that the RFZ3 mass was largely in the atmosphere when the insolation at the south pole at summer solstice was at a maximum, which for the past one million years occurred about 600,000 years ago (obliquity = 34.76°, eccentricity = 0.085, longitude of perihelion = 259.4° (21)).

To assess the impact on some first-order climate parameters, we ran a fast version of the NASA/Ames Mars GCM (version 1.7.3) for these orbital conditions with a total exchangeable CO2 inventory (atmosphere plus caps) equal to the present inventory (7.1 mbar) plus 5 mbar. We found that most of the additional 5 mbar of CO2 ended up in the atmosphere. Surface pressures rose uniformly around the planet, with global-mean annually averaged pressures equaling 10.5 mbar. Annual mean cap masses in agreement with global-mean annually averaged pressures rose uniformly around the planet, with global-mean annually averaged pressures equaling 10.5 mbar. Annual mean cap masses increased by about 0.8 mbar, not accounting for the previously equaling 10.5 mbar. Annual mean cap masses increased by about 0.8 mbar, not accounting for the unlikely assumption that RFZ3 does not extend beyond SHARAD’s data gathering locales, which are limited by MRO’s orbital inclination. See (20).

There are two implications of these changes in the climate system. First, the increased CO2 pressure expands the geographic locations where these pressures exceed the triple-point pressure of water, thereby permitting liquid water to persist without boiling (although it may still evaporate, as on Earth) (22). Second, higher surface pressures will lead to higher surface wind stresses, which will loft more dust in the atmosphere, leading to an increase in dust storm frequency and intensity. Given the complex interplay between the dust, water, and CO2 cycles, additional changes in the climate system are very likely.

References and Notes
10. Materials and methods are available as supporting material on Science Online.
16. RFZ3 is seen discontinuously in radargrams here, but key reflectors could not be mapped with high confidence likely because of surface scattering interference, resolution limitations, and lack of coverage.
17. A lower value of 4000 to 4500 km is obtained with the unlikely assumption that RFZ3 does not extend beyond SHARAD’s data gathering locales, which are limited by MRO’s orbital inclination. See (20).

Acknowledgments: Various researchers have provided useful comments on an earlier version of the paper. Remarks by two anonymous referees were exceedingly helpful. Funding for this work was provided by the NASA MRO project. The radar and imaging data are available through NASA’s Planetary Data System.

Supporting Online Material
www.sciencemag.org/cgi/content/full/science.1203091/DC1 Materials and Methods SOM Text Figs. S1 to S5 Tables S1 to S4 References
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Late Mousterian Persistence near the Arctic Circle

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Palaeolithic sites in Russian high latitudes have been considered as Upper Palaeolithic and thus representing an Arctic expansion of modern humans. Here we show that at Byzovaya, in the western foothills of the Polar Urals, the technological structure of the lithic assemblage makes it directly comparable with Mousterian Middle Palaeolithic industries that so far have been exclusively attributed to the Neandertal populations in Europe. Radiocarbon and optical-stimulated luminescence dates on bones and sand grains indicate that the site was occupied during a short period around 28,500 carbon-14 years before the present (about 31,000 to 34,000 calendar years ago), at the time when only Upper Palaeolithic cultures occupied lower latitudes of Eurasia. Byzovaya may thus represent a late northern refuge for Neandertals, about 1000 km north of earlier known Mousterian sites.

Most of the Russian Arctic was free of glacier ice throughout the past 50,000 years, including during the Last Glacial Maximum (LGM) (1). A varied herbivorous fauna existed in high Arctic areas that are presently wet tundra or almost barren Arctic deserts (2). Recent archaeological evidence demonstrates that Ice Age humans also at least temporarily lived and hunted in these northern landscapes beginning around 35,000 to 36,000 14C years before the present (yr B.P.) (3) to 40,000 yr B.P. in calibrated/ calendar (cal) years (3–7) (fig. S1). It has not been clear whether the early visitors were members of a fossil population [such as Homo sapiens neanderthalensis and affiliated groups (8, 9)] or whether modern humans (H. sapiens sapiens) expanded northward into a previously uninhabited area.

This question is related to the Middle Palaeolithic (MP) to Upper Palaeolithic (UP) cultural transition in Eurasia. This transition, which has been considered to have taken place around 40,000 to 37,000 yr B.P. in most of Eurasia, saw the global extinction of the Neandertals and thus the end of their specific MP (Mousterian) culture. The Neandertals were replaced by modern humans, who were the bearers of all known UP cultures.

Here we describe lithic technology and age constraints from the Byzovaya site near the Polar Urals and show that humans bearing MP stone technology persisted to 32,000 to 34,000 cal yr B.P. in the Eurasian Arctic (Fig. 1). Byzovaya, which is among the northernmost known Palaeolithic sites, was previously considered to be an Early Upper Palaeolithic (EUP) site mainly on the basis of a few radiocarbon dates that suggested an age of about 27,000 14C years or younger.

The Byzovaya site (65°01′26″N, 57°25′12″E) is located on the right bank of the Pechora River, which flows northward across the lowland areas west of the Ural Mountains (Fig. 1). First described in 1965 by Guslitser et al (10), the locality was investigated several times by Russian archaeologists (11); later by a Norwegian-Russian team, since 1996 (6, 12); and by a French-Russian team since 2007. More than 300 stone artefacts and 4000 animal remains have been recovered during the various excavations, which together cover an area of approximately 550 m².

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The site is located in a paleo-gully that is incised into Triassic sandstone. The gully, which is about 250 m long and 300 m wide, starts from a shoulder in the river valley at an altitude of about 100 m above sea level (a.s.l.) and ends near the shore of the Pechora River about 44 m a.s.l. Artefacts are encased in a layer of sandy gravel up to 2.5 m thick that rests directly on the bedrock at the bottom of the paleo-gully. This layer crops out along the river cliff (Fig. 2 and fig. S7). The sediments that contain the archaeological finds accumulated during a series of successive debris flows. We were not able to determine whether there were breaks between each flow or if they all happened during one single event, although some individual flows are separated by thin layers of silt. Several meters of well-sorted windblown (aeolian) sand overlay and interfinger with the debris flow deposits (Fig. 2). Most of the bones and artefacts are well preserved. Both the excellent preservation of the bones and the inferred paleotopography indicate that the debris flows moved only a short distance, most likely less than a few tens of meters or so. The bones and artefacts occur throughout the gravelly layers. Several well-preserved mammoth bones and tusks were found on the surface of this formation, draped by the overlying windblown sand (fig. S8). Some bones and artefacts are concentrated within one of the mentioned silt horizons in the middle of the layer and may represent in situ deposits.

More than 97% of the identified faunal remains are from mammoth (Mammutthus primigenius) and represent at least 21 individuals. In addition, several other animals have been identified (supporting online material (SOM)): woolly rhinoceros (Coelodonta antiquitatis), reindeer (Rangifer tarandus), musk ox (Ovibos moschatus), horse (Equus callabus sp.), brown bear (Ursus arctos), wolf (Canis lupus), and polar fox (Alopex lagopus). Many of the animal remains from the top deposit have cut marks that indicate processing by humans (figs. S10 and S11).

We obtained 33 $^{14}$C dates from the bones (table S1). The mean age for all samples is $28,570 \pm 1370$ 14C yr B.P., but $28,450 \pm 820$ when 12 dates with large uncertainties are omitted (SOM text). The distribution of the $^{14}$C ages is almost Gaussian (fig. S2), and the simplest interpretation is that the spread of ages is mainly an artefact of random counting uncertainties and that all samples should therefore have a similar age. We conclude that the age of $28,450 \pm 820$ 14C yr B.P. is the best age of the human occupation (fig. S2). Conversion of 14C ages to sidereal (cal) years is problematic for such old samples, but this age corresponds to the calibrated age intervals of 33,650 to 31,670 and 34,580 to 31,370 cal yr B.P. for the 68 and 95% confidence intervals, respectively, when using the IntCal09 (13) data set. As a further test, we obtained four optically stimulated luminescence (OSL) dates from the windblown sand draping the find-bearing strata. The ages were all between 30,000 and 33,300 yr B.P., with an uncertainty (1σ) of 2000 to 3000 years (Fig. 2 and table S2) and a mean of 32,000 ± 2000 yr B.P. The interfinger contact between the debris flow layer and the sand suggests that the ages of the layers are overlapping in time. Indeed, the OSL ages overlap with the calibrated 14C ages of the bones.

These ages demonstrate that the human occupation of Byzovaya happened during the latter part of marine isotope stage (MIS) 3, well before the buildup of the Barents-Kara Ice Sheet during MIS 2. The age fits roughly into the period when the Bryansk soil developed on the Russian Plain farther to the south (14). This interstadial (31,000 to 24,000 14C yr B.P.) was slightly warmer than the preceding and following periods, but the climate was still much colder than at present. The radiocarbon chronology indicates that the human visits at Byzovaya took place a few hundred years after the mild Alesund interstadial in Scandinavia, an interval that has been correlated with Greenland interstadial (GI) 8 to 7 (15). Taken at face value, the calibrated age of Byzovaya corresponds to the ice core interval GI 6 to 5.

A total of 313 lithic artefacts have been collected during the various excavations. The artefacts are mainly composed of local raw materials coming from the gravels of the Pechora River (table S3). These rocks are abundant on the river shore and also in thick glacial and glaci-lacustrine sediments in the river bank (12). Our experimental in situ knapping shows that the local raw materials are applicable for any kind of flaking technology.

This industry consists of flakes, 11 cores, and as many as 80 defined typological tools. End products are well represented for a collection of this size (80 out of 313). The cores were used exclusively for flake production. Four pieces are typical Levallois cores, a flaking method that is considered to be a distinctive feature in MP assemblages (Fig. 3, no. 2). This technology is also
represented by some well-defined Levallois flakes. The remaining seven cores are based on disoid (fig. S5, no. 3) and polyhedral flaking, which are a common combination in MP contexts. The applied stone technology is based on Levallois and discoid flake production. There are neither technological blades nor bladelets nor other elements that could be ascribed to the technical representation of UP technologies. We conducted experiments on the same raw materials and were able to make similar flakes only by direct hard hammer percussion. The preserved flakes could have been used to make side-scrapers of various types and sizes. Some flakes were directly used without any retouching, because some of their edges are worn (fig. S12).

None of the 313 artefacts reflects a tool production technology typical of UP cultures. Furthermore, diagnostic tools that are common in any UP industry of Eurasia such as burins, backed tools, pointed blades, or bladelets are not represented. There are 11 end-scrapers, but none of these were prepared from UP blades. Varieties of end-scrapers, prepared from flakes, are common elements in any European MP industry, known since the first Mousterian typological analysis (16). Typological tools are mainly members of the Mousterian group (16), dominated by distinctive side-scrapers made out of flakes (fig. S5, nos. 1 and 2) that are typical for MP industries (17) (fig. S6 and table S4). Six of these tools have been retouched to form a bifacial tool. Most of the bifacial tools are thick, with a plano-convex section: one face shaped by large flakes and the opposite face formed by a semi-abrupt retouch. This way of shaping has been used for producing so-called Keilmesser tools (plano-convex and backed bifacial tools, Fig. 3, no. 1), which are considered to be specific artefacts of some archetypal MP industries of Central and Eastern Europe (18–20). Two of the bifacial tools from Byzovaya present a thin regular transformation of their faces that illustrates the technological similarities between this industry and the Eastern European MP (18, 19), where the so-called Blattspitzen (short foliate) tools occur frequently.

The lithic industry of Byzovaya is technically and typologically homogeneous and shows a combination of diagnostic features that belong exclusively to MP traditions from Central and Eastern Europe, previously known from sites dating from MIS 3 to 4 (19). All lithic tools and bones are stratigraphically associated, and 22 faunal remains show anthropogenic modifications. This is in accordance with the use wear of lithic tools related to butchering activities. Two of our dates are on a cut marked mammoth bone and a modified reindeer antler (table S1).

The EUP complexes that succeeded the MP complexes present specific archaeological features that distinguish them from the MP industries. Blades, bladelets, and projectile points constitute the lithic background for EUP assemblages in Eurasia. For example, at Kostenki 14, along the Don River in southern Russia (Fig. 1), these EUP elements appear in layer IV, dated to 45,000 to 41,000 cal yr B.P., which is about 10,000 years earlier than the human occupation at Byzovaya (21–23). At Zaozor’e, farther to the north and closer to Byzovaya, blades and bladelets were produced by humans sometime between 39,000 and 37,000 yr B.P. (Fig. 1) (4, 6). Russian EUP sites that are more or less contemporary with Byzovaya, such as Sungir (24) and Garchi (6), are characterized by lithic triangular projectile points. A rich bone and ivory technology with spear points, figurines, ornaments, and beads is common in most EUP Eurasian sites where organic materials are well preserved (as at Byzovaya). It has been recently proposed that some of the Kostenki sites show some archaic traits resulting from a specialized tool kit made by UP hunters at a kill-butchery site (25). However, tools from the Gorotsovian and Streletskian layers at Kostenki do not resemble the Byzovaya assemblage but are dominated by typical UP traits reflecting their specific cultural associations (standardized triangular foliated spear points, in the Streletskian layers, and rich bone and ivory technologies in the Gorotsovian).

There is no evidence that the assemblage at Byzovaya can be explained by site-specific activities such as mammoth exploitation and butchering. At all well-dated sites with abundant mammoth remains, the artefacts that are found with the animal remains also reveal the cultural affiliation of the humans who made them. This is true for MP sites such as Mont-Dol (26) or Salzgitter-Lebenstedt (27) and for EUP Gravettian sites of Central Europe, such as Milovice in Moravia and Krakow-Spadzista in Poland (28, 29). Theoretically, one may also wonder if the lack of some UP elements,
such as blades and bladelets, can be explained by the quality of the raw material at hand. However, various siliceous rocks of good quality were easily available and were also used for tool production at an adjacent Mesolithic site containing almost exclusively well-prepared and regular blades and bladelets.

Most researchers agree that classical Mousterian industries in Europe were exclusively produced by Neandertals (30, 31). However, whether Byzovaya represents a Neandertal site or not cannot be demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts represent a Neandertal site or not cannot be demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found. If the Byzovaya artefacts were struck by modern humans, this would have demonstrated beyond doubt until human bones or DNA are found.

References and Notes
5. V. V. Pitulko et al., Science 303, 52 (2004).
24. O. Bader, Sungir Upper Palaeolithic Site (Nauka, Moscow, 1978) [in Russian].
Acknowledgments: L.S., H.P., and A.B. analyzed the archaeological material; J.I.S., J.M., and H.P.H. performed the stratigraphic, palaeoenvironmental, and chronological descriptions and interpretations; and P.Y.P. organized the archaeological field missions. All contributed to the writing of the paper. Supported by the Fondation des Maisons des Sciences de l’Homme, the French-Russian Center for Social and Human Sciences in Moscow, the French Ministry of Foreign and European Affairs, the Research Council of Norway, and Russian Foundation for
Experimental Evidence Supports a Sex-Specific Selective Sieve in Mitochondrial Genome Evolution

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Mitochondria are maternally transmitted; hence, their genome can only make a direct and adaptive response to selection through females, whereas males represent an evolutionary dead end. In theory, this creates a sex-specific selective sieve, enabling deleterious mutations to accumulate in mitochondrial genomes if they exert male-specific effects. We tested this hypothesis, expressing five mitochondrial variants alongside a standard nuclear genome in Drosophila melanogaster, and found striking sexual asymmetry in patterns of nuclear gene expression. Mitochondrial polymorphism had few effects on nuclear gene expression in females but major effects in males, modifying nearly 10% of transcripts. These were mostly male-biased in expression, with enrichment hotspots in the testes and accessory glands. Our results suggest an evolutionary mechanism that results in mitochondrial genomes harboring male-specific mutation loads.

The mitochondrial-eukaryote union represents one of life’s most important symbioses, equipping the eukaryotic cell with a highly efficient means of energy conversion. The upshot of this union is that contemporary metazoan harbor two obligate genomes. The genome located within the cell nuclei (nuclear genome) contains the vast majority of function-encoding genetic material (about 14,000 genes in Drosophila melanogaster) (1), whereas the mitochondrial genome (mtDNA) is diminutive in size, consisting of just 37 genes (13 protein-coding, 22 tRNA, and 2 ribosomal RNA) (2). Although few in number, mitochondrial genes serve an essential function, with both nuclear- and mtDNA-encoded proteins interacting within the mitochondria to perform cellular respiration. The tight coordination in gene expression necessary for organelle function is achieved by extensive signaling between mitochondrial and nuclear genomes, via anterograde and retrograde regulation (3).

Unlike their nuclear counterparts, mitochondrial genomes generally have solely maternal transmission, resulting in evolutionary dead ends for the mtDNA of males (4). As such, mtDNA should only be able to make a direct evolutionary response to selection through females [but see (5, 6)]. This should pose no problem for traits with iden-

tical function across males and females. However, mutations in mtDNA that contribute to the expression of traits exhibiting different sex-specific optima (i.e., sexually dimorphic or sexually antagonistic traits) will be subject to a sex-specific selective sieve. This means that selection will fail to prevent the accumulation of mtDNA mutations that are deleterious when expressed in males, if the same mutations are only slightly deleterious (4), neutral (7), or beneficial (8, 9) when expressed in females.

If a sex-specific selective sieve is important in mitochondrial genome evolution, then we predict that mitochondrial genomes should generally harbor a mutation load that is more pronounced in males. Also, the effect of the mutation load should increase with the degree of male-biased sexual dimorphism of the trait or tissue in question, because the benefits that males can salvage from relying on female-specific adaptation of mtDNA will diminish as the level of sex-biased expression increases and the intersexual genetic correlation erodes.

We tested these predictions on the basis of the facts that extensive signaling takes place between mitochondrial and nuclear genomes (3) and that polymorphisms in mtDNA typically exert their phenotypic effects through interactions with the nuclear genome (10). We explored genome-wide variation in nuclear gene expression across strains of D. melanogaster that differ only in the origin of their mitochondrial genomes by using GeneChip Drosophila Genome 2.0 microarrays (Affymetrix, Incorporated, Santa Clara, CA). We examined five distinct, naturally occurring mitochondrial genomes from around the globe [Alstonville (New South Wales, Australia), Brownsville (Texas, USA), Dhahomy (Benin), Japan, and Mysore (India)]. An abundance of nonsynonymous and synonymous polymorphisms exists across the protein-coding sequences of these five genomes [supporting online material (SOM) text]. Each mitochondrial genome was coexpressed with the isogenic nuclear background, w118, in two replicates per strain. Replicates for each mtDNA strain were created as a safeguard to ensure that inferences regarding effects of mtDNA polymorphism were not confounded by cryptic genetic variation that might have accumulated in the nuclear background during the period in which the strains were created and assayed. No differential expression between replicates of any mtDNA strain was found (P > 0.05 after multiple testing corrections in two-tailed t tests for all the transcripts, for each pair of replicate introgressions). Other environmental variables (e.g., food source, temperature, light, age, and mating status) were carefully controlled to minimize sources of variation.

Fig. 1. Differentially expressed genes. (A) Venn diagram representing the intersections between the sets of nuclear genes showing a significant effect of mitochondrial strain in males (blue, top left), in females (red, top right), and in the full data set (black, bottom). (B) Expression levels (in log2, scale) of the same sets of genes (blue triangles and dark blue and black dots), in male and female adults of D. melanogaster. Gray dots in the background represent the expression level of non–differentially expressed genes.
Supporting Online Material for

Late Mousterian Persistence near the Arctic Circle

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Supporting Online Material for
Late Mousterian Persistence near the Arctic Circle

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Fig. S7. Overview of the excavation.
Fig. S8. Photo of tusk and mammoth bone draped by aeolian sand.
Fig. S9. Photo of tool and bones in the excavation (during the 2000 field excavation).
Fig. S10. Photo of the dated antler with human modification.
Fig. S11. Photo of mammoth ribs with butchery cut marks
Fig. S12. Photos showing macro- and microscopic traces of butchering on worked stone edges (lithic artifacts) and on bones.
METHODS AND DISCUSSION OF DATING RESULTS

RADIOCARBON DATES
As many as 33 radiocarbon dates have been obtained from bones, tusks, teeth and antlers that were uncovered from the find bearing strata (Table S1, Fig. S2). Thirty of the dated samples were collected during excavations organised by the Norwegian-Russian co-operative project "Paleo Environment and Climate History of the Russian Arctic" (PECHORA) in the years 1997 and 2000. Most samples were dated with conventional radiocarbon methods because sufficiently large samples were easily available, but we have also obtained 8 AMS 14C dates (Table S1). Contamination of the animal remains is a possible source of error that may have influenced the dating results. Samples that are this old are sensitive to contamination by young carbon, but much less sensitive to contamination with old carbon (13,38). We will therefore here give a description of the applied preparation methods and also comment in some detail on the dating uncertainties.

Preparation
At the Trondheim laboratory (pre-fixes T- and TUa-), led by S. Gulliksen, the bone samples were prepared according to established procedure in the laboratory (39). After initial removal of the outermost parts and subsequent washing, the bones were crushed to fragments <2 mm. This bone powder was then hydrolyzed with 25 % HCl at room temperature and under vacuum (repeated if necessary). The insoluble residue (collagen) was treated with 5 % NaOH for 5 minutes at room temperature and washed before it was dissolved in distilled water at 90 °C adjusted to pH 3.0. Insoluble remains were removed by centrifugation. The remaining solution was heated to evaporate the water content and in the end the collagen was recovered as gelatin. At the St. Petersburg laboratory (pre-fix LU-) led by Kh. Arslanov they used an almost identical preparation method described in detail by Arslanov and Svezhentsev (40).

In the Trondheim laboratory the 13C content was measured (Table S1) and used for correction of isotopic fractionation. In the St. Petersburg laboratory (LU- and probably also the LE- and the now-closed Ta-laboratories) 13C was not measured. According to Kh. Arslanov (pers. comm. 2010) they decided not to correct such old samples for fractionation because the correction would be insignificant. The mean δ13C value for a large number of bone samples that have been measured in Trondheim is -21.7 ‰. By using this value the corrected ages of the samples from the St. Petersburg laboratory (LU-) would only be about 50 years older than shown in Table S1, and we therefore preferred to use the “officially” reported ages, and have not adjusted the given LU-ages.

Preservation of the bones and reliability of the ages
There are several reasons, explained below, why we consider that that most of the dated samples from Byzovaya are not much contaminated by young carbon and that they most likely yielded trustworthy ages.

1) In our opinion the visual inspection and judgement by experienced geologists, archaeologists and palaeontologists is an important criterion for assessing the preservation and quality of the animal remains, and here we all agreed on the excellent preservation of the bones. Our judgment is supported by the high collagen yields that were measured in the dating laboratories (Table S1). The experience at the Trondheim laboratory is that these bones are better preserved than many shallow-buried bones from Norway that are only some few hundred years old (S. Gulliksen, pers. comm. 2010).

2) The good preservation and presumably low contamination is explained, and indeed argued for, by the fact that the bones have been buried in permafrost for at least 20,000 years during the Ice Age. Also during the last 10,000 years (the Holocene) the temperature in the ground has been low and thus the degradation was slow. Present day mean annual air temperature is -2.5 ºC and the temperature in the bone-bearing layer would be close to this value. Furthermore, the bones were buried underneath several meters of almost sterile sediments (sand and silt), and it seems unlikely that significant amounts organic contaminants could reach the find-bearing strata.

3) The applied preparation methods efficiently remove possible contaminants. For example, in a recent study from Norway the Trondheim laboratory analyzed a series of about 50 samples of animal bones from a cave site that yielded ages in the range 34–28 14C ka (15). These dates correlate well with the Greenland ice core chronology when using paleomagnetic and other correlation methods. In recent years it has frequently been argued that ultra-filtration more efficiently removes contamination from poorly preserved bones (38). This is probably correct in most cases, but some studies show that the methods that were used to prepare our bones yielded as good results (41,42).

4) The consistent ages that were obtained for almost all samples from Byzovaya are also an argument for minimal influence of contamination. This argument is especially relevant considering that different materials
were dated, including hard ivory, teeth, antlers and several types of bones. If contamination was a serious problem at this site we would expect that it should have affected individual samples differently, and thus caused a larger scatter of dating results than this data set.

5) Four parallel sub-samples of bones and tusks were analysed at different laboratories; AMS dating in Uppsala (TUa-), scintillation counting in St. Petersburg (LU-) and proportional CO₂ counting in Trondheim (T-). In Fig. S3 the results from the AMS method are plotted versus the results from the conventional dating method, both ages are plotted with an uncertainty of ± 1σ. One of the conventional dating results that were obtained in the Trondheim laboratory (T-13438) gave a younger age than the parallel date from St. Petersburg (LU-3992), whereas the latter sample yielded an almost identical age as was obtained by AMS dating of the same sample (TUa-7307, Table S1). Most of the remaining dates are overlapping within ± 1σ (Fig. S3) and they all overlap within ± 2σ. The small deviations in the dating results are probably mainly due to counting errors, but some additional uncertainties may have been introduced during preparation. There may also be small differences because the laboratories dated different parts of the bones, which may have been differently influenced by contamination. But the bottom line is that re-dating at different laboratories yielded almost identical results.

6) Field observations show that the overlying aeolian sand fingers into the find bearing strata implying that these two units must overlap in time. The mean age of the four OSL samples in the sand is 32 ± 2 (± 1σ) ka, which is indeed overlapping with the calibrated ¹⁴C ages of 33.7 – 31.7 (68 % confidence interval) and 34.6 – 31.0 cal ka BP (95 %). The OSL results therefore support our assumption that at least the older ¹⁴C ages are not contaminated by younger carbon.

**Averaging and calibrating**

In Figure S2 we have plotted all available radiocarbon ages that were obtained from the find bearing strata. We did not find any age differences related to stratigraphic position and therefore the samples are simply plotted with increasing ages. The (non-weighted) pool mean for all samples is 28,570 ± 1370 ¹⁴C years BP. Aiming at a better precision we omitted the 12 samples with 1σ > 1.5 % of the respective age (marked with black crosses and error lines in Fig. S2). This calculation gave a nearly identical mean value 28,450 ± 820 (± 1σ) but with a smaller uncertainty. Almost all samples, including those 12 that were left out from the calculation, fall within the age range of ± 2σ from this mean value (Fig. S2). We mention that the weighted mean age is 28,320 ± 70 ¹⁴C years BP. However, the samples do not fill the criteria for calculation of a weighted mean. This mainly because there may be (small) real age differences between the samples, including differences due to contamination, but also because different measurement methods were used. We therefore conservatively consider the calculated mean value of 28,450 ± 820 ¹⁴C years BP to be a representative and trustworthy age of the animals remains, and thus also for the presence of humans at the site.

Calibration of ¹⁴C ages to sidereal (calendar) years is still problematic and in fact controversial for the time interval of our samples. However, a calibration is necessary in order to make a direct comparison with the optically stimulated luminescence (OSL) ages that were obtained from the overlying beds. It is also a general goal to express ages on a calendar year timescale. A new version of the community calibration scale (IntCal09) has recently been published (13). The new version is extended back to 49 ¹⁴C ka BP and we have therefore used the corresponding internet calibration program Calib6.0 (http://intcal.qub.ac.uk/calib/) for calibration (Table S1). When calibrating our concluded mean age of 28,450 ± 820 ¹⁴C years BP we obtained the ages 33,650 - 31,670 and 34,580 – 31,370 cal years BP for the 68 % and 95 % confidence intervals respectively. In order to facilitate comparison with results from earlier studies we have also applied the older calibration programs of Weninger and Jöris (43) and Fairbanks et al. (44) and obtained ages of 32,990 ± 705 and 33,830 ± 870 cal years BP respectively.

**Discussion and conclusion**

The distribution of ¹⁴C ages (Fig. S2) can be interpreted in different ways. The distribution is close to what would be expected by a random (Gaussian) distribution due to counting errors, and the simplest interpretation would therefore be that all bones have a similar age. An alternative interpretation would be that the humans visited the site repeatedly during an extended period that may have lasted several hundred years or even longer, and that some of the age differences between individual samples might be real. We can not rule out the possibility that some of the samples were slightly contaminated and that the tail of younger ages partly is due to contamination. If this latter explanation is valid, and if the period of human occupation was short, then the correct age should be closer to the older end of the age distribution (Fig. S2), i.e. at around 29 ka ¹⁴C BP, or 33 - 32 ka cal BP. It should also be noted that the sample that yielded the youngest age (Ta-121) probably was prepared by a simpler method in a laboratory that is now closed. To some degree the bones must have been mixed when moved by the debris flows. Therefore, the limited scatter of ages is in itself an argument that most, if not all, the animal remains have nearly the same age.

Our main conclusion is that the dates are trustworthy. We therefore consider the calculated mean value of individual ages with 1σ < 1.5 % as a reliable age of the human occupation at Byzovaya, i.e. 28,450 ± 820 ¹⁴C
years BP. The corresponding calibrated age intervals are 33.7-31.7 and 34.6-31.4 cal ka BP for the 68 % and 95 % confidence intervals respectively.

OPTICALLY STIMULATED LUMINESCENCE (OSL) DATES
We obtained a series of OSL dates from the sediment sequence above the strata with artefacts and bones. In this paper we only discuss the four dates that were obtained from the lowermost wind-blown sand (Fig. 2, Table S2). All dates were performed with the standard methods at the Nordic Laboratory for Luminescence Dating under leadership of Andrew Murray, who also provided the description of the method below.

Sample preparation and analytical facilities
Quartz-rich extracts (90-150 μm) were separated by sieving and chemical treatment (HCl, H₂O₂, HF, but without the use of heavy liquids) and tested for the absence of feldspar contamination using infrared stimulation; no sample showed a significant IR signal compared to that from blue stimulation. Routine measurements used an 8 mm diameter monolayer of grains mounted on stainless steel discs, and a standard Risø TL/OSL reader with blue light (470 nm; ~40 mW.cm⁻²) stimulation (the growth curve in Figure S4 used ~80 mW.cm⁻²); OSL detection was through 7 mm of U-340 filter, and irradiations employed calibrated beta source delivering ~0.1 Gy.s⁻¹. A SAR protocol (45) employing a 260 °C preheat for 10 s and 160 °C cut-heat was used for all dose measurements, with aliquots held at 125 °C during optical stimulation (40 s). OSL signals were derived from the integral of the first 0.8 s of the stimulation decay curve, less a background based on the last 3.2 s. Two dose measurements (out of 326) were rejected as outliers. Dosimetry is based on high resolution gamma spectrometry (46), with assumed water contents set equal to laboratory measurements of saturated water content (the relevant layers probably lay close to or at the water table before excavation began). Cosmic ray dose rates are based on ref. (47), and on average contribute ~11 % to the total.

Fig. S4 shows a representative growth curve obtained using an aliquot of sample 012506, with the recycling points given as open circles, and the recuperation point as an open triangle. A typical natural stimulation decay curve is shown inset. The latter is clearly dominated by a rapidly decaying signal (the ‘fast component’ (48)), which contributes 80 % of the initial OSL signal. It can be seen that the data are reproducible, and that the growth curve passes close to the origin. To test the suitability of the SAR protocol, dose recovery tests were undertaken on 6 aliquots each of samples 012506, 012516, 982512 and 982513; these were optically zeroed by exposure to blue light, given a dose approximately equal to the natural dose, and then this dose was measured as if it were an unknown ‘natural’ dose. The average measured to given dose ratio was 1.014 ± 0.012 (n=24), indicating that the protocol was able to measure accurately a dose given in the laboratory before any thermal treatment.

All the relevant chronological information is summarised in Table S2, and it can be seen that samples 012506, 012516, 982512 and 982513 are all consistent with a mean age of 32 ± 2 ka (weighted according to the random uncertainties in each age; systematic components are 5-6 % of the age).

Discussion and conclusions
Wind-blown sand is considered to be the most reliable sediment for OSL dating because the sand grains are assumed to have been well exposed to sunlight. Thus, the dated samples should be well suited for OSL dating. In principle the four OSL ages from the lowermost sand provide minimum ages for the animal remains and artefacts. However, as described in the main text the sand layer at places inter-finger with the underlying bone and artefact-bearing layer, a fact suggesting that there is no time break between deposition of the two units. The OSL samples from the sand yielded ages 30-33 ka with ± 1σ errors of 2-3 ka (Table S2). As mentioned above the mean for the four samples is 32 ± 2 (± 1σ) ka which is overlapping with the calibrated ¹⁴C ages of 33.6 – 31.7 cal ka BP (68 % confidence interval) and 34.6 – 31.4 cal ka BP (95 %). The OSL results therefore support the validity of the ¹⁴C ages and indeed also our assumption that the animals that were utilized by the humans lived when the debris flow activity took place and that the finds were rapidly and permanently sealed by aeolian sand.
THE FAUNAL REMAINS

THE FAUNA
Field campaigns during the 1960’s yielded 2,067 faunal remains representing at least 21 mammoth individuals, 3 reindeers, 2 wolves, a woolly rhino, a musk ox, a horse, a brown bear and a polar fox (52). Unfortunately all these samples were lost in a boat accident on the Pechora River after the excavation. New excavations at the end of the 1990’s and during the 2000’s gave a “new start” for bone sampling at this site.

We studied this new collection of 1,779 faunal remains accounting for at least 10 mammoths, 2 reindeers, a woolly rhino, a wolf and a bear. However, (some of) the “new” samples might stem from the same individuals as those from the old (lost) collection. We therefore in this article conservatively cite a minimum number of 21 mammoths.

CUT MARKS
A total of 22 bone remains (mammoth, reindeer and brown bear) have cut marks or show intentional modifications by humans. Among these, two have been directly dated: a reindeer antler at 29,230 ± 340 14C BP and a mammoth rib at 27,800 ± 440 14C BP (Table S1). The antler has been intentionally worked and cut up: it concerns the upper extremity of the beam, the brow tine and the bay antler (Fig. S10). This antler, coming from the upper part of the debris flow, was directly linked with mammoth remains, including two ribs bearing cut marks (butchery) as well as a stone tool (Fig. S9). Parts of these mammoth remains belong to two carcasses that apparently have not been much disturbed/moved since they were covered by sediments (6).

Criteria used by zoo-archaeologists to distinguish butchering cut marks from natural marks (soil flow movement, trampling etc.) have been described for 40 years (53,54). A butchering cut mark can be identified following these points: 1) V-shape in cross section, 2) the mark is elongated, 3) multiple, fine parallel striae on the walls of the mark, 4) anatomical location and orientation, 5) each mark corresponds to a detectable anatomical purpose or another reason for being man-made, 6) the cut mark rarely follows the 'contour' of the bone surface. Marks resulting from land slides or other flows usually have U-shaped cross sections, cover a large surface of the bone, are not located at the same place from one specimen to another, and do not correspond to an anatomical purpose. Moreover, marks resulting from the debris flow should have been found on all the types of bones and not only on the internal concave part of the ribs, which is the dominant case at Byzovaya.

At Byzovaya the bone surfaces are very well preserved and provide an excellent opportunity to apply the cited criteria to identify the origin of cut marks. The result of our analysis revealed that 22 samples show traces of being modified by humans, of which there are 13 ribs and one cervical vertebra bearing butchery cut marks. Only 2% of the bones present marks due to trampling or abrasion.

Such a large representation of anthropogenic modifications on mammoth bones is rather uncommon. At the Gravettian site Milovice in the Czech Republic, over 42 000 mammoth bones (from 86 individuals) have been found, but only one bone shows clear cut marks (28). Bones with cut marks were neither found at Achchagyi-Allaikha, Northeastern Russia (1000 bones, 14 individuals) (55), Berelyok, Northeastern Russia (8500 bones, 100 individuals) (55), nor at Svesk, southwest of Moscow (3700 bones, 33 individuals) (56). At the Epigravettian site Yudinovo on the Russian Plain 517 bones (53 individuals) were used for the dwelling structure but a cut mark was found only on a tibia (57). This means that cut marks on mammoth remains are not that common whether the site is anthropogenic or not.

Byzovaya is thus a fantastic site for documenting a butchering practice for food procurement from the mammoth carcasses. These cut marks are very diagnostic and cannot be confused with any other kind of stigmas (Fig. S11 and S12).
### Supporting Table S1. Radiocarbon ages from the bone- and artefact-bearing layer at Byzovaya.

<table>
<thead>
<tr>
<th>Field sample ID</th>
<th>Meth.</th>
<th>Lab. ID.</th>
<th>(^{14}C) age Conv. (^{14}C) years</th>
<th>(\delta^{13}C) %</th>
<th>Coll. (%)</th>
<th>Cal. age. 2(\sigma) range. (\sigma)</th>
<th>Dated material</th>
<th>Stratigraphy, Comments</th>
<th>Refs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997-3030</td>
<td>Conv.</td>
<td>LU-4007</td>
<td>33,180±3,030 33,850-41,990 Bone (rib), mammoth</td>
<td>11.0</td>
<td>33,850-41,990 Bone (rib), mammoth</td>
<td>Middle part of debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997-3057</td>
<td>Conv.</td>
<td>T-13441</td>
<td>27,920±370 31,380-33,090 Bone (jaw), mammoth</td>
<td>-21.4</td>
<td>31,380-33,090 Bone (jaw), mammoth</td>
<td>Middle part of debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997-3058</td>
<td>Conv.</td>
<td>T-13440</td>
<td>28,080±260 31,550-33,050 Mammoth tusk</td>
<td>-21.3</td>
<td>31,550-33,050 Mammoth tusk</td>
<td>Top of debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997-3058</td>
<td>AMS</td>
<td>TUa-7310</td>
<td>28,380±340 31,550-33,620 Mammoth tusk, from same tusk as T-13440</td>
<td>5.5</td>
<td>31,550-33,620 Mammoth tusk, from same tusk as T-13440</td>
<td>Top of debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997-3058</td>
<td>Conv.</td>
<td>LU-3983</td>
<td>29,170±340 32,970-34,630 Mammoth tusk, from same tusk as T-13440</td>
<td>5.7</td>
<td>32,970-34,630 Mammoth tusk, from same tusk as T-13440</td>
<td>Top of debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997-3059</td>
<td>Conv.</td>
<td>LU-3995</td>
<td>27,110±240 31,080-31,700 Bone, (vertebrae) mammoth</td>
<td>10.2</td>
<td>31,080-31,700 Bone, (vertebrae) mammoth</td>
<td>Debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
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<tr>
<td>1997-3069</td>
<td>Conv.</td>
<td>LU-3979</td>
<td>29,160±430 32,640-34,720 Bone (rib), mammoth</td>
<td>10.3</td>
<td>32,640-34,720 Bone (rib), mammoth</td>
<td>Basal part of debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997-3069</td>
<td>AMS</td>
<td>TUa-7309</td>
<td>29,020±300 32,860-34,570 Bone (rib), mammoth. From same bone as LU-3979</td>
<td>5.8</td>
<td>32,860-34,570 Bone (rib), mammoth. From same bone as LU-3979</td>
<td>Basal part of debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
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<tr>
<td>1997-3070</td>
<td>Conv.</td>
<td>T-13439</td>
<td>28,490±290 31,710-33,900 Bone (rib), mammoth</td>
<td>-22.3</td>
<td>31,710-33,900 Bone (rib), mammoth</td>
<td>Top of debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
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<tr>
<td>1997-3070</td>
<td>AMS</td>
<td>TUa-7308</td>
<td>29,110±320 32,940-34,600 Bone (rib), mammoth. From same bone as LU-3979</td>
<td>6.4</td>
<td>32,940-34,600 Bone (rib), mammoth. From same bone as LU-3979</td>
<td>Top of debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
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<tr>
<td>1997-3075</td>
<td>Conv.</td>
<td>LU-4010</td>
<td>28,230±920 31,170-34,600 Mammoth tooth</td>
<td>5.0</td>
<td>31,170-34,600 Mammoth tooth</td>
<td>Sand above debris flow sequence, probably redeposited</td>
<td>(49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997-3087</td>
<td>Conv.</td>
<td>T-13438</td>
<td>26,560±260 30,700-31,410 Bone, woolly rhinoceros</td>
<td>-22.6</td>
<td>30,700-31,410 Bone, woolly rhinoceros</td>
<td>Debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
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<tr>
<td>1997-3087</td>
<td>Conv.</td>
<td>LU-3992</td>
<td>28,510±310 31,750-33,970 Bone, woolly rhinoceros. From same bone as T-13438</td>
<td>11.1</td>
<td>31,750-33,970 Bone, woolly rhinoceros. From same bone as T-13438</td>
<td>Debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997-3087</td>
<td>AMS</td>
<td>TUa-7307</td>
<td>28,420±280 31,720-33,510 Bone, woolly rhinoceros. From same bone as T-13438</td>
<td>6.9</td>
<td>31,720-33,510 Bone, woolly rhinoceros. From same bone as T-13438</td>
<td>Debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
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<tr>
<td>1997-3088</td>
<td>Conv.</td>
<td>LU-3989</td>
<td>27,490±330 31,180-32,600 Bone, mammoth</td>
<td>10.0</td>
<td>31,180-32,600 Bone, mammoth</td>
<td>Debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000-3476</td>
<td>Conv.</td>
<td>LU-4591</td>
<td>29,270±390 32,950-34,710 Unidentified bone, mammal</td>
<td>7.2</td>
<td>32,950-34,710 Unidentified bone, mammal</td>
<td>Top of debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
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<tr>
<td>2000-3491</td>
<td>Conv.</td>
<td>LU-4575</td>
<td>29,710±520 33,000-35,180 Mammoth tusk</td>
<td>9.1</td>
<td>33,000-35,180 Mammoth tusk</td>
<td>Top of debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
<td></td>
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<tr>
<td>2000-3505</td>
<td>Conv.</td>
<td>LU-4590</td>
<td>29,980±470 33,290-36,130 Bone (pelvis), mammoth</td>
<td>5.0</td>
<td>33,290-36,130 Bone (pelvis), mammoth</td>
<td>Middle part of debris flow sequence with artefacts</td>
<td>(49)</td>
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<tr>
<td>2000-3550</td>
<td>Conv.</td>
<td>LU-4583</td>
<td>28,690±250 32,130-34,420 Bone (skull), mammoth</td>
<td>8.0</td>
<td>32,130-34,420 Bone (skull), mammoth</td>
<td>Upper part of debris flow sequence with artefacts</td>
<td>(49)</td>
<td></td>
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<tr>
<td>Date Code</td>
<td>Method</td>
<td>Code</td>
<td>Age (± Error)</td>
<td>Delta</td>
<td>V (± Error)</td>
<td>Age Range</td>
<td>Description</td>
<td></td>
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<tr>
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<tr>
<td>2000-3571-1</td>
<td>AMS</td>
<td>TUa-7313</td>
<td>29,190±290</td>
<td>-21.1</td>
<td>6.7</td>
<td>33,120-34,600</td>
<td>Bone, mammoth</td>
<td>Upper part of debris flow sequence with artefacts</td>
<td></td>
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<tr>
<td>2000-3601</td>
<td>Conv.</td>
<td>LU-4589</td>
<td>27,100±380</td>
<td>11.0</td>
<td>30,920-32,220</td>
<td>Unidentified bone, mammal</td>
<td>Middle part of debris flow sequence with artefacts</td>
<td></td>
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<tr>
<td>2000-3605</td>
<td>Conv.</td>
<td>LU-4584</td>
<td>29,930±1,840</td>
<td>9.0</td>
<td>31,070-38,530</td>
<td>Unidentified bone, mammal</td>
<td>Middle part of debris flow sequence with artefacts</td>
<td></td>
<td></td>
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<tr>
<td>2000-3609</td>
<td>Conv.</td>
<td>LU-4576</td>
<td>27,800±440</td>
<td>11.4</td>
<td>31,270-33,120</td>
<td>Bone (rib), mammoth</td>
<td>Middle part of debris flow sequence with artefacts. Human made marks.</td>
<td></td>
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<tr>
<td>2000-3612</td>
<td>Conv.</td>
<td>LU-4582</td>
<td>29,680±900</td>
<td>9.1</td>
<td>31,960-36,280</td>
<td>Unidentified bone, probably mammoth</td>
<td>Lower part of debris flow sequence with artefacts</td>
<td></td>
<td></td>
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<td>2000-3601</td>
<td>AMS</td>
<td>TUa-7311</td>
<td>29,160±270</td>
<td>-21.0</td>
<td>11.3</td>
<td>33,130-34,580</td>
<td>Unidentified bone, probably mammoth</td>
<td>Lower part of debris flow sequence with artefacts</td>
<td></td>
</tr>
<tr>
<td>2000-3615</td>
<td>Conv.</td>
<td>LU-4574</td>
<td>28,640±570</td>
<td>8.6</td>
<td>31,680-34,530</td>
<td>Unidentified bone, probably mammoth</td>
<td>Middle part of debris flow sequence with artefacts</td>
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<tr>
<td>2000-3616</td>
<td>Conv.</td>
<td>LU-4581</td>
<td>28,590±380</td>
<td>8.0</td>
<td>31,830-34,230</td>
<td>Unidentified bone, probably mammoth</td>
<td>Middle part of debris flow sequence with artefacts</td>
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<td>2000-3647</td>
<td>Conv.</td>
<td>LU-4573</td>
<td>28,500±340</td>
<td>10.7</td>
<td>31,680-34,030</td>
<td>Unidentified bone, probably mammoth</td>
<td>Middle part of debris flow sequence with artefacts</td>
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<tr>
<td>2000-3549</td>
<td>AMS</td>
<td>TUa-7314</td>
<td>29,520±390</td>
<td>-20.7</td>
<td>13.5</td>
<td>32,200-34,840</td>
<td>Unidentified bone, probably mammoth</td>
<td>Top of debris flow sequence with artefacts</td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Conv.</td>
<td>Ta-121</td>
<td>25,540±380</td>
<td>29,560-31,000</td>
<td>Unidentified bone, mammal</td>
<td>Debris flow sequence with artefacts</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1The first four digits give the year of collection.
2Dating method: AMS = Accelerator mass spectrometry; Conv = conventional methods.
4Collagen.
5Calibrated age using internet program Calib 6.0, based on IntCal09 (13).
6All mammoth remains are from *Mammuthus primigenius*.
7Both these dates were in Ref. (49) erroneously cited as 26,555 ± 250 14C years BP.
Supporting Table S2: Summary of dosimetry, equivalent dose measurements and optically stimulated luminescence (OSL) ages

<table>
<thead>
<tr>
<th>Field sample no.</th>
<th>Risø sample no.</th>
<th>Burial depth, cm</th>
<th>$^{226}$Ra, Bq.kg$^{-1}$</th>
<th>$^{232}$Th, Bq.kg$^{-1}$</th>
<th>$^{40}$K, Bq.kg$^{-1}$</th>
<th>Total Dose rate, Gy.ka$^{-1}$</th>
<th>wc, %</th>
<th>$D_e$, Gy</th>
<th>(n)</th>
<th>Age, ka</th>
</tr>
</thead>
<tbody>
<tr>
<td>00-3482</td>
<td>012506</td>
<td>870</td>
<td>10.6 ± 0.5</td>
<td>7.4 ± 0.4</td>
<td>203 ± 12</td>
<td>0.87 ± 0.05</td>
<td>26</td>
<td>26.0 ± 0.9</td>
<td>23</td>
<td>30 ± 2</td>
</tr>
<tr>
<td>97-3022</td>
<td>982513</td>
<td>800</td>
<td>8.1 ± 0.6</td>
<td>8.9 ± 0.8</td>
<td>322 ± 17</td>
<td>1.16 ± 0.06</td>
<td>27</td>
<td>38 ± 2</td>
<td>24</td>
<td>33 ± 3</td>
</tr>
<tr>
<td>97-3026</td>
<td>982512</td>
<td>650</td>
<td>7.9 ± 0.4</td>
<td>7.6 ± 0.4</td>
<td>231 ± 10</td>
<td>0.95 ± 0.05</td>
<td>27</td>
<td>32.0 ± 1.2</td>
<td>8</td>
<td>33 ± 3</td>
</tr>
<tr>
<td>00-3689</td>
<td>012516</td>
<td>750</td>
<td>5.0 ± 0.3</td>
<td>4.8 ± 0.2</td>
<td>167 ± 7</td>
<td>0.69 ± 0.04</td>
<td>26</td>
<td>23.0 ± 0.5</td>
<td>18</td>
<td>33 ± 2</td>
</tr>
<tr>
<td>00-3538</td>
<td>012507</td>
<td>620</td>
<td>14.4 ± 0.3</td>
<td>14.4 ± 0.3</td>
<td>376 ± 8</td>
<td>1.46 ± 0.06</td>
<td>25</td>
<td>33.6 ± 0.8</td>
<td>18</td>
<td>23.0 ± 1.2</td>
</tr>
<tr>
<td>00-3539</td>
<td>012508</td>
<td>600</td>
<td>14.3 ± 0.3</td>
<td>15.8 ± 0.3</td>
<td>381 ± 8</td>
<td>1.43 ± 0.06</td>
<td>30</td>
<td>34.7 ± 0.7</td>
<td>18</td>
<td>24.2 ± 1.3</td>
</tr>
<tr>
<td>97-3008</td>
<td>982511</td>
<td>515</td>
<td>18.5 ± 0.7</td>
<td>20.7 ± 0.6</td>
<td>422 ± 17</td>
<td>1.71 ± 0.09</td>
<td>27</td>
<td>41 ± 2</td>
<td>21</td>
<td>24 ± 2</td>
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<tr>
<td>00-3540</td>
<td>012509</td>
<td>400</td>
<td>22.2 ± 0.6</td>
<td>26.9 ± 0.5</td>
<td>478 ± 18</td>
<td>1.80 ± 0.08</td>
<td>35</td>
<td>36.2 ± 1.0</td>
<td>18</td>
<td>20.1 ± 1.1</td>
</tr>
<tr>
<td>00-3690</td>
<td>022509</td>
<td>350</td>
<td>10.1 ± 0.4</td>
<td>10.2 ± 0.3</td>
<td>314 ± 8</td>
<td>1.22 ± 0.06</td>
<td>26</td>
<td>20.8 ± 0.4</td>
<td>24</td>
<td>17.0 ± 1.0</td>
</tr>
<tr>
<td>00-3628</td>
<td>012515</td>
<td>250</td>
<td>7.5 ± 0.5</td>
<td>7.9 ± 0.4</td>
<td>305 ± 16</td>
<td>1.09 ± 0.06</td>
<td>25</td>
<td>16.4 ± 0.7</td>
<td>24</td>
<td>15.0 ± 1.1</td>
</tr>
<tr>
<td>97-3002</td>
<td>982510</td>
<td>120</td>
<td>5.8 ± 0.6</td>
<td>5.8 ± 0.5</td>
<td>291 ± 15</td>
<td>1.10 ± 0.06</td>
<td>27</td>
<td>18.8 ± 1.2</td>
<td>12</td>
<td>17.0 ± 1.5</td>
</tr>
<tr>
<td>00-3404</td>
<td>012505</td>
<td>20</td>
<td>9.5 ± 0.5</td>
<td>9.4 ± 0.4</td>
<td>308 ± 16</td>
<td>1.13 ± 0.06</td>
<td>26</td>
<td>17.3 ± 0.4</td>
<td>26</td>
<td>15.3 ± 0.9</td>
</tr>
</tbody>
</table>

Notes:
1. Mean age of the stratigraphic four lower samples (012506, 012513, 982512 and 982516) is 32 ± 2 ka (weighted by random uncertainties).
2. Dry dose rates derived from concentration measurements using data given in ref (51).
3. Total dose rates include water content correction, grain-size dependent beta dose attenuation, cosmic ray contribution and assumed internal dose rate of 0.06 ± 0.03 Gy.ka$^{-1}$ (see ref (12)). Saturated water contents (wc, %) assumed to apply throughout burial period. Cosmic ray dose rates derived from ref (47).
4. (n) is the number of aliquots measured to give the average equivalent dose, $D_e$.
5. All uncertainties are random only, except those on ages which include estimates of both random and systematic contributions in a 68% confidence interval.
6. All dates are published in ref. (12). Dose rates, total dose and ages are different from the published values. The changes are all in the least significant figure, and arise from minor changes in the dose rate assumptions and rounding off.
### Table S3. Technical composition of the lithic industry from the Byzovaya site.

<table>
<thead>
<tr>
<th>Lithological categories</th>
<th>RM1</th>
<th>RM2</th>
<th>RM3</th>
<th>RM4</th>
<th>RM5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large flakes &gt; 2cm</td>
<td>2</td>
<td>3</td>
<td>45</td>
<td>4</td>
<td>24</td>
<td>78</td>
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<tr>
<td>large flakes frag.</td>
<td>2</td>
<td>60</td>
<td>5</td>
<td>8</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Prox.</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Mes.</td>
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<td>35</td>
<td>3</td>
<td>2</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Dist.</td>
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<td>21</td>
<td>1</td>
<td>5</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Flake &lt; 2cm</td>
<td></td>
<td>21</td>
<td>1</td>
<td></td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Typological tools</td>
<td>4</td>
<td>8</td>
<td>42</td>
<td>11</td>
<td>15</td>
<td>80</td>
</tr>
<tr>
<td>Debris</td>
<td>1</td>
<td>35</td>
<td>7</td>
<td></td>
<td>43</td>
<td></td>
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<tr>
<td>Levallois cores</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Discoid cores</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Polyedric cores</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
<td>2</td>
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</tr>
<tr>
<td>Core frag.</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Pebble frag.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>9</td>
<td>12</td>
<td>210</td>
<td>21</td>
<td>59</td>
<td>313</td>
</tr>
</tbody>
</table>


### Table S4. Typological categories of the retouched tools from the Byzovaya site.

<table>
<thead>
<tr>
<th>Lithological categories</th>
<th>RM1</th>
<th>RM2</th>
<th>RM3</th>
<th>RM4</th>
<th>RM5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple convex side-scraper</td>
<td>1</td>
<td>13</td>
<td>2</td>
<td>4</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Simple straight side-scraper</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Tools on pebbles</td>
<td>3</td>
<td></td>
<td>4</td>
<td></td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>Large Quina-type side-scraper</td>
<td>2</td>
<td></td>
<td>4</td>
<td></td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Convergent scraper</td>
<td></td>
<td>3</td>
<td>1</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>transverse side-scraper</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>End-scraper on extremity of side-scrapers</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Proximal end-scraper</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td></td>
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<tr>
<td>Double déjeté side-scraper</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>3</td>
<td></td>
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<tr>
<td>Keilmesser</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td>3</td>
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<tr>
<td>Déjeté side-scraper</td>
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<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Blattspitzen</td>
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<td>1</td>
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<td></td>
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<tr>
<td>End-scraper</td>
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<td></td>
<td>2</td>
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</tr>
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<td>fragmented side-scraper</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
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<tr>
<td>Retouched notch</td>
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<td></td>
<td></td>
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<tr>
<td>Ventral retouch side-scraper</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
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<td>Scraper on splintered piece</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>End-scraper on extremity of notched tool</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Bifacial convergent altern side-scraper</td>
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<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Simple concave side-scraper</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Double convex side-scraper</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Plano-convex side-scraper</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Total by raw materials</strong></td>
<td>3</td>
<td>8</td>
<td>43</td>
<td>11</td>
<td>15</td>
<td>80</td>
</tr>
</tbody>
</table>
Fig. S1. A section of the Northern Hemisphere illustrating the known distribution of Neanderthals and the suggested extension to the Byzovaya site, near the Arctic Circle in Northern Russia. The age of this site is 34,580-31,370 cal years BP (95% confidence interval). The assumed size of the Scandinavian Ice Sheet at this time is shown. Photos and artefacts from Byzovaya are inserted on top.
Fig. S2
All 14C ages (± 1σ) from the artefact-bearing layer plotted according to increasing ages.
Samples with 1σ > 1.5% of the age are shown with black crosses and error bars. Those with 1σ < 1.5% are plotted red. The pool mean with ± 1σ and ± 2σ for the latter group is marked with vertical lines.
The stratigraphic position (lower, middle, upper) in the layer is marked.
The three samples yielding youngest ages were collected before the Norwegian–Russian excavations.

Fig. S3
A plot of AMS versus conventional radiocarbon ages obtained from the same specimen (in 14C years BP ± 1σ).
The samples are identified with the lab ID of the conventional methods; other details are given in Table S1. The one to one line is marked.
The samples T-1340 and LU-3992 are plotted versus the same AMS date (TUA-7310) because all three were performed on the same bone, and T-13440 and LU-3903 are for the same reason plotted against TUA-7310.

Fig. S4
Dose response curve for an aliquot of sample 012506, showing the recycling (open circles) and recuperation (open triangle) points, and the interception of the natural signal on the fitted curve (of form y = A(1 - exp(-bx)) + C(1 - exp(-cx)), where A, b, C and d are constants). The natural OSL signal is shown inset on a logarithmic stimulation time scale and has been fitted with the linear sum of 3 exponential decays and a constant. The first (fastest decaying) component makes up 80% of the initial signal.
Fig. S5. Photographs and drawings of selected stone artefacts from Byzovya. 1-2: Mousterian scrapers; 3: Discoid core. Photos Ludovic Slimak and Hugues Plisson. Drawings Ludovic Slimak.
Fig. S6. Photographs of large quartzite side-scraper from Byzovaya with Quina-type retouch. Photos Ludovic Slimak.
Fig S7. Byzovaya during the 2000 field campaign of excavation. A bay of Pechora River to the right. Photo by John-Inge Svendsen.
Fig. S8. Photo of tusk and mammoth bone lying at the very surface of the find-bearing strata and draped by aeolian sand (during the 2000 field excavation). Stick is 1 m. Photo by Herbjørn Presthus Heggen.
Fig S9. Photo of a lithic tool (large quartzite side-scraper) and bone in the excavation. The reindeer antler (upper right) is directly dated and shows anthropogenic modifications (see Fig. S10). Stick is 1 m. Photo by John-Inge Svendsen.
Fig S10 Photo of the dated antler with human modification. Photos by Alexis Brugère
Fig. S11. Photo of mammoth ribs with butchery cut marks. Photos by Alexis Brugère
Fig. S12 Photos showing macro- and microscopic traces of butchering on worked stone edges (artefacts) and on bones.
1/ edge damage of cutting motion on the retouched edge of a plano-convex flint side-scraper;
2/ microscopic detail of the same use wear, resulting from a contact with a bone surface;
3/ edge damage of a scraping motion on the edge of a flint flake.
4/ Skinning cut marks on the mandible of a Brown bear;
5/ Butchering cut marks on the internal face of a mammoth rib;
6 Multiple striations from lithic tools on the edge of a mammoth rib.

White scale: 1 cm
Grey scale: 100 µ

Photos Hugues Plisson
References and Notes


20. O. Jöris, Zur chronostratigraphischen Stellung der spätmittelpaläolithischen Keilmessergruppen. Der Versuch einer kulturgeographischen Abgrenzung einer mittelpaläolithischen


24. O. Bader, *Sungir Upper Palaeolithic Site* (Nauka, Moscow, 1978) [in Russian].


44. R. G. Fairbanks et al., Radiocarbon calibration curve spanning 0 to 50,000 years BP based on paired $^{230}$Th/$^{234}$U/$^{238}$U and $^{14}$C dates on pristine corals. Quat. Sci. Rev. 24, 1781 (2005).


52. V. I. Kanivets, The Palaeolithic of the Extreme North-East of Europe (Paleolit Krainego Severo-Vostoka Yevropy) (Nauka, Moscow, Russia, 1976). [in Russian]


