Human presence in the European Arctic nearly 40,000 years ago

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The transition from the Middle to the Upper Palaeolithic, approximately 40,000–35,000 radiocarbon years ago, marks a turning point in the history of human evolution in Europe. Many changes in the archaeological and fossil record at this time have been associated with the appearance of anatomically modern humans[1,2]. Before this transition, the Neanderthals roamed the continent, but their remains have not been found in the northernmost part of Eurasia. It is generally believed that this vast region was not colonized by humans until the final stage of the last Ice Age some 13,000–14,000 years ago[3,4]. Here we report the discovery of traces of human occupation nearly 40,000 years old at Mamontovaya Kurya, a Palaeolithic site situated in the European part of the Russian Arctic. At this site we have uncovered stone artefacts, animal bones and a mammoth tusk with human-made marks from strata covered by thick Quaternary deposits. This is the oldest documented evidence for human presence at this high latitude; it implies that either the Neanderthals expanded much further north than previously thought or that modern humans were present in the Arctic only a few thousand years after their first appearance in Europe.

The Mamontovaya Kurya site is located on the southern bank of the Usa river at the Arctic circle (66° 34′ N; 62° 25′ E), close to the polar Urals (Fig. 1). The riverbed at this site has been known as a place for finding mammoth tusks and bones since the end of the 18th century, but finds of artefacts have not been reported. In order to clarify the stratigraphic context of these bones and to find out if they could be related to early human activities, archaeological and geological field investigations were carried out during the summer seasons of 1992, 1994, 1996 and 1997.

A rich faunal assemblage and several stone artefacts were uncovered for the basal layers of a 12–13 m high river bluff which is cut into the terrace along a bend in the river (Fig. 2). The finds, which were scattered throughout the excavated area (48 m^2) without any clear concentrations, were incorporated in cross-bedded gravel and sand that accumulated on the floor of an old river channel. Many of the bones uncovered were encapsulated in silt and we also noticed frequent mud clasts within the basal part of the find-bearing channel deposit, which probably reflects slumping from an ancient river terrace covered by over-bank mud. In all, 123 mammalian bones, primarily mammoth (114), but also horse (2), reindeer (5) and wolf (2), were collected (Table 1). The most important find was a 1.3-m-long tusk from a young, 6–8-year-old female mammoth which exhibits a series of distinct grooves (Figs 3 and 4). The marks are 1–2 mm deep, 0.5–1 cm long and appear as densely spaced rows of lines lying crosswise along the tusk. Microscopic analysis reveals that the grooves were made by chopping with a sharp stone edge, unequivocally the work of humans. It is uncertain whether the marks were formed during processing while using the tusk as an anvil, or if they reflect intentional marks with artistic or symbolic meaning. The stone artefacts that were excavated from the same strata comprise five unmodified stone flakes, a straight side-scraper on a massive cortical blade and a bifacial tool (Fig. 3). The edges of the stone artefacts are sharp and the tusks and bones show minimal signs of wear, indicating a very short transportation and that the material were swiftly buried by alluvial deposits. The few artefacts are not diagnostic and resemble Middle Palaeolithic Mousterian as well as the earliest Upper Palaeolithic assemblages in eastern Europe[5], a time interval which is also in accordance with the radiocarbon dates discussed below. Similar bifaces are reported for Late Mousterian sites on Crimea, for instance Zaskalnaya V (ref. 6), but they are also known from early Upper Palaeolithic complexes in Eastern Europe, among them Kostenki XII at the Don river[7]. However, we are not able to determine the cultural affiliation on the basis of the sparse material found.

The bones and tusks were in good condition, well suited for radiocarbon dating. The tusk with incision marks was radiocarbon dated to ~36,660 ^{14}C years before present (yr BP) and three other bones from the same unit yielded similar ages in the range of 34,400–37,400 yr BP (Table 2). This time interval is close to the maximum limit for obtaining accurate radiocarbon dates and the calculated standard deviations for age determinations using conventional dating techniques are normally larger than for accelerator mass spectrometry (AMS) dates. Considering that relatively large amounts of contamination by 'old' inactive carbon is needed to significantly affect the radiocarbon dates, it seems unlikely that the animal remains are significantly younger than the obtained ages. All five radiocarbon dates of various animal remains from the same strata indicate very similar ages. We think it very likely that the artefacts from this layer are of the same age as the tusk and the bones, because the find-bearing strata were buried by several metres of sediment soon after their deposition. Terrestrial plant remains from a slumped mud clast within the find-bearing sand and gravel were dated to ~31,380 and ~30,160 yr BP by using an AMS technique, indicating that the alluvial formation is younger than the bones.

The find-bearing strata is covered by thick layers of cross-bedded sand followed by ripple- and planar-laminated mud, which together are interpreted as a point-bar sequence (arcuate ridge deposit) that accumulated along the inner bend of a meandering river by the addition of individual accretion accompanying migration of the channel. Then follows a 6–10-m-thick formation of diffusely laminated aeolian (wind-driven) silt and sand, in contrast to the pronounced stratified strata below. A series of eight AMS dates of terrestrial plant remains from the alluvial sediments covering the

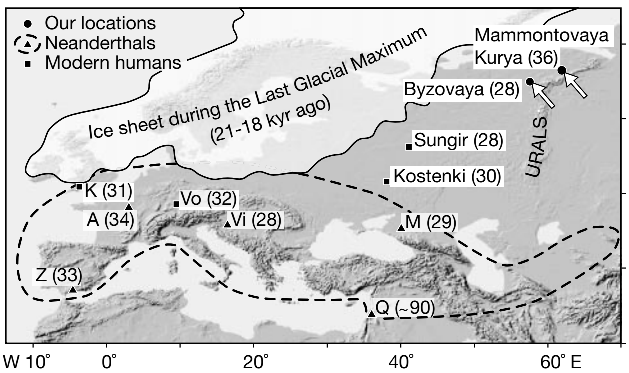

Figure 1 Map showing the location of the Palaeolithic sites Mamontovaya Kurya and Byzovaya discussed in the text and the maximum extent of the Eurasian ice sheets during the Last Glacial Maximum (21,000–18,000 yr BP)[10]. The area within which Neanderthal remains have been found is indicated with a dotted line[25]. The location of radiocarbon-dated European sites with skeletal remains of late Neanderthals and early modern humans are also shown[20]: A, Arcy-sur-Cure; K, Kent's Cavern; M, Mazmaiskaya; Vi, Vindija; Vo, Vogelherd; Z, Zafarraya; and Q, Qufzeh[27]. Numbers in parentheses indicate radiocarbon ages ($\times 10^3$ yr BP).

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find-bearing strata yielded ages ranging between ~31,420 and ~23,860 yr BP whereas optical stimulated luminescence (OSL) dates from the aeolian sediments above give consistently younger ages ranging from ~19,900 to ~13,800 calendar years BP.

The sedimentological and stratigraphic evidence suggests the following geological history for Mamontovaya Kurya: (1) The refuse of the human occupation was left on the flood plain at around 36,000 yr BP and was shortly thereafter covered by sediments. (2) Slightly before 27,000 yr BP the meandering river undercut these strata and bones and artefacts slumped into the river where they were concentrated in the channel gravel. (3) The bone-bearing gravel was quickly buried by alluvial point-bar deposits as the meander-loop migrated across the site. (4) Aeolian loess-like sediments accumulated on top of the alluvial deposits during the final stage of the Ice Age from ~20,000 to ~13,000 calendar years ago. (5) Finally the Usa river incised into the terrace during the Holocene and exposed the bones and artefact-bearing layer.

The bone material from Mamontovaya Kurya indicates that humans preyed on, or at least utilized, large herbivorous animals, mostly mammoths. Pollen analysis of the alluvial silt clasts that were found in association with the bones reflects a treeless steppe environment dominated by herbs and grasses, presumably with local stands of willow scrubs (*Salix* spp) along the river banks[8]. Human occupation probably occurred during a relatively mild interlude of the last Ice Age, although the climate at this time was probably considerably colder and more continental than today. This mild interlude may correspond with the Hengelo interstadial (39,000–36,000 yr BP) in western Europe[9]. A palaeo-environmental reconstruction[9] suggests that the landscapes in The Netherlands and northern Germany and eastwards were then covered by a shrub tundra. The northern rim of the Eurasian continent was evidently not glaciated[10] and probably only small mountain glaciers existed in the Ural Mountains[11,12]. The Scandinavian ice sheet was probably much smaller than during the Last Glacial Maximum some 20,000 yr BP (Fig. 1).

The fact that humans were present in this area as early as around 36,000 yr BP leads us to reassess the history of the earliest human occupation in the Arctic. Until now, the oldest known Palaeolithic sites in the Eurasian Arctic are dated to 13,000–14,000 yr BP[3,4,13]. However, there is an early Upper Palaeolithic site close to the Byzovaya village along the Pechora river, approximately 300 km to the southwest of Mamontovaya Kurya (Fig. 1). At this site nearly 300 artefacts and more than 4,000 animal bones (mainly of mammoth) have been unearthed during several excavations[12,14–17]. The lithic industry of Byzovaya is classified as eastern Szeletien with Aurignacian traits[15,17], which is typical for many sites of the early Upper Palaeolithic in Eastern Europe[5,18]. An early Upper Palaeolithic age has recently been supported by 13 radiocarbon dates on bones from the find-bearing layer which have yielded ages in the range of 26,000–29,000 yr BP with a mean of ~28,000 yr BP[12].

Table 1 List of bones from Mamontovaya Kurya

Mammuthus primigenius Blum (woolly mammoth)	*Rangifer tarandus* L. (reindeer)	*Canis lupus* L. (wolf)	*Equus caballus* (horse)
7 ribs	1 antler	1 metacarpal	2 teeth
1 pelvis	1 pelvis	1 unspecified	
2 tusks	1 shoulder		
1 lower jaw	2 unspecified		
1 skull fragment			
3 teeth, upper jaw			
2 vertebrae			
70 unspecified mammoth			

The table shows animal remains collected from the excavated site that could be identified to species. An additional 27 bond fragments could not be identified, but most of them are probably of mammoth.

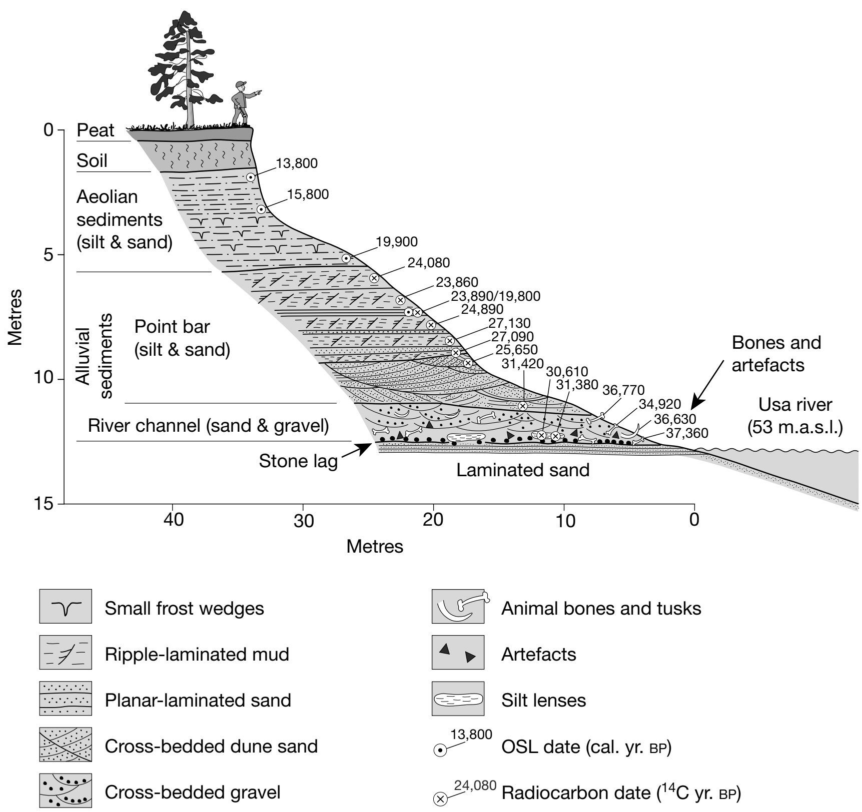

Figure 2 The excavated sediment section at Mamontovaya Kurya on the southern bank of the Usa river. The artefacts and bones were uncovered from the river channel deposits near the base of the exposure. Radiocarbon and optically stimulated luminescence (OSL) dates from the various layers are indicated (Table 2). We note that the radiocarbon dates are given in ^{14}C years BP, whereas the OSL dates are in principal calendar years before the present. m.a.s.l., metres above sea level.

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We believe that survival of humans in this arctic environment on a year-round basis would have required long-term planning and an extended social network, qualities that are generally associated with modern human behaviour[1]. A pressing question is whether the pioneers who lived in these northern landscapes were members of the ancient Neanderthal population (*Homo sapiens neanderthalensis*) or newcomers from the south. Most scholars associate the Aurignacian industry—the more advanced stone-tool technology that appeared in Europe at around 40,000 yr BP—with the emergence of modern humans[19]. However, the earliest indisputable remains of humans with a fully modern morphology (*Homo sapiens sapiens*) date to 30,000–35,000 yr BP[20]; that is, well after the archaeologically defined transition from the Middle to the Upper Palaeolithic. In European Russia, well preserved skeletons from the famous Palaeolithic site of Sungir, northeast of Moscow (Fig. 1), show that anatomically modern humans were present there not later than ~28,000 yr BP[21,22]. At the Kostenki IV site on the west bank of the Don river, bones of modern humans have been uncovered from strata dated to ~30,000 yr BP[22]. The stone-working technology reflected in the Byzovaya material is similar to that of Sungir and other early Upper Palaeolithic sites of the eastern Szeletien tradition, indicating that these artefacts were manufactured by modern humans. However, whether the person who inflicted the marks on the tusk from Mamontovaya Kurya, as much as 8,000-9,000 years earlier, belonged to the same human lineage as the residents at Byzovaya and other Palaeolithic sites further to the south is more

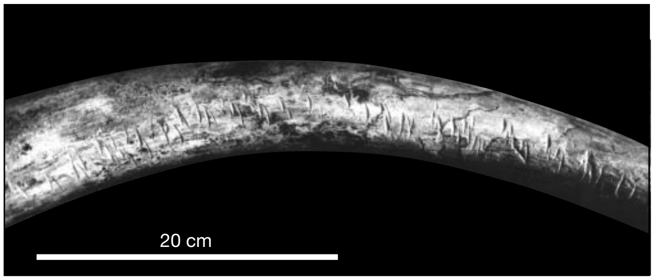

Figure 4 Photograph of the mammoth tusk from Mamontovaya Kurya. The marks appear to have been inflicted by a sharp stone tool.

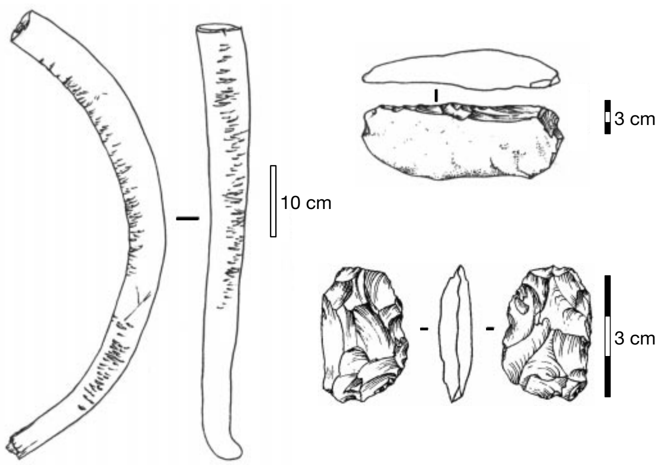

Figure 3 Drawings of the mammoth tusk with human-made marks, a side-scraper and a bifacial stone tool (knife?) that were uncovered from the excavated river channel deposits at the Mamontovaya Kurya section.

Table 2 Optically stimulated luminescence and radiocarbon dates

Depth below terrace (m)	Laboratory number	Age	Dating method	$\delta^{13}C$ (‰)	Material dated
2.0	99253-1	13,800 ± 1,100†	OSL	–	Aeolian sand
–	99253-2	14,400 ± 900†	OSL	–	Aeolian sand (adjacent section)
3.3	99253-3	15,800 ± 1,000†	OSL	–	Aeolian silt
4.6	99253-4	19,900 ± 1,300†	OSL	–	Aeolian silt
7.4	99253-0	19,800 ± 2,100†	OSL	–	Alluvial silt
6.0	ETH-20830*	24,080 ± 220‡	^{14}C	–25.9	Terrestrial moss
6.9	Beta-11950*	23,860 ± 120‡	^{14}C	–25.8	Terrestrial moss
7.4	Beta-119502*	23,890 ± 140‡	^{14}C	–26.0	Terrestrial moss
7.9	ETH-20831*	24,890 ± 210‡	^{14}C	–25.1	Terrestrial moss
8.5	Beta-4072*	27,130 ± 180‡	^{14}C	–26.4	Terrestrial moss
8.9	ETH-20832*	27,090 ± 240‡	^{14}C	–24.4	Terrestrial moss
9.4	TUa-1514*	25,650 ± 535‡	^{14}C	–28.2	Terrestrial plants
10.9	ETH-21437*	31,420 ± 370‡	^{14}C	–21.0	Terrestrial moss
11.7	T-11503	36,770 + 2,620/–1,980‡	^{14}C	–	Horse tooth
12.0	ETH-21439*	30,610 ± 350‡	^{14}C	–18.9	Terrestrial moss
12.1	ETH-21438*	31,380 ± 380‡	^{14}C	–22.2	Terrestrial moss
12.1	T-11403	36,630 +1,310/–1,130‡	^{14}C	–	Mammoth tusk with marks
12.1	T-11504	34,360 ± 630‡	^{14}C	–	Mammoth bone
12.1	LU-4001	37,360 ± 970‡	^{14}C	–	Mammoth bone
–	LU-3994	34,920 ± 1,040‡	^{14}C	–	Mammoth tusk (uncertain context)

* AMS date.
† Calendar yr BP.
‡ ^{14}C yr BP.
The OSL dates (calendar years), measured on quartz grains in the sand grain fraction, were produced at the Nordic Laboratory for Luminescence Dating, Risø National Laboratory, Denmark. The radiocarbon dates (^{14}C yr BP) were carried out at various laboratories. Beta, Beta analytic; ETH, the Swiss Federal Institute of Technology AMS Facility; T, Trondheim Radiocarbon Laboratory; TUa, prepared at the Trondheim and measured at the accelerator at the Svedberg Laboratory, Uppsala; LU, St Petersburg University.

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uncertain. If this person was a modern human who descended from temperate areas, as predicted by the 'Out of Africa' hypothesis[2], then the Russian Arctic was occupied by *Homo sapiens sapiens* shortly after the first newcomers entered Europe[23,24]. On the other hand, if the person was a Neanderthal, then these humans expanded much further north than hitherto assumed, implying that their stage of cultural development was not a barrier to colonization of this Arctic habitat. Whoever she or he was, the findings from Mamontovaya Kurya provide evidence that the European part of the Arctic was inhabited by humans long before the Neanderthals vanished from the continent soon after 28,000 yr BP[20,25,26]. □

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A cellular mechanism of reward-related learning

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Positive reinforcement helps to control the acquisition of learned behaviours. Here we report a cellular mechanism in the brain that may underlie the behavioural effects of positive reinforcement. We used intracranial self-stimulation (ICSS) as a model of reinforcement learning[1], in which each rat learns to press a lever that applies reinforcing electrical stimulation to its own substantia nigra[2,3]. The outputs from neurons of the substantia nigra terminate on neurons in the striatum in close proximity to inputs from the cerebral cortex on the same striatal neurons[4]. We measured the effect of substantia nigra stimulation on these inputs from the cortex to striatal neurons and also on how quickly the rats learned to press the lever. We found that stimulation of the substantia nigra (with the optimal parameters for lever-pressing behaviour) induced potentiation of synapses between the cortex and the striatum, which required activation of dopamine receptors. The degree of potentiation within ten minutes of the ICSS trains was correlated with the time taken by the rats to learn ICSS behaviour.

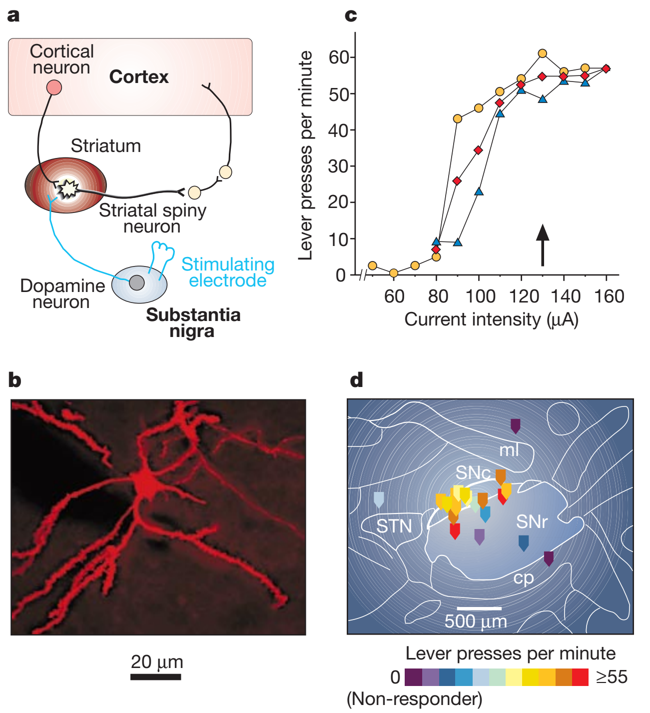

Figure 1 Intracranial self-stimulation of the nigrostriatal system. **a**, Overview of the circuit studied. **b**, Confocal micrograph of a striatal spiny neuron injected with biocytin during intracellular recording (streptavidin-Texas Red label). **c**, Lever-pressing rate for one rat in response to increments (yellow circles) and decrements (blue triangles) in substantia nigra stimulus intensity. Arrow indicates the optimal current that just maximized the average rate (red diamonds). **d**, Approximate midpoint of the final stimulating electrode positions (sagittal section at mediolateral +1.9 mm; ref. 30). Arrowheads coded by maximum lever-pressing rate. SNr, substantia nigra pars reticulata; STN, subthalamic nucleus; cp, cerebral peduncle; ml, medial lemniscus.

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