffecker et al., 2008).

Kostenki12 layer 21 is an alluvium of the ravine spring buried terrace (Fig. 3, Table 1). It is pale loam with a large quantity (40%) of carbonate gravels and rolled small pebbles (about 2 cm) found in the section of 2003 (in excavation unit 81/83 ЬI). It is a lower part of the unit IA: calcareous silt loam (alluvium?) with common carbonate gravels and nodules, and pockets and lenses of organic matter (Holliday et al., 2007). Most of the Kostenki12 layers below layer 11 with tephra are floodplain terrace sediments, and four paleosols (D, C, B, A) formed *in situ* (Holliday et al., 2007).

Fig. 3 illustrates the correlation of the sediments of Kostenki12 buried terrace and the overlying diluvial fan with Borschevo5. The correlation of the lowest Kostenki12 (D) and Borschevo5 paleosols is especially important because both are characterized by domination of elm pollen.

Kostenki12 has a single hiatus between the beginning of the coniferous megastage and before the deposition of tephra in Kostenki. This hiatus is an indicator of a lower position of the erosional surface between the two levels of the second terrace. The two levels are characterized by two types of pollen diagrams: 1) "elm"-type of Kostenki12 (with sediments of periglacial steppe and only the first phase of "coniferous" megastage before hiatus) and 2) "coniferous"-type of all other Kostenki diagrams (except for four diagrams of cryoxerophilous megastage E of Late Glacial time).

3.1.3. Pollen data on sediments under CI/Y5 tephra at Kostenki1, Kostenki12, Kostenki14, Kostenki17, Borschevo5, and Kostenki stratigraphical bore-pit

Kostenki 1 site: The individual maxima of elm pollen are represented at Kostenki1 below all archeological layers in the lower parts of two diagrams by M.P. Gritchouk (Lazukov, 1954) and Levkovskaya (1977). A "Coniferous"-type diagram is published for Kostenki1 section from the 1974 pit (Spiridonova, 1991). The lowest Kostenki1 Upper Paleolithic layer was formed during the end of interstadial within the "coniferous" megastage (Gritchouk, 1969). However, the Paleolithic layer of the "*Ulmus-Alnus*" optimum with *Abies* pollen and charcoal was discovered under the CI/Y5 tephra at Kostenki1 (excavations of M.V. Anikovich in 2007; unpublished data of G.M. Levkovskaya).

Kostenki12 site: Near Kostenki12, older and younger levels of the second terrace existed before the appearance of tephra in the region. Two diagrams were published for Kostenki12 (Levkovskaya, 1977; Levkovskaya et al., 2005). The lower parts of these diagrams (under CI/Y5 tephra) characterize sediments of the "elm" and "steppe" megastages, the first phase of "coniferous" megastage, whereas their upper parts represent only individual fragments of younger Pleistocene sediments. The erosional contact between the older and younger levels of the second terrace was found at Kostenki12 during excavations in 1958. Pollen characteristics of sediments below and above this contact have been described (Levkovskaya, 1977). Two lowest Paleolithic layers at Kostenki12 correspond to the "elm" megastage, and layer III corrsponds to the steppe (lower part) and beginning of "coniferous" (its upper part) megastages.

Kostenki14 site: At Kostenki14, the older level of the second terrace with "elm" megastage sediments has not been found. Three diagrams obtained for Kostenki14 characterize the sediments under CI/Y5 tephra, synchronous with the younger level of the second terrace. Only "steppe" and "coniferous" megastages are presented on pollen diagrams of this section obtained by different palynologists (Malyasova and Spiridonova, 1982; Velichko et al., 2009;

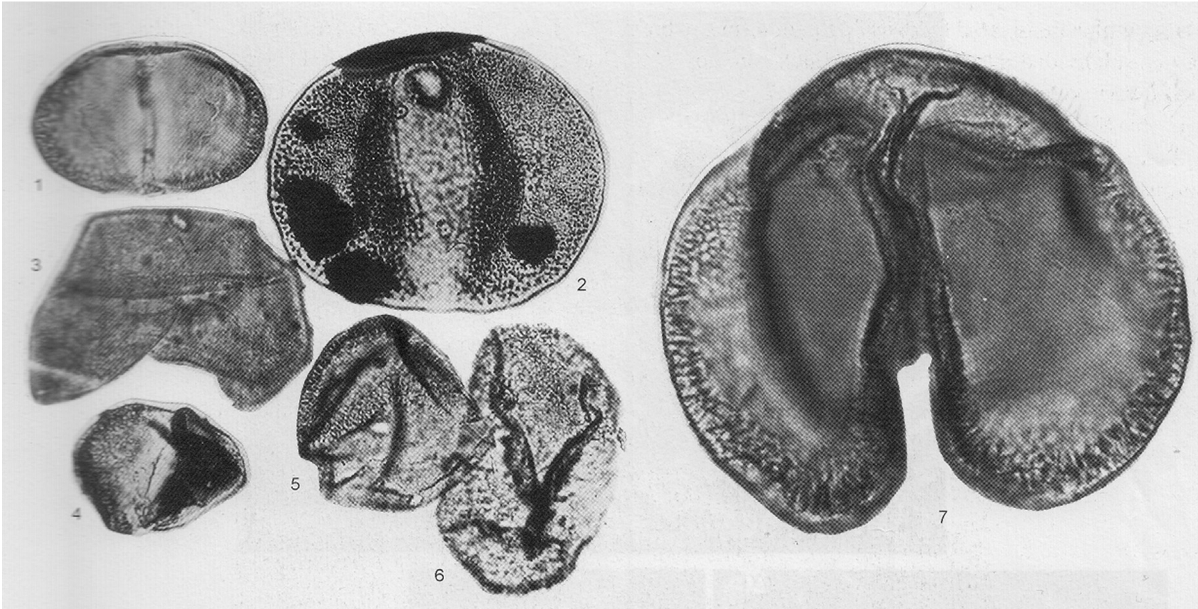

Fig. 9. Examples of variations of Pleistocene spruce (*Picea*) pollen grains morphology from beginning of "coniferous" megastage in the Kostenki-Borschevo region. Micrographs illustrate 1) normally developed and dwarf pollen grain: general view; 2) for comparison, Cretaceous pollen of *Pseudopicea* sp. from Ognevskaya site (Mtchedlishvili, 1977); 3) pollen with two asymmetrical sacs; 4) dwarf pollen grain with one abnormally developed sac; 5,6) – mutually adherent palynoteratical grains from a single anther with poorly developed ornamentation; 5 – crumpled pollen grains; 6 – pollen grain with undifferentiated sacs; 7 – palynoteratical giant grain. Magnification 1–7: ×400. The complex with dominance of morphologically abnormal pollen grains of spruce is typical for the beginning of "coniferous" (D) megastage in Kostenki-Borschevo region (data on Kostenki1, 12, 14), and for transitions: stadial–interstadial and interstadial–stadial. Some palynologists excluded such forms from Kostenki Quaternary complexes. As described in Levkovskaya et al. (1983), seven palynologists (specialists on Holocene, Pleistocene stadials, Neogene, Cretaceous palynology, and modern pollen morphology) studied the same samples from Kostenki14. All of them interpreted the atypical spruce pollen grains as Quaternary, because they are similar to morphologically abnormal pollen grains of coniferous plants that dominate in modern immature anthers and exhibit dark yellowish colors, as do Cretaceous forms (Ananova, 1966).

Levkovskaya, unpublished data on A.N. Rogachev bore pit). According to the pollen data of V.I. Pisareva, the lowest Upper Paleolithic layer (IVb) of Kostenki14 (geological layer 23) was formed during the treeless megastage C, during the transition between "steppe" and "coniferous" megastages (Velichko et al., 2009). According to Spiridonova (2002), layer IVb is associated with the "coniferous" megastage.

Kostenki17 site: (excavations of P.I. Boriskovskiy, 1963). Layer II is connected with the "coniferous" megastage (Gritchouk, 1969), but it was formed before the warmest interstadial optimum within the coniferous megastage (Fedorova, 1963) and possibly correlates to Hengelo.

Borschevo5: The lowest paleosol of Borschevo5, lying below all archeological layers, was formed during the "elm" megastage (Fig. 3).

In the Kostenki stratigraphical bore pit, only sediments of the "coniferous" megastage are represented (Malyasova and Spiridonova, 1982).

3.1.4. Kostenki12 paleosols as a basis of the most ancient Paleolithic layers stratigraphy

Many ancient Upper Paleolithic layers are found in the lower humic bed in the region, under sediments with CI/Y5 tephra. Four K12 Paleolithic paleosols were found under the tephra at Kostenki12, and the most ancient Paleolithic layers in the region are connected with them. According to soil micromorphological analysis (Holliday et al., 2006, 2007), Kostenki12 paleosols D, C, B, and A were formed *in situ*, indicated by presence of subaerially weathered chalk clasts, mesofauna, worm carbonized traces, horizontal krotovinas, and roots.

Kostenki12 has small displacement of all layers along slope, but not redeposition (Fig.2). Paleosols B, C, and D were well preserved, whereas paleosol A was well preserved only in the central part (Figs. 2 and 3). The description of these paleosols and other sediments of Kostenki12 section is provided in Table 1.

The oldest Kostenki12 cultural layer V was found in paleosol D. Its upper part corresponds to a thin horizon of lenses on the contact of layers 18 (paleosol D) and 17 with a small maximum of microtherm bushes (zone 4) within the "elm" megastage. It divided the Glinde and Moershoofd interstadials. The Upper Paleolithic layer IV is connected with paleosol B, and the first phase of the Kostenki-Strelets cultural layer III with paleosol A.

The upper level of the second terrace at Kostenki12 has the oldest paleosols of the region. The stratigraphical correlation of Kostenki12 and Borschevo5 (Fig. 3, Table 1) shows that paleosols D and A of K12 have analogies in Borschevo5, suggesting the general trend of environmental development in the Kostenki-Borschevo region.

3.2. Correlations of general paleoenvironmental patterns with Russian Plain climatostratigraphical scale

The most detailed chronostratigraphical scale of the Russian Plain Late Pleistocene is worked out on the pollen data of the glacial zone (Zarrina et al., 1980; Nalivkin, Sokolov, 1984; Spiridonova, 1991). Therefore, some paleoenvironmental characteristics of the global events concern more northerly areas than Kostenki, and their age and paleoenvironmental data cannot be directly correlated with the Kostenki chronology.

Megastage A (bushy tundra): Kostenki megastage A with cold and wet climate corresponds to the final stage of the Early Valdai glaciation (~60 ka), during which the ice sheet advanced into the mainland from the continental shelves in the Barents and Kara seas (Mangerud et al., 2004).

Megastage B (elm forests and meadows): Kostenki megastage B with two "elm" interstadials could be correlated with the Russian

Plain megainterstadial Grazhdanskiy (~50–40 ka), which has two optima. The key section of the Grazhdanskiy interstadial is located in Saint Petersburg in the modern taiga zone. Therefore, the dominance of coniferous forests with small quantities of broad-leaved trees is characteristic for this period in the Russian Plain climatostratigraphical scale. Elm forests dominated in Kostenki flood terrace refugium during this time. Kostenki pollen paleoenvironmental reconstructions are agreed with paleozoological data (red deer dominates in the "elm" megastage), and with paleoclimatic data for the DO12 optimum. Paleotemperatures at about 10 °C (in comparison with the former cold stage) are registered in Villars Cave, Western France (Genty et al., 2003), in Southern France palaeolake sediments, based on insect identification (Guiot et al., 1993), and in Iberian marine cores (Cavre et al., 1999).

Megastage C (periglacial steppes): Kostenki periglacial steppe megastage C possibly corresponds to the Russian Plain Bugrovskiy cryophase, characterized by continental and cold climate (~40–37.5 ka). Because sediments of this megastage are found in Kostenki under CI/Y5 tephra at Kostenki1, Kostenki12, Kostenki14, and Kostenki17, the age of this Russian Plain cryophase might be more than 40 ka.

Megastage D (coniferous forests and meadows): Kostenki coniferous megastage D lasted for a long time. It corresponds to the time of deposition of the sediments of the lower level of the second terrace (with upper humic bed of the region and Bryansk soil of Russian Plain (Velichko, 1961)), lower level of the first terrace and diluvial fan under which both terraces are buried. Most of it correlates to the period between the Bugrovskiy cryophase (37.5 ka BP) and the maximum of the Middle Valdai glaciation (17 ka BP). This span corresponds to Middle Valdai megainterstadial during the Last Glacial. The Scandinavian and North American ice sheets formed and reached their maximal size during Last Glacial Maximum about 17 ka BP. However, the Barents-Kara ice sheet did not inundate the Russian mainland to the east of the White Sea, which implies that vast areas remained ice-free.

Two interstadials are differentiated on the Russian Plain within the Middle Valdai megainterstadial for the time of "coniferous" megastage in Kostenki: Kashinskiy (~37.5–34 uncal ka BP) and Dunaevskiy (~32.5–25 uncal ka BP). Calibrated dates reveal that the first interstadial begun about 42.4 ka BP, and the second about 37.5 ka BP. Analogies of these interstadials are not differentiated exactly in the Kostenki-Borschevo region. The Kostenki17 interstadial was registered before the appearance of tephra in Kostenki (about 40 ka BP). However, its sediments were found only in one section (Fedorova, 1963).

The Gmelinskiy interstadial and paleosol were discovered by N.D. Praslov (Praslov and Ivanova, 1982) at Kostenki21 within the cryohydrophilous stage of the glacial, and before the Last Glacial Maximum. The age of the Gmelinskiy interstadial is about 21 ka BP.

Similarly to the Black Sea core M72/5-25-GC1 (Shumilovskikh et al., 2014), pollen records of K12 and the fullest section K21 with the Gmelinskaya paleosol (unpublished pollen data of G.M. Levkovskaya) indicate a pronounced cryohydrophilous trend towards 20 ka (Shumilovskikh and Levkovskaya, 2013), the time of growth of the glacial ice sheets in the northern regions of Eurasia. The cryohydrophilous end of the coniferous megastage is characterized by especially active development of diluvial fans in the region. These fans buried ancient relief and practically all Paleolithic sites.

Megastage E (steppe): This corresponds to the second (cryoxerophilous) stage of the Late Glacial period. The youngest Upper Paleolithic site (Borschevo2; excavation of S.N. Lisitsyn) was occupied during the Allerød. Megastage E was the time of maximum loess deposition in the Kostenki region, connected with the precipitation deficit in the Eurasian continent during the maximum lowering of sea level.

3.3. Supra-regional correlations of Kostenki12 for the period between 53 and 42 ka

In this section we present the supra-regional correlations for the period ~53–42 ka for archeological layers, paleosols, reconstructed vegetation, paleoclimate, paleozoological complexes, and pollen zones (Table 2, Fig. 5).

3.3.1. Tephra CI/Y5 as a basis for correlations

Initial and early Upper Paleolithic layers were found in the Kostenki region under the layers with volcanic ash. This tephra is connected with the CI/Y5 eruption about 40 ka BP at the Flegrian caldera in Southern Italy (Melekeszev et al., 1984; De Vivo et al., 2001; Ton-That et al., 2001; Fedele et al., 2003; Pyle et al., 2006). The age of the tephra horizon in some Black Sea cores is 39.28 ± 0.11 ka (Nowaczyk et al., 2012). Three horizons of the same trachitic tephra from Ishia and Campanian centers of Flegrian province are found in the Adriatic Sea core KET-8218. The Adriatic tephra horizons have the following dates: ^{13}C – 40.0 ± 2.0, ^{14}C – 41.8 ± 2.0, ^{16}C – 51.0 ± 2.2, ^{17}C – 55.4 ± 2.2 (Paterne, 1992). The calibrated ^{14}C age of charcoal from tephra in the Upper Paleolithic layer of Kostenki14 is 40 ka (Douka et al., 2010). These dates indicate occupation by humans before the volcanic eruption.

Pollen characteristics of sediments with tephra vary between sites. This could reflect redeposition of tephra or (possibly?) tephra of different eruptions from the Flegrian field. Tephra was found in some layers of Kostenki1 by J.F. Hoffecker and at two levels of Kostenki14 by R. Housley and P. Haesaerts. A new joint pollen and tephra study should be organized to resolve this problem.

3.3.2. Paleomagnetic studies as basis of the stratigraphy of K12

Review of materials on different magnetic excursions (Laj et al., 2006; Laj and Channell, 2007; Valet et al., 2008) shows that there are variations in the chronology of the Laschamp geomagnetic excursion: 45–40 ka (Langereis et al., 1997), 41 ka (Laj and Channell, 2007). According to geomagnetic data obtained from several Black Sea cores, this excursion age is 40.7 ± 0.95 ka (Nowaczyk et al., 2012).

Magnetic and paleomagnetic studies of sediments from the stratigraphic profile of K12 began in 2002 (Pospelova, 2003, 2005, 2008; Pospelova et al., 2005). Seven sample-blocks were studied from lithological units 18, 16, 15, 14, 13, and 12. According to magnetic susceptibility values and natural remnant magnetization (NRM), the sediments are weakly magnetic, except samples from the organic-rich unit 18 (Fig. 3). Values of Qn and thermal demagnetization results indicated that the NRM is stable. The remnant magnetization (ChRM) of the sediments, derived from their thermal demagnetization at 600–680°C and component analysis of the data, suggest reversed polarity in the sample from paleosol A (unit 12). Some anomalous inclinations occur in samples from units 15 and 13. The samples with reversed and anomalous ChRM directions indicate that a geomagnetic excursion might have been recorded in the section. The most reliable result was obtained on sample 4, taken from humified lithological unit 12 (cultural layer III) (Pospelova, 2005, 2008). Previous palynological and geomagnetic studies on the Laschamp excursion from a borepit section in Uzbekistan and other regions (Petrova, 1998; Pospelova et al., 2000; Pospelova, 2003) demonstrate that the geomagnetic excursion coincides with a warm climatic phase, and lasted over several climatic phases.

Pollen and paleozoological data on unit 12 with geomagnetic excursion of Kostenki12 site shows a rapid change from steppe conditions to forest tundra and later stratigraphical lacuna is registered for the time of Kostenki17 optimum (Levkovskaya et al., 2005). Possibly the magnetic pole reversal could have caused the paleoenvironmental change in layer 12. However, more extensive experimental data, analyzed in 2003–2004, could not confirm this result (Pospelova et al., 2005).

Pospelova (2003) and Pospelova et al. (2000) conclude that it is difficult to consider sporadic samples with reverse magnetization as a reliable record of the Laschamp-Kargapolovo excursion. Moreover, samples selected in deep, freshly excavated units allow detection of the excursion, but after a year or two the sediments in open sections become remagnetized by the modern geomagnetic field. Thus, the detected presence of the geomagnetic excursion is more significant than its absence in later analysis.

The stratigraphical position of the Laschamp excursion in other Kostenki sites is not clear. At K14, this reversal was found only in one sample with evidence of erosion (Gernik and Gus'kova, 2002; Sinitsyn, 2002). Laschamp was not found as a result of later researches (Løvlie, 2006). At Kostenki17, this excursion was found at the level of Upper Paleolithic layer II.

3.3.3. Paleolithic layer V, paleosol D, PZ 3b: Glinde interstadial (54–49 ka BP, with optimum 51–50 ka BP)

The results of supra-regional correlations of the pollen diagram shows that layer V, connected with paleosol D (Fig. 5: CorI, zone 3b, Tables 1 and 2) was formed during the first (Glinde) interstadial of the Kostenki "elm" megastage. It is connected with the optimum of this interstadial (zone 3b). The uppermost part of layer V is the 8-cm layer of pale brown loam (ACb6) (Holliday et al., 2006), which according to pollen data was formed during a short cool phase (zone 4), which subdivides the "elm" Glinde and Moershoofd interstadials of one "elm" megastage.

The age of the optimum of the Glinde interstadial vary between 51.6 and 47 ka BP in its key-section (Behre and van der Plicht, 1992) and 54–51 ka BP in pollen record of the Black Sea core M72/5-25-GC1 (Shumilovskikh et al., 2014). The layer formation corresponds to Dansgaar–Oeschger (DO) oscillation 14 on the $^{13}C/^{14}C$ scale Vil.9 and DO 14 on the $^{16}O/^{18}O$ scale GISP2. IRSL/OSL dates for sediments just under Layer V, sample UIC-917 (50.52 ± 4.38 ka, 51.33 ± 4.95 ka, and 52.44 ± 3.85 ka) coincide with the Glinde age of soil D and sediments just under it, whereas UIC-945 (44.15 ± 0.78 ka, 44.65 ± 3.8 ka, 45.2 ± 3.26 ka) correspond to the Moershoofd interstadial (Table 1). Possible mistakes in dating of samples UIC-945 and UIC-947 are discussed below.

The sediments of paleosol D consist of calcareous ravine terrace alluvial sediment with traces of mammal coprolites and subaerially lower humic bed weathered chalk clasts. The dark upper layer is locally organic-rich and appears to be depositional in origin, reworked locally by mesofauna and probably slightly later rooting. This sediment was possibly seasonally accreted with likely syn-depositional biological working such as rooting and mesofauna and/or with moderate calcareous cementation (Holliday et al., 2006), that indicates *in situ* soil formation.

The lithic tool assemblage consists of 10 stone artifacts, two with secondary treatment (Fig. 6). They were made with Kostenki local "colored" Cretaceous flint, found in combination with paleozoological remains. Their attribution to the Upper or Middle Paleolithic remains problematic (Anikovich et al., 2008).

The mammalian fauna includes *Rangifer tarandus* L. (dominant), *Mammuthus primigenius* Blum., *Coelodonta antiquitatis* Blum., *Cervus elaphus* L., *Canis lupus* L., and *R. tarandus*, indicating mild climate and afforestation of the area (Anikovich, 2005a,b). The mollusc complex includes *Vallonia tenuilabris ladacensis* Nevill (1 specimen), *Pupilla loessica* (Loһek) (2), *Pupilla muscorum densegyrata* (Loһek) (4), *Cochlicopa lubrica* (Müller) (5), *V. tenuilabris* (A. Braun) (15), *Trichia hispida* (Linnaeus) (20), *Pupilla sterri* (Voith) (109), *Vallonia costata* (Müller) (146), *Succinea oblonga elongata* (Sandberger) (341), and *P. muscorum* (Linnaeus) (465). Indicators of wet soils sharply dominate (75.6%). Some elements of cold climate are present such as *P. loessica* and *S. oblonga elongata* (31%). This complex corresponds to a thin (8 cm) layer of pale brown loam (ACb6) from the upper part of layer V (Holliday et al., 2006). It indicates cool climatic conditions at the end of paleosol formation.

According to the pollen data (Fig. 5: CorI, zone 3b; Tables 1 and 2), the level of afforestation of the area was rather high (AP 60%). Elm forests with occasional hornbeam, spruce, alder, and birch, and wet meadows are reconstructed for the ravine terrace refugia of the Kostenki area. The meadows supported various mesophilous grasses, sedges, and *Botrychium* cf. *ramosum*. Xerophilous plant communities, formed by *Artemisia*, *Chenopodiaceae* with bushes of *Ephedra* and *C. orientalis*, grew on the watersheds, according to reconstructions for the Strelica site (Bolikhovskaya, 1995), located close to Kostenki.

The pollen of broad-leaved trees such as Carpinus betulus, Tilia platyphyllos, Tilia cordata, Ulmus laevis, Ulmus campestris/U. foliacea/U. minor, Quercus robur, Corylus avellana, Fraxinus, and *Acer* with dominance of mesoxerophyte and microtherm elm (*Ulmus laevis*) suggest a warm climate. *C. orientalis* was identified in contemporaneous sediments of the Strelitsa watershed (Bolikhovskaya, 1995). *C. betulus, C. orientalis* and *Tilia platyphyllos* are absent in the present flora and grow in western region of the former USSR, in the Caucasus, and in the southern Don River basin. However, *C. betulus* L. was documented in Kostenki Upper Paleolithic ravine refugia (Lazukov, 1957; Fedorova, 1963; Gritchouk, 1969; Levkovskaya, 1977; Levkovskaya et al., 2005) and *T. platyphyllos* was identified from Kostenki in the younger optimum of coniferous megastage from Kostenki17 (Gritchouk, 1969). Other identified arboreal pollen from layer V includes *Alnus*, *Betula sect. Albae*, *Lonicera*, *Salix*, *Pinus sylvestris*, *Picea.* NAP includes *Ericaceae, Liliaceae, Caryophyllaceae, Menyanthes trifoliata* (water and bog plant), *Polygonum aviculare* (ruderal plant), Fabaceae, *Cichoreaceae, Asteraceae, Cyperaceae, Plantago sp., Plantago major* (ruderal indicator), *Chenopodiaceae, Artemisia, Poaceae,* and *Batrychium cf. ramosum* (plant of dry meadows and forest clearings). Flora of water plants includes isolated *Trapa natans*, indicating a warm climate, and *Myriophyllum* sp. The supra-regional paleoenvironmental correlations show that the maximum of elm in the Kostenki-Borschevo region, corresponding to the optimum of Glinde interstadial in Northern Germany, is characterized by the maximum of oak in Black Sea core M72/5-25-GC1 (Fig. 5: Cor. III, Table 2) and in the Lake Monticchio (Italy) record (Fig. 5: Cor. II; Table 2).

3.3.4. Upper Paleolithic layer IV, paleosol B, PZ 7-8: Moershoofd interstadial optimum (46.3–45.4) and its thermohydrophilous phase (45.4–43.5)

The pollen diagram of Kostenki12 (Fig. 5: Cor I) and table with supra-regional correlations (Table 2) illustrate that layer IV and paleosol B were formed during the second half of the Moershoofd interstadial optimum (zone 7), spanning 46–44 ka in various regions, and its thermohydrophilous stage (zone 8). The Moershoofd optimum in Black Sea core M72/5-25-GC1 is about 46.3–45.4 ka. The data from Villars cave showed that DO-12 started at about 46.8 ka, reached its optimum at 45.3 ka, had thermohydrophilous and cryohydrophilous phases during 45.3–42.3 ka, when the rate of stalagmite growth was maximal, and abruptly terminated at 42.3 ka. Four dates obtained for IRSL/OSL samples UIC-915 and UIC-946 correspond to the span 44.62–43.47 ka, which is synchronous to the Moershoofd interstadial (46.2–43.5 ka). IRSL/OSL dates of UIC-917 correspond to the span 47.39–48.87 ka, synchronous with the Glinde interstadial (51.55–47.0 ka). This unagreement is explained in the note to Tables 1 and 2.

According to Holliday et al. (2007), paleosol B with Upper Paleolithic layer IV is characterized by lenses of pale brown (6.5/4) and lighter brown (10 YR+5.5/4) loam 5–10-mm thick with fine lenses of light tan decalcified loam <5 mm thick and krotovinas. The micromorphological studies (Holliday et al., 2007) showed that the sediments of paleosol B consist of layers of silt interbedded with decalcified soil aggregate and both humic and nonhumic beds, exhibiting biological and freeze–thaw activity. It is mainly waterlain alluvium with typical calcareous sediment and partially decalcified soil aggregates as colluvium, possibly eroded from slopes.

Kostenki12/IV was discovered by M.V. Anikovich in 2001. The lithic tool assemblage consists of 72 stone artifacts, 10 with secondary treatment (Fig. 7). The raw material was Kostenki local colored flint. Flakes and fragments dominate among the blanks. The cores resemble Mousterian types. A large number of small flat flakes may be interpreted as bifacial trimming flakes. In addition, there are a blade and bladelets of Cretaceous flint, as well as a perfect crested blade (Figs. 6 and 7), suggesting the existence of highly developed Upper Paleolithic prismatic core technology. The archaic features of this industry were caused by poor quality raw material (Anikovich et al., 2008). They are found in combination with palaeozoological remains.

The paleozoological complex includes *M. primigenius* Blum. (dominant), *Equus latipes* Grom., *Bison priscus* Boj., *Alces alces* L., *R. tarandus* L. (?), and *Lepus tanaiticus* Gureev. This combination indicates moderately warm climate, forest-steppe vegetation and mosaic landscapes.

According to the pollen data (Fig. 5: CorI, Table 2), the level of forestation of Kostenki was lower than during the Glinde optimum, indicated by lower AP percentages of 20%. However, the pollen spectra is similar to the Glinde interstadial with elm and alder dominance in the forests and various grasses dominant in wet meadows. This warm optimum appears to have been wetter than the Glinde optimum. Indicators of xerophilous plant societies are represented in the first half (zone 5) but full absent (zone 6) in the second half of this interstadial. The second maximum of elm corresponds to the second oak maximum in the Black Sea pollen records of M72/5-25-GC1 (Fig. 5: CorIII, Table 2) and Monticchio Lake (Fig. 5: CorII, Table 2).

3.3.5. Kostenki-Strelets culture layer III (first phase), paleosol A, PZ 10-11 (~42,3 ka BP)

The pollen diagram demonstrates that layer III and paleosol A (Fig. 5: CorI, Tables 1 and 2) were formed during unstable climatic conditions of megastages B (zone 10, periglacial steppes) and C (zone 11, first phase of "coniferous" megastage). The both occurred after the final part of the Moershoofd interstadial about 43.5 ka. Data from Monticchio shows that this cold phase after Moershoofd began approximately 43 ka (Watts et al., 1996) and corresponds to the end of DO 12 on the $^{16}O/^{18}O$ Greenland scale GISP2 and in $^{13}C/^{14}C$ stalagmite Vil.9 at about 43.2 ka.

The sediments of the top of lower humic bed of Kostenki12 are gray calcareous silt, strongly humic, with *in situ* calcite. Strongly burrowed series of calcareous marls and more mineralogenic alluvium display weak structural collapse. Seasonal variations in sedimentation and biological activity/slaking of soil/sediment are possible (Holliday et al., 2007).

K12/III was discovered by A.N. Rogachev in 1950. Currently, the lithic assemblage includes more than 250 tools with secondary treatment. The complex is classified as an "archaic" ("transitional") one. The raw material is almost exclusively Kostenki local colored flint. Mousterian types (such as Mousterian points, sidescrapers) are found together with typical Upper Paleolithic tools (various types of endscrapers, high transverse chisels, scaled pieces) (Anikovich, 2003; Anikovich et al., 2008). There is also a series of triangular bifacial points with concave bases ("Streletskian type"), and other types of bifacial foliates. The complex was interpreted as representing the oldest stage of the Upper Paleolithic Kostenki-Streletskaya culture (Anikovich et al., 2004; Anikovich, 2013). While typologically it appears somewhat archaic, the technology of biface manufacture is fully Upper Paleolithic in character (Bradley et al., 1995).

The paleozoological complex consists of *E. latipes* Grom. (dominant), *R. tarandus* L. (co-dominant), *M. primigenius* Blum., *Capreolus capreolus* L. (?), *Alces alces* L., and *C. lupus* L. Detailed taphonomical research (Hoffecker et al., 2005, 2010) showed that the bones of horse (*E. latipes* L.) and reindeer (*R. tarandus* L.) exhibited evidence of different taphonomic histories, and probably were deposited at different times.

The mollusc complex includes *P. muscorum* (Linnaeus), *T. hispida* (Linnaeus), *V. costata* (Müller), species of vast geographic range, and *S. oblonga elongata* (Sandberger), a North-European and Arctic species. These molluscs indicate treeless landscapes of the flood terrace biotopes. Some loess periglacial forms presented in the complex suggest loess accumulation.

The Kostenki12 pollen diagram suggests that Paleolithic layer III and paleosol A were formed in unstable climatic conditions. The lower part of the Paleolithic layer III (zone 10) is characterized by an almost complete absence of morphologically typical pollen grains of all taxa, indicating geobotanical stress (Levkovskaya, 1999; Levkovskaya and Bogolyubova, 2011; Levkovskaya, 2012), by dominance of dwarf and immature grains of *Chenopodiaceae* (Fig. 4) and other taxa. It was formed under cold and dry periglacial conditions. The vegetation is characterized by periglacial steppe with *Artemisia* and *Chenopodiaceae* dominance, which is consistent with the predominance of horse in the lower part of layer III. Only isolated trees and microtherm bushes were present in the region, such as *Alnus*, *Alnaster*, *Betula*, *B. nana*, *Pinus sylvestris* and *Picea*.

The upper part of Paleolithic layer III (zone 11) is characterized by the first appearance of spruce forests in the region. The vegetation was a combination of spruce forest and various types of meadows. The beginning of the spruce phase is characterized by the almost complete absence of morphologically typical *Picea* pollen grains simultaneously at Kostenki14 (Fig. 9; Levkovskaya et al., 1983; Levkovskaya, 1999) and at Kostenki12.

3.4. Supra-regional correlations of Kostenki12 as chronological basis for the most ancient paleosols and archeological layers of Kostenki-Borschevo region

The Kostenki12 pollen diagram suggests that Paleolithic layer V, paleosol D and layer 19 below it were formed during the optimum of the interstadial correlated with the Glinde (Fig. 5: CorI, zones 3a, 3b Fig. 8), in different regions spanning from 53.9 to 47 ka BP. The chronology of the Glinde optimum in the Black Sea core M72/5-25-GC1 (DO 14) (Fig. 5: CorIII), the closest site to Kostenki, provide the date of 53.9–51 ka (Shumilovskikh et al., 2014). Kostenki IRSL/OSL dates obtained for the first half of the Glinde optimum in K-12 (for zone 3a) belong to the span 52.44–50.52 ka. However, the IRSL/OSL data of UIC-945 (45.2–44.16 ka) seems to be too young for paleosol D in layer V, formed in the Glinde interstadial optimum (zone 3b) (Tables 1 and 2). This age corresponds to the Moershoofd interstadial, although UIC-945 was associated with sediments of Paleolithic layer V of the Glinde interstadial (Anikovich et al., 2004). Moreover, UIC-947 (50.12–46.91 ka BP) was published for sediments, which were formed at Moershoofd optimum zone 6 (Anikovich et al., 2004), and appear to be too old, based on supra-regional correlations (Table 2). The supra-regional correlations suggest that the places of collection of the samples UIC-945 and UIC-947 might be unclear. We suggest that the UIC-945 date could be used for sediments under soil B, while UIC-947 relates to soil D. Both indicate an older age of paleosol D with Paleolithic layer V and sediments just under paleosol B (with Upper Paleolithic layer IV), associating them with the Glinde/Moershoofd interstadial. Uncalibrated radiocarbon dates (Table 1) are much younger and vary between 38.41 ± 0.3 and 41.3 ± 0.45 ^{14}C ka BP (Housley et al., 2006; Anikovich et al., 2008; Hoffecker et al., 2008).

Pollen diagram shows that paleosol B (with Upper Paleolithic layer IV) was formed during the second half of the optimum (zone 7) and thermohydrophilous phase (zone 8) of interstadial correlated with the Moershoofd (Fig. 6). The span of Moershoofd optimum in different regions is 46–44 ka, but its thermohydrophilous phase, best dated at Vil.9 stalagmite $^{13}C/^{14}C$ graph, is about 45–43.5 ka. According to IRSL/OSL dates, UIC-915 and UIC-946 with clear stratigraphical position, the sediments just under layer IV formed between 48.87 and 43.47 ka. The calibrated radiocarbon date of 41,240 ± 550 cal a BP is much younger than IRSL/OSL dates (Table 1).

The lower part of Paleolithic layer III of the Kostenki-Strelets culture's first phase (paleosol A) was formed during the extreme dry and cold treeless megastage C of abrupt beginning of stadial (about 42.3 ka BP). The upper part of paleosol A was formed after 42.3 ka BP (Table 2): during the beginning of coniferous megastage D, correlated to the later phase of Kostenki14 site Paleolithic layer IVb. The age of Kostenki14 layer IVb is ~42–41 ka (Velichko et al., 2009; Sedov et al., 2010; Sinitsyn, 2012, 2013; Pietsch et al., 2014). The calibrated radiocarbon dates for this period are younger, 41,732 ± 190 and 41,909 ± 218 cal BP (Table 1). There are no IRSL/OSL dates for soil A.

Analysis of radiocarbon and IRSL/OSL dates in context of supra-regional correlations shows that, in spite of their variations, most IRSL/OSL dates correlate well with the chronology of global paleoenvironmental events synchronous in Kostenki and different regions in Europe. Radiocarbon dates (calibrated and uncalibrated) are about 4–10 ky younger than the IRSL/OSL dates, which is well expected due to well-known tolerance limit of the radiocarbon dating of 40 ka.

4. Conclusions

Archaeological site Kostenki12, located on the Middle Don River, provides a key stratigraphic profile for regional paleopedological, paleoenvironmental, geological and cultural sequences, containing the oldest known cultural layers of the region (layer V – Paleolithic, layer IV – Upper Paleolithic, layer III – Kostenki-Strelets culture early phase) dating to the early part of MIS3, or, in chronometric terms, to 54–42 ka. The Kostenki12 pollen standard is correlated with $^{16}O/^{18}O$ Greenland GISP2 scale (Grootes et al., 1993; Johnsen et al., 2001), $^{13}C/^{14}C$ record from the stalagmite of Villars cave (Genty et al., 2003) and pollen records at Monticchio (Watts et al., 1996), M72/5-25-GC1 (Shumilovskikh et al., 2014) and the Glinde and Moershoofd interstadials from northern Germany (Behre and van der Plicht, 1992).

1. The general trend of Paleolithic paleoenvironment change is presented for Kostenki-Borschevo region of the Russian Plain. It is a pattern for the Late Pleistocene ravine terrace refugia from the modern forest steppe zone of the upper part of the Don River basin.
2. Five paleoenvironmental megastages are differentiated. A – bushy tundra during the time of glacial advance in Northern Europe about 50–60 ka. B – elm forests with *Carpinus* and meadows of two interstadials – Glinde and Moershoofd. Red deer dominated in the paleozoological complex of the Glinde, and mammoths in the Moershoofd optima. The Glinde interstadial corresponds to the time of formation of the lowest paleosols of Kostenki12 (D) and Borschevo5, and the most ancient Paleolithic layer of the region, Kostenki12/V (Mousterian? or Upper Paleolithic). The Moershoofd interstadial corresponds with the time of formation of paleosol B and the most ancient Upper Paleolithic layer of the region, Kostenki12/IV. C – periglacial steppes with horse dominance in the paleozoological complex. At Kostenki12, this was the time of formation of the lower part of paleosol A, and the lower part of layer III of the Kostenki-Strelets culture first phase, and at Kostenki14/IVb. D – coniferous forests and meadows with reindeer dominance. The first phase of this megastage is reconstructed at Kostenki12 for the upper part of paleosol A and the upper part of layer III of Strelets culture first phase. Several interstadials and stadials alternated within this long coniferous megastage (~42–12 ka BP), but their specific features are not clear. E – steppes of cryoxerophilous Late Glacial Maximum with the most optimal conditions for loess formation.
3. Supra-regional correlations suggest a new chronological scale for Kostenki. The most ancient Paleolithic Layer V and paleosol D, characterized by elm dominance, correlate to the second half of the optimum of the Glinde interstadial at 51–48 ka, corresponding to DO 14. The most ancient Upper Paleolithic Layer IV and paleosol B, characterized by coexistence of elm forests and wet meadows, began to form during the second part of the Moershoofd interstadial optimum at 46–44 ka, correlating with DO 12. The paleosol A and layer III of the Kostenki-Strelets culture began to form after abrupt end of the Moershoofd interstadial about 43.5 ka, and have two periods. The lower part, characterized by geobotanical stress and dominance of horse, indicates that the first phase of the Kostenki-Strelets culture was formed during an extreme cold and dry climatic phase after the Moershoofd interstadial. The upper part was formed during the phase of the first appearance of spruce forests in the Kostenki flood terrace refugium, with dominance of reindeer.
4. The upper part of Strelets culture layer III first phase (upper part of Kostenki12 paleosol A) is possibly synchronous with the lower part of Kostenki14 layer IVb: both are connected with the end of periglacial steppe and the beginning of the “coniferous” megastages. Kostenki12 may be considered a key section for regional geological and cultural sequences for the period 53–42 ka, complementing Kostenki14 (Markina Gora) site, which is a key section for the period 42–27 ka.
5. More accurate dating of the Paleolithic layers and paleosols of Kostenki-Borschevo region is one of the most important results of this study, showing the previously reported calibrated and uncalibrated radiocarbon dates on layers below the CI tephra are probably too young, but the OSL chronology appears to be generally accurate, in good agreement with the chronology of global paleoenvironmental events.
6. The new data from Kostenki12 shows that the age of the most ancient Paleolithic layer of Kostenki (Kostenki12/V) is about 50 ka and the Upper Paleolithic (Kostenki12/IV) appeared in the Kostenki-Borschevo region about 45 ka.

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