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Chronology and function of a new circular mammoth bone structure from Kostenki 11

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Abstract

We report on assemblages of charcoal, burnt bone and microlithic debitage retrieved by flotation from a new circular mammoth bone feature discovered at Kostenki 11-Ia, Russian Federation, the first time a mammoth bone circle has ever been systematically sampled in this way. New radiocarbon dates are used to provide the first coherent chronology for the site, revealing it as one of the oldest such features on the Russian Plain and confirming occupation of this region during Greenland Stadial 3 at the onset of the last glacial maximum. Implications for human activity within and around the mammoth bone feature are discussed.

Introduction

Circular mammoth bone features associated with late Upper Palaeolithic artefact assemblages are found widely across eastern Europe, dating to c.22kya and later (Soffer, 2003). These features are characterised by a concentrated ring of mammoth bones several metres in diameter, and almost invariably surrounded by a series of large pits interpreted variously as evidence for food storage, bone fuel storage, rubbish disposal, or simply quarries for loess used in construction (Soffer, 1985). The circular features themselves are widely considered to be the remains of dwellings, offering shelter during long full-glacial winter seasons or possibly year round (Iakovleva, 2015, Pidoplichko, 1998, Soffer, 1985).

One of the best-known sites to have mammoth bone features is Kostenki 11, located on the Don River near Voronezh, on the eastern margin of the Central Russian Upland where two such structures were discovered during excavations of the 1950s and 1960s (Rogachev and Popov, 1982). In 2013, V.V. Popov recommenced survey work at the site and in 2014, a new mammoth bone feature was discovered, located near the museum building. Three further excavation seasons followed in 2015–2017, exposing a well-preserved circular mammoth-bone structure partially surrounded by three large pits.

We report here on the first results of a program of flotation carried out during the 2015 excavation season: the first time such a method has been systematically applied to both the interior and exterior occupation surfaces and the pits surrounding the same circular mammoth bone feature. The aims of this program were to:

- Recover ancient plant or other organic remains, including any evidence of plant foods, for study in an on-going Leverhulme Trust-funded project considering Palaeolithic food storage
- Investigate the fuel choices made at the site
- Recover any evidence that might contribute to identifying activity areas within the site, including lithic microdebitage and other cultural remains, so as to understand better site function.

Archaeological context

Kostenki 11 (also known as Anosovka 2) is located on the west bank of the Don River near the city of Voronezh in the Russian Federation at 51°23′08″ North 39°03′05″ East. The site was discovered by A.N. Rogachev in 1951 but was not excavated until 1960–1965, when Rogachev exposed 150 m^2, uncovering the first mammoth-bone feature near the modern surface of the site in layer Ia (K11-Ia)(Rogachev and Popov, 1982, Popov et al., 2004). This structure is now preserved *in situ* in the State Archaeological Museum-Preserve at Kostenki. A second mammoth bone feature was discovered in 1970, located 17m NE of the first (Rogachev and Popov, 1982). Around a third of this structure was excavated, together with one large pit, with the remainder now lying beneath modern buildings on private land. Further details are given in the Online Supplementary Material (OSM).

Figure 1 around here: Plan of the K11 site

The third mammoth bone feature

The newly-discovered mammoth bone structure is located approximately 20 m west and slightly upslope of the first discovered structure(Figure 1)(Dudin et al., In press). At the time of discovery this area was covered with trees around 35 years old belonging to species of birch, pear and cherry, together with shrubby undergrowth. The uppermost bones of the structure lay within 0.6 m of the modern ground surface and partly within the B-horizon of the modern soil. As a result much of layer Ia was contaminated with modern roots and animal burrows. Nonetheless, the bones themselves were remarkably well preserved and appeared to lie largely intact and undisturbed in the positions in which they were originally deposited (Figure 2).

FIGURE 2 around here

The mammoth bone circle is large with a diameter of approximately 12.5m and sits today on an east-facing slope with an incline of approximately six degrees. The bones form a continuous circle and no obvious entranceway has been identified. A large area of combustion deposits was discovered in the SE quadrant of the structure comprising layers of rubified loess mixed with burnt bone and charcoal (Figure 3). At least three large pits 1-2m in diameter were discovered on the SE margins of the circle, each containing large mammoth bones. The lithic assemblage collected in the 2015 season from the vicinity of the structure numbered 1275 pieces of which 190 (15%) were retouched (Fedyunin, 2016). These lithics were similar to those found in the first mammoth bone structure at Kostenki 11-Ia and have been attributed to the Zamyatnin Culture, (Rogachev and Popov, 1982), a poorly-defined grouping of lithic assemblages that show clear differences from earlier Gravettian industries (Popov et al., 2004, Sinitsyn, 2015, Bessudnov, 2016). A detailed faunal report is not yet available. However, an assessment of the material indicates that the assemblage is comprised almost exclusively of mammoth bones, with other species only rarely represented. A preliminary scan of the bones at the end of the 2015 season identified 51 mandibles and 64 crania of mammoth (Fedyunin, 2016), indicating a minimum number of individuals significantly higher than the >40 animals used to construct the first mammoth bone feature (Popov et al., 2004).

Figure 3 around here: Photo of combustion deposits

<u>Chronology</u>

Six conventional radiocarbon dates of bone and ivory from the first mammoth bone feature span a range from 12,000 to 19,900 ^{14}C years BP (Popov et al., 2004)(Figure 5). It remains unclear which, if any, of these date are reliable. Similar mammoth bone structures from eastern Europe are mostly dated to the post-LGM period (Iakovleva and Djindjian, 2005). Meanwhile, sites associated with the Zamyatnin lithic industry are assigned to the post-Gravettian, LGM and later period but otherwise are poorly dated and their cohesiveness as a lithic cultural unity has long been debated (Bessudnov, 2016). During this project three new AMS radiocarbon dates were obtained on fragments of charcoal – rather than bone or ivory – extracted by floatation in the 2015 season. These fragments were analysed by the INSTAAR Laboratory for AMS Radiocarbon Preparation and Research, at the University of Colorado. Simultaneously, six further samples of mammoth bone and one charcoal sample collected during the summer of 2014 were dated by L. Lbova at the experimental AMS Radiocarbon Laboratory, Centre for Cenozoic Geology at the Institute of Archaeology and Ethnography of the Siberian branch of the Russian Academy of Sciences in Novosibirsk (Dudin et al., In press). As discussed below, these new dates correspond with the oldest of the bone-based dates obtained previously and confirm that Kostenki 11-Ia contains some of the earliest examples of circular mammoth bone features yet discovered.

Method

Sediment samples were collected from eleven locations within and around the mammoth bone structure to evaluate differences between areas and features associated with the site as follows:

- Five approximately 30 x 30 cm sondages of various depth located within the mammoth bone circle;
- A small sondage 70 cm x 15 cm by 20 cm deep excavated through the combustion deposits in the centre of the structure; samples were divided according to the visible layers within the deposit.
- Samples from three of the pits on the outside margins of the structure. These samples were collected from exposed vertical sections (Pit 2), or, when vertical sections were not available, from whichever sediments were available at the time of sampling (Pits 1 and 3);
- Two approximately 30 x 30 cm sondages outside of the structure, located away from obvious pit features.

No clear stratigraphic divisions were noted in the 30 x 30 cm sondages or during collection of samples from the pits, and samples were therefore collected as arbitrary, horizontal spits between 5-15 cm deep. The 32 resulting samples varied in size from 0.1 L to 10 L (300 up to 10,000 cm^3) according to how sediments were divided into units during excavation. While these sample sizes are relatively small, systematic flotation programs have only rarely been conducted at Palaeolithic sites (e.g. Beresford-Jones et al., 2010), and our sample sizes are significantly larger than the only flotation samples previously reported from a similar mammoth bone feature at Mezhyrich, Ukraine, which varied between 100-1000 cm^3 (Marquer et al., 2012, Soffer et al., 1997:59). Excavation in each sondage typically ceased upon reaching large bones extending across more than 50% of the sondage area (such bones were apparently related to activity in layer Ia and were left *in situ*) or, in the case of the deepest sondage 3, upon finding a lithic belonging to cultural layer K11-2 at a depth of 45 cm. In total 148 litres of sediment samples were floated.

Figure 4 around here: Aerial photograph of site

Flotation

Samples were floated using a combination of bucket-flotation and a standard field-built flotation tank. The light fraction was extracted using a 0.5 mm mesh while the heavy residue was collected using a 1.0 mm mesh. Analysis of lithic debitage is useful for characterising local knapping activities as it is likely to be left behind at the knapping location even when larger flakes, tools and cores have been removed for further use elsewhere. Microlithic debitage including chips (pieces <20 mm) and minute lithics (pieces <10 mm) were therefore extracted and analysed following the methods described by Nadel (2001).

Table 1: summary of flotation samples and results

Results

Dating

Three AMS radiocarbon dates measured at the University of Colorado on charcoal floated from Sondage 5, Sondage 2 and the combustion deposits produced dates of 20,670 ± 160 (CURL-21040), 20,360 ± 150 (CURL-21043) and 20,620 ± 150 (CURL-22804) respectively (Table 2). Two of the bone-based dates measured in Novosibirsk match these results closely, forming a cohesive group of five dates with a calibrated date range of 25,063-24,490 cal BP at 95.4% probability when modelled using the Combine function in OxCal version 4.3 and the IntCal 13 atmospheric curve (OSM; Bronk Ramsey, 2009, Reimer et al., 2013). The dated samples come from widely spaced locations across the site affirming the stratigraphic integrity of the bones and floated remains, strongly supporting a chronological link between the charcoal and human occupation of the site. Two further bone-based dates (NSKA 885 and 889) are slightly younger (Figure 5; OSM) and may indicate either a second phase of occupation or reflect the incomplete removal of contaminants (see discussion in OSM). Two more bone dates from the Novosibirsk laboratory failed to produce usable results (Table 2), while the charcoal date from Novosibirsk is too young to be considered alongside the other results. The five cohesive bone and charcoal dates confirm human occupation of the structure at the onset of the LGM in Greenland-Stadial 3 and mean Kostenki 11-Ia is the oldest circular mammoth bone structure associated with modern humans yet discovered on the Russian Plain (see OSM).

Figure 5: INSERT OXCAL DIAGRAM

Table 2: INSERT TABLE OF 14C DATES

Lithic debitage

The lithic debitage assemblage from the heavy fractions comprised 338 mostly minute lithics <10 mm in size and some chips up to 20 mm. Following the terminology of Nadel (2001), the debitage comprised: microflakes and microblades with bulbs of percussion and striking platforms; angular fragments (also termed *shatter fragments*; Newcomer and Karlin 1987); and some burnt pieces. Cortex was also present on some lithics. Preliminary analysis of the chips has indicated hard hammer knapping and also a smaller component of probable tool retouch using soft hammers (wood or antler) characterised by microblades with thin bulbs of percussion and pointed striking platforms. Density estimates extrapolated from the mammoth bone circle and pit samples vary from 123 to 1178 lithics per m^2 (1.2 to 6.0 lithics per L), being greatest towards the central and northern parts of the circle in sondages 2 and 5 (Figure S2, OSM). Debitage from the combustion deposits included both burnt and unburnt chips, confirming a degree of post-depositional mixing of deposits inside the circle; this might be related to anthropogenic activity (e.g. trampling, hearth rake-out), or have occurred after the site was abandoned. No significant difference was found between lithic densities in the pit fills and the sondages inside the mammoth bone circle (p = .376). Lithic chip densities from the sondages outside the mammoth bone circle were substantially lower, around 0.2 lithics per L in the NE sondage and zero chips discovered in the SW sondage. This dramatic fall in lithic chip density indicates that activity at Kostenki 11 was tightly focused around the pits and the area inside the mammoth bone circle.

The discovery of minute lithic debitage inside the mammoth bone circle at Kostenki 11 is significant, because small debris is likely to be left behind at the knapping location even when the tools, larger flakes and cores have been cleaned away or removed for further use elsewhere (Clark, 1986). Little comparative data is available concerning the densities of minute debitage retrieved using flotation. Wet sieving at Mezhyrich produced “several thousand smaller sized tiny flint chips and splinters”, but no information on find density is given (Pidoplichko, 1998:129). Lithic density data is, however, available from the Epipalaeolithic site of Ohalo II, Israel, which provides a useful reference point for interpreting the Kostenki 11 data. Here, flotation of samples from internal dwelling floors 10-30cm thick yielded lithic chip densities that varied from 1000-5000 microblades and flakes per m^2 and from 10,000-27,000 chips per m^2 (Nadel, 2001), at least 10 times that recorded at Kostenki 11. Irrespective of the duration the sites were occupied for, it is clear from this that the intensity of flint knapping activities at Kostenki 11 was far lower than that occurring inside the huts at Ohalo II.

Burned bones

A total volume of 4.1 L of non-lithic heavy residue was extracted from the samples, almost entirely comprising bone and ivory fragments 1-15 mm in size. A large proportion of these fragments were burnt, ranging in condition from partially/fully carbonised to calcined (representing categories 1-6; Stiner et al., 1995). The largest quantities of bone and ivory fragments were found in units from the combustion deposits near the centre of the structure where they comprised between 3-18% of the volume of floated material, compared with 1-8% in other samples (Figure S3, OSM). As with the lithic distribution, no significant differences were observed between bone densities in the pits and those collected from inside the mammoth bone circle (p = .849). As with lithic distribution the density of bone residue drops dramatically in the sondages excavated outside of the circle.

Bosch et al. (2012) propose eight models for interpreting burnt bone fragments at Palaeolithic sites, distinguishing between scenarios including bones burned naturally, while roasting meat, during marrow and fat extraction, in waste disposal, and when burned deliberately for fuel. Applying their criteria to the K11 assemblage we note the high proportion of carbonised and calcined bones; the small size of the burned fragments; and the paucity and degradation of the accompanying wood charcoal. A visual inspection of the burned bone fragments also indicated an approximately 50%-50% split between spongy and dense cortical bone fragments, together suggesting deliberate bone burning either as a source of fuel or for waste disposal (cf. Beresford-Jones et al., 2010).

Charcoal assemblage

Fragments of highly disintegrated charcoal and microcharcoal were recovered from all sampled contexts, the first ever from Kostenki 11-Ia. The abundance of charcoal is positively correlated with the abundance of bone residue in every sampled context located inside the mammoth bone circle ($r^2 = 0.73$, $p = 0.002$), with clear concentrations of material in the hearth, and around the middle and northern edges of the circle respectively (sondages 2 and 5). Meanwhile, sondages 1, 3 and 4 towards the western and eastern periphery of the circle produced much lower concentrations of material (Figure S4, OSM). The co-occurrence of bone and charcoal residues and their dispersal throughout the site suggests they were subject to similar depositional and post-depositional processes, potentially including hearth rake-out and trampling. No significant differences were observed between charcoal concentration in the pit fills and in samples collected from inside the mammoth bone feature (p = .502). Virtually no charcoal was recovered from the sondages dug outside the mammoth bone circle.

The charcoal assemblage included 474 fragments sized >2 mm. The largest fragment measured >1cm on its longest axis but most were much smaller, around $3mm^3$. The charcoal assemblage included no vitrified remains, although many pieces showed significant distortions of the internal structures caused by burning of the wood at high temperatures (Théry-Parisot, 2002). Charcoal preservation was nonetheless sufficient to allow for 409 charcoals to be identified as woods of coniferous tree species including *Pinus* spp. and *Picea*/*Larix* sp.. No charcoals from deciduous hardwood trees were identified.

Conifer charcoal fragments preserving sufficient transverse sections showed consistently narrow growth rings between 0.1 and 0.2 mm wide (e.g. Figure 6), suggesting generally difficult growing conditions for the trees (Beresford-Jones et al., 2011). Charcoal fragments with wider growth rings were occasionally observed (up to 0.45 mm and many cells wide) also suggesting that some trees were able to grow more quickly in the vicinity of Kostenki in the prelude to the LGM. Meanwhile, 12 charcoals showed tightly curved growth rings deriving from the central part of stems or narrow-stemmed wood used as kindling (Figure 6), although there were no surviving outer cortex elements allowing distinction between the two.

The charcoal assemblage also included 37 pieces lacking visible cellular structure when viewed with a light microscope, around 7% of the >2mm fraction (Figure 5). These charcoals had a cratered appearance with few discernible features, suggesting possible identification as parenchymous plant tissue (cells specialised in the storage of starch). When viewed under a scanning electron microscope around 25% of these pieces were identified as degraded conifer wood (a typical occurrence when searching for charred archaeological parenchyma; Pryor et al., 2013, Hather, 1993:3). Among the remaining fragments, several showed partly preserved vessel elements, features that occur in flowering plants (Angiosperms), and not in the conifers that comprise the entirety of the Kostenki 11 charred wood assemblage. No other characteristics useful for identification were observed, although the fragments were comparable to pieces of charred soft non-woody plant tissue reported previously from the Gravettian site of Dolní Věstonice II, which also lacked clearly discernible cellular structure and were tentatively identified as the remains of starchy plant materials processed by grinding and mashing for consumption (Pryor et al., 2013). While the number of fragments from Kostenki 11 is smaller and the pieces less-well preserved, their presence expands the number of sites where charcoals showing this particular morphology are known and we mention them here as an encouragement to future research into charred soft plant tissues at Palaeolithic sites.

More than 50 small charred seeds were also found scattered all across the site and in particularly large numbers in Sondage 3. Their seed coat morphologies have not survived, leaving only minute, rounded or sub-rounded, and ellipsoid or globular spheres of parenchyma 0.5-0.7 mm in diameter and mostly lacking any further structure (Figure 6). It therefore remains unclear whether these seeds are present due to deliberate plant gathering activities of the people at Kostenki 11, or whether they were accidentally incorporated into the assemblage, for instance, through *in situ* plants present inside the mammoth bone circle at the time of burning.

Figure 6 around here: Photographs of charred remains

Fills of the three large pits

The concentrations of lithic debitage, bone debris and charcoal in the fills from the three large pits are statistically indistinguishable from the sediments located inside the mammoth bone circle. The pit fills thus appear to derive from sediments subjected to the same intensity of cultural activity as those inside the circle. This pattern may result from some form of deliberate rubbish disposal, but there is no evidence for the dumping of concentrated hearth deposits as was identified in pit 5 at Mezhyrich (Soffer et al., 1997). For this reason, it seems more likely that the pits were in-filled either deliberately by the hunter-gatherers who occupied the site, or by post-depositional displacement of sediments from the cultural layer after the site was abandoned. This finding does not preclude the pits being used for different purposes prior to becoming infilled (e.g. storage of food and bone; Soffer et al., 1997).

Discussion and Conclusions

Lithic typology and radiocarbon dating evidence has hinted at complex population dynamics on the central Russian Plain during the mid-late Upper Palaeolithic (Sinitsyn, 2015, Reynolds et al., 2015, Bessudnov, 2016). The new charcoal and bone radiocarbon dates for K11-Ia contribute towards understanding these dynamics by confirming a human presence on the Russian Plain at 51°N during Greenland Stadial 3, a period of intense cold when similar latitudes across the rest of Europe were already abandoned in the face of ice sheets advancing rapidly towards the LGM. Yet despite this cold, the widespread distribution of charcoal and burnt bone at Kostenki 11 indicates the availability of wood fuel and the sustained use of mixed-fuel fires of wood and bone. Bone has often been thought of as the primary fuel at mammoth bone sites due to an apparent lack of charcoal and presumed climatic constraints on tree growth (Pidoplichko, 1998). However, as long ago as the 1960s, Pidoplichko argued on taphonomic grounds that wood must have been an important fuel at Mezhyrich (Pidoplichko, 1998), and use of firewood has since been demonstrated by the recovery via flotation of micro-charcoal across that site (Marquer et al., 2012). Kostenki 11 is therefore the second site with circular mammoth bone features where habitual wood burning has been identified using flotation, and in a context some 5,000 years older. The charcoal data also adds to a growing corpus of macrofossil evidence indicating that trees survived in mammoth steppe environments on the Russian Plain throughout the last glacial cycle (Tzedakis et al., 2013). The availability of deadwood fuel supplies is a prerequisite for many contemporary hunter gatherers in high latitude cold climates (Pryor et al., 2016). The presence of conifer trees near Kostenki, perhaps located in low-lowing, moist and sheltered areas in the ravines near to the site, will have represented an important resource attracting hunter-gatherers to the area during the glacial period, perhaps holding the key to human persistence in this region while other equivalent areas of northern Europe were abandoned.

The distribution of the minute lithic debitage at Kostenki 11 indicates a clear focus of activity inside the mammoth bone circle rather than the areas outside, but the intensity of these activities appears strikingly low compared with, for instance, the Epipalaeolithic dwellings at Ohalo II. Using lithic production and repair as a proxy for domestic activity more generally entails a number of uncertainties. For example, surfaces may have been swept clean or hides may have been put down to collect lithic debris for disposal elsewhere; yet, no evidence for dumping has been noted in the pits or the excavated area around the structure where minute lithic densities are equivalent or substantially below those found inside. The relative scarcity of minute debitage seems incongruous for a putative dwelling where knappers could be expected to have regularly produced and repaired lithic tools while seeking refuge by the fire.

This unexpected finding of apparently short duration or low intensity occupation at K11-Ia raises important questions regarding the function and human use of circular mammoth bone structures, that required such significant time and energy to build. It has been convincingly argued that some examples, such as Mezin and Mezhyrich, functioned as dwellings (Iakovleva, 2015). However, Kostenki 11-Ia is now known to be significantly older and displays several features in addition to the apparently low intensity of lithic working which are harder to reconcile with this interpretation, including a large-diameter internal area that would have been difficult to roof and a paucity of evidence for any prey other than mammoth to provide for food and hides for clothing. Such problems have stimulated a long history of debate concerning the role of the structures as monumental architecture or possible ceremonial features (e.g. Allsworth-Jones, 1998, Gavrilov, 2015), and in a future article we will argue that their function as food storage facilities should be given further consideration. Sieving and/or floating for the fine fraction, as demonstrated here, has the potential to provide spatially resolved data necessary to clarify how humans actually used these spectacular mammoth bones sites, making them less enigmatic and more accessible to archaeological investigation.

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Figure 1

A) Relative locations of three mammoth bone features from Kostenki 11-Ia (Image credit: I.V. Fedyunin of LLC "Terra"). Feature 1 is preserved today in the Kostenki Museum.
B) Plan of the third mammoth bone structure as it appeared at the end of the 2015 excavation season. Sampling locations for floated sediments indicated by black rectangles.

Figure 2: Photograph taken from the museum roof in July 2017, looking north-west towards the third mammoth bone structure. The two visible scales are 5m long each. Image credit: A.E. Dudin.

Figure 3: Images of the combustion deposits within the mammoth bone circle. A) View looking north towards the combustion deposits immediately prior to sample collection. B) Close-up of rubified layer showing densely packed charred bone fragments including white vitrified pieces. C) Cross-section of combustion feature part-way through excavation. The thick rubified layer overlies a thin black deposit that fades to sterile loess below. The pale sediments cutting through the rubified layer on the right hand side of the section result from animal burrowing. Just to the left of this a lithic is visible protruding from the section.

Figure 4: Aerial photograph of the new mammoth bone structure at Kostenki 11, taken using a drone during excavations in 2015 (image credit: A.Yu. Pustovalov and A.M. Rodionov). Location of the burnt deposits, pit features and sampling locations are shown.

Figure 5: Old and new radiocarbon dates for Kostenki 11-Ia (Rogachev and Popov, 1982, Popov et al., 2004), calibrated in Oxcal version 4.3.2 using the IntCal13 calibration curve (Bronk Ramsey, 2009, Reimer et al., 2013). The δ^{18}O curve from the NGRIP ice core is also shown. The new dates match closely with the oldest bone-based date measured on the first-discovered mammoth bone complex.

Figure 6: Charred materials from Kostenki 11. A) Charcoal fragment a single growth ring wide; B) Most charcoal showed consistently narrow growth rings. In this fragment average ring width was 0.13 mm. C) Charcoal fragment with tight ring curvature deriving from the centre of the stem. Based on ring curvature the stem was at least 6 mm in diameter. D) Examples of seeds (currently unidentified). E and F) Scanning electron microscope images of charcoal fragments lacking cellular structure, tentatively identified as crushed soft plant tissue.

Table 1: Summary of flotation samples and results

Table 2: Radiocarbon dates for the third mammoth bone feature from K11-Ia

Table 1

Context	Grid square	No. of samples (n)	Total volume (L)	Bone residue (mL)	Bone residue per litre (mL / L)	Lithic chips (n)	Lithics per m2 (n/m^2)	Lithic chips per L (n/L)	Weight charcoal (mg)	Charcoal (mg/L)
Below combustion deposits	1-9	3	5.1	112	22.0	13	123.8	2.5	62.4	12.2
Combustion deposits	1-9	8	8.9	825	93.2	33	314.3	3.7	308.5	34.9
Sondage 1	-4 / 13-14	2	17.0	240	14.1	26	288.9	1.5	62.1	3.7
Sondage 2	-2 / 14	1	7.0	220	31.4	27	360.0	3.9	133.9	19.1
Sondage 3	2 / 14	5	45.0	900	20.0	54	514.3	1.2	207.4	4.6
Sondage 4	-5 / 11	1	4.0	45	11.3	5	125.0	1.3	16.5	4.1
Sondage 5	-2 / 12	2	18.0	980	54.4	106	1177.8	5.9	516.9	28.7
Pit 1	2 / 4	3	16.0	650	40.6	54		3.4	314.5	19.7
Pit 2	4-5 / 5/6	1	1.5	40	26.7	9		6.0	10.0	6.7
Pit 3	5-6 / 7/8	1	2.7	75	27.8	7		2.6	106.8	39.6
Control 1 (NE corner)	4 / 16	4	17	100*	5.9*	4.0	38.1	0.2	22.0	1.3
Control 2 (SW corner)	-8 / 4	1	6	10*	1.7*	0.0	0.0	0.0	5.3	0.9

* Approximate figures

Table 2:

Context / grid square	Material	Lab code	δ^{13}C	^{14}C BP	Min. calibrated ^{14}C BP (68.2% probability)	Max. calibrated ^{14}C BP (68.2% probability)	Min. calibrated ^{14}C BP (95.4% probability)	Max. calibrated ^{14}C BP (95.4% probability)
AMS radiocarbon dates from INSTAAR laboratory, University of Colorado								
Sondage 2	Conifer wood	CURL-21043	-21.2‰	20360 ± 150	24224	24707	24077	25007
Sondage 5	Conifer wood	CURL-21040	-21.3‰	20670 ± 160	24621	25136	24424	25348
Combustion deposits	Conifer wood	CURL-22804	-25.3‰	20620 ± 150	24575	25065	24399	25277
AMS radiocarbon dates from Institute of Archaeology and Ethnography, Novosibirsk								
-X3/У10	Burnt bone	NSKA-885		19514 ± 257	23169	23820	22885	24121
-X5/У9	Burnt bone (calcined rib)	NSKA-886		20728 ± 316	24342	25342	24214	25699
-X3/У10	Mammoth bone (scapula)	NSKA-888		Measurement error				
-X3/У7	Mammoth bone	NSKA-889		20006 ± 319	23670	24450	23337	25030
-X2-X3/У6	Mammoth bone (rib)	NSKA-890		20838 ± 519	24489	25650	23895	26135
-X6/У8	Mammoth bone (3 rib fragments)	NSKA-891		Measurement error				
-X2/У3	Charcoal	NSKA-892		13854 ± 139	Rejected as too young			

Supplementary Information

Chronology and function of a new circular mammoth bone structure from Kostenki 11

Pryor, A.J.E., Beresford-Jones, D.G., Dudin, A.E., Ikonnikova E.M., Hoffecker, J. F., Gamble, C.S.

Archaeological context

Kostenki 11 (aka Anosovka 2) is located on the west bank of the Don River near the city of Voronezh in the Russian Federation at 51°23′08″ North 39°03′05″ East. It is one of 25 open-air Upper Palaeolithic sites—most of them multi-layered—found within and around the villages of Kostenki and Borshchevo (Klein, 1969, Praslov and Rogachev, 1982, Anikovich et al., 2008). Most of these sites are found at the mouth of large ravines incised into the west bank of the river, and Kostenki 11 occupies a spur at the confluence of two ravines (Anosov and Stranyi). The remains, including the mammoth-bone features, are buried in Aeolian and slope deposits that contain traces of soil formation (Lazukov, 1982: 27–29, Holliday et al., 2007: 209–212).

Kostenki 11 was discovered by A.N. Rogachev in 1951, but not subject to excavation until 1960–1965 when Rogachev exposed 150 m², including a mammoth-bone feature near the modern surface of the site in what is now known as layer Ia. Kostenki 11 is now known to contain seven or possibly eight archaeological levels, including layer Ib which lies stratigraphically above the mammoth-bone features found in layer Ia, and at least five lower layers (Rogachev and Popov, 1982, Dinnis et al., 2018).

Prior to survey work in 2013, two circular mammoth bone structures located 17 m apart were known from layer Ia (Popov et al., 2004, Rogachev and Popov, 1982). The first discovered structure was exposed completely and in order to preserve the feature *in situ*, Rogachev constructed a wooden building over the exposed feature in the 1960s, later replacing it in 1979 with a larger brick museum building that covers 720 m² of excavated occupation floor (Rogachev and Popov, 1982: 116–132; Popov *et al*., 2004; Anikovich *et al*., 2008: 32–35). The second structure has only been partially excavated over approximately one third of its area together with one large pit and the remainder now lies beneath modern buildings on private land.

The first (preserved) structure is c. 9 m in diameter and surrounded by five storage pits 1-2 m in diameter and c. 70 cm deep, all filled with mammoth bones. The area inside the mammoth bone circle is described as having been dug out to produce a level or horizontal floor surface inside the ring of mammoth bones (Anikovich et al., 2008: 208-202). The depth of this floor, from what is determined to have been the ground surface at the time of occupation, ranges from 56 cm in the west (upslope) to 30 cm in the east (downslope). 573 bones from at least 40 mammoth were identified in the vicinity of structure 2 (Popov et al., 2004). All body-parts of the mammoth are represented among the bones forming the circle, but bones scattered across the inner area are dominated by flat pelvic and shoulder blades, interpreted by the excavators as weights used to hold down a hide roof. Beneath these bones, contexts interpreted as a living floor 50 cm thick were excavated across the centre of the circle "full of kitchen leftovers, bone charcoal, split remnants of stones and individual stone and bone tools" (translated from Praslov and Rogachev 1982:123). No hearth was found inside the structure, although 65 burnt lithics were recovered in addition to 6 kg of burnt bone. The lithic assemblage inside the structure comprised 12,245 fragments including 263 cores, 412 tools, 566 flakes/blades and 774 microblades all belonging to the Zamyatnin techno-cultural complex (Rogachev and Popov, 1982). The total lithic assemblage recovered outside the structure comprised 902 lithics.

Another possible mammoth bone structure containing the same Zamyatnin lithic industry was also found at Kostenki 2, around 160m to the north of Kostenki 11 on the opposite bank of the Anosovka Ravine (Boriskovskii, 1959). However, the material was strongly affected by slope-wash processes that had redeposited the finds down slope and no link to the K11-1a deposits has ever been demonstrated.

Results

Dating – comparison to other sites

The oldest-known example of a mammoth bone structure dates to more than 44,000 ^{14}C years BP and was found during excavations at the Neanderthal Mousterian site of Molodova I layer 4, on the River Dniestr in Ukraine (Demay et al., 2012). A second possible structure is also known from the adjacent and stratigraphically equivalent deposits at Molodova V layer 11 (Klein, 1973:69-73). Virtually all other instances of mammoth bone structures are found on the Central Russian Plain along the Desna/Dnepr River systems and have been described collectively as the 'Mezinian' cultural grouping (Iakovleva, 2016, Iakovleva, 2015). More than 72 radiocarbon dates for these Mezinian sites span a period from 21,000 to 12,000 ^{14}C years BP, but the majority fall between 15,500-14,000 ^{14}C years BP and this is argued on climatic and stratigraphic grounds to be the most likely timeframe for activity at these sites (Iakovleva and Djindjian, 2005 and references therein, Iakovleva, 2016). Radiocarbon dates for Radomyshl' I of 19,000 and 19,600 demonstrate this site is a little older (Kononenko, 2015), while dates older than 20,000 BP from Mezin are exceptional, and have been discounted after re-dating or rejected outright due to laboratory errors (Iakovleva and Djindjian, 2005). The new dates from Kostenki 11-Ia therefore place it chronologically prior to the Mezinian mammoth bone constructions and to Radomyshl' I, and identify it as the oldest such structure associated with modern humans yet discovered on the Russian Plain.

Dating – calibration and internal site stratigraphy

The new dating results for charcoal (CURL 21043, CURL-21040, CURL-22804) and bones (NSKA-885, NSKA-886, NSKA-889, NSKA-890) were analysed using OxCal version 4.3 and the IntCal 13 atmospheric curve (Bronk Ramsey, 2009, Reimer et al., 2013). When the seven dates are modelled all together using the Combine function, which assumes the dated elements all derive from a single settlement phase shorter than a few hundred years, the results show poor agreement with an A_{comb} of just 11%. This problem can be resolved by separating the two youngest bone-based dates (NSKA-885 and 889) into a new group, producing an earlier 'bone-and-charcoal' grouping (5 dates) and a later 'bone-only' grouping (2 dates)(Figure S1; Table S1). It should be noted that the oldest radiocarbon date for the first structure at K11-Ia (GIN-2532), measured on burnt bone, shows poor internal agreement when modelled using OxCal's Combine function with group 1, but fits well with Group 2 (A_{comb} = 108.8%).

Figure S1: Plot produced in OxCal showing results of the Combine function analyses described in the text.

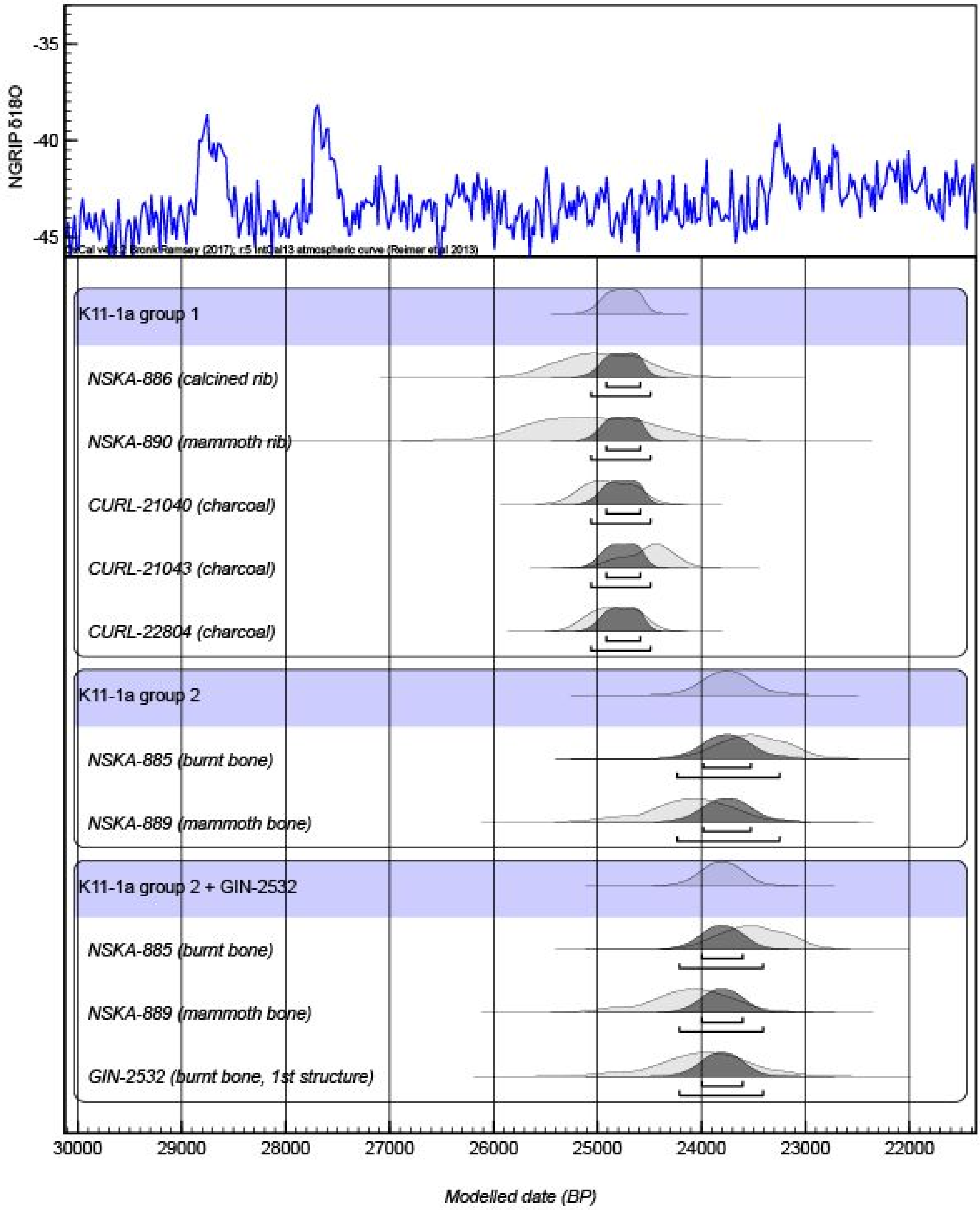


Table S1: Results produced by OxCal for the Combine function analysis.

Name	Unmodelled (BP)				Modelled (BP)				Indices	
	68.20%		95.40%		68.20%		95.40%			
	from	to	from	to	from	to	from	to	A_{comb}	A
Kostenki 11-Ia Group 1	24915	24587	25063	24490					107.4	
CURL-21040	25136	24621	25348	24424	24915	24587	25063	24490		113.8
CURL-21043	24707	24224	25007	24077	24915	24587	25063	24490		68.6
CURL-22804	25065	24575	25277	24399	24915	24587	25063	24490		108.6
NSKA-890	25650	24489	26135	23895	24915	24587	25063	24490		117.9
NSKA-886	25342	24533	25699	24214	24915	24587	25063	24490		117.3
Kostenki 11-Ia Group 2	23986	23525	24232	23249					91.9	
NSKA-889	24450	23670	25030	23337	23986	23525	24232	23249		94.1
NSKA-885	23820	23169	24121	22885	23986	23525	24232	23249		94.4
Kostenki 11-Ia Group 2 + GIN	23998	23604	24211	23409					108.8	
NSKA-889	24450	23670	25030	23337	23998	23604	24211	23409		104.8
NSKA-885	23820	23169	24121	22885	23998	23604	24211	23409		89
GIN-2532 (1st structure)*	24374	23529	24936	23095	23998	23604	24211	23409		124.2

* (Popov et al., 2004)

These new data may be interpreted in two ways. Taken at face value the new dates indicate at least two occupation phases at Kostenki 11-Ia, with an earlier phase focused around the 3rd mammoth bone structure and a later phase occurring approximately 1000 years later that included activity at both the 1st and 3rd structures. Alternatively, the new group 2 bone-based dates may reflect the incomplete removal of contaminants from the dated samples, a well-known problem with Palaeolithic bone-based radiocarbon dates (van der Plicht and Palstra, 2016, Higham et al., 2006). If the latter interpretation is accurate then only a single phase of occupation is needed to explain the results. It is not currently possible to distinguish between these possibilities on the basis of the dating evidence alone and further investigation of the possible phasing at the site is needed. However, we note that all the charcoal samples are in close agreement and align firmly with the group 1 bone-based dates. Five dates from charcoal and bone there give an unambiguous indication of human activity at the third mammoth bone structure between 25,063 and 24,490 cal years BP at 95.4% probability (modelled using the Combine function).

Spatial distribution maps

Figure S2: Graphical representation of lithic chip densities.

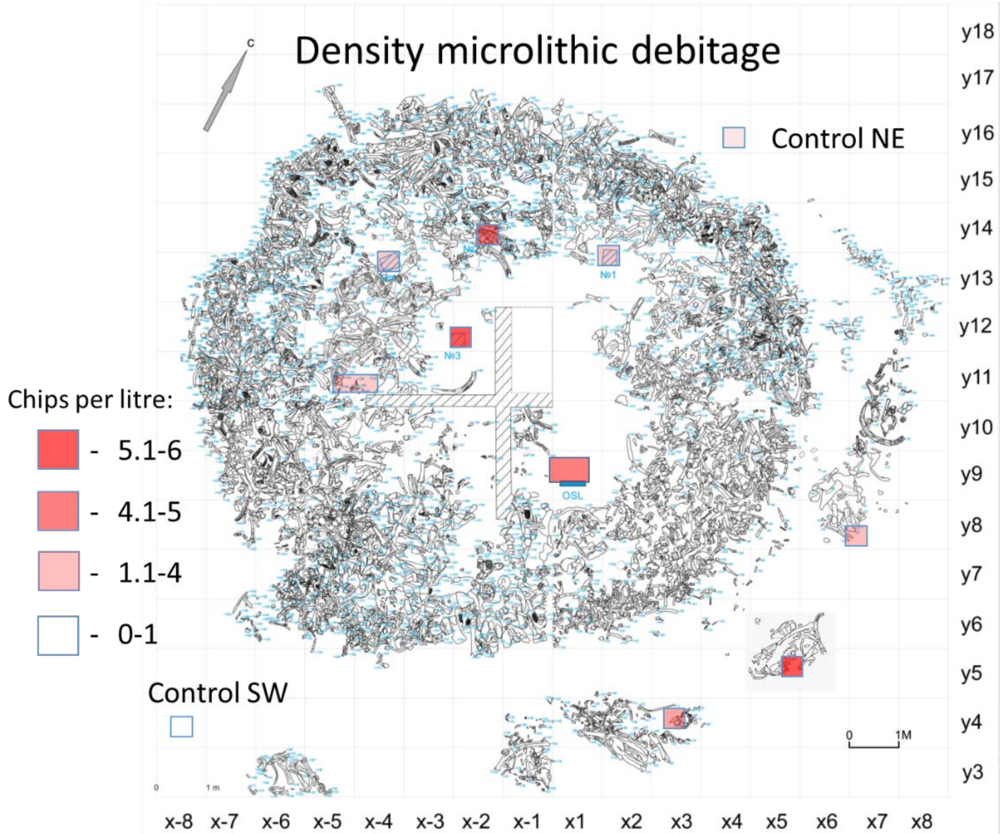


Figure S3: Graphical representation of burned bone fragment densities.

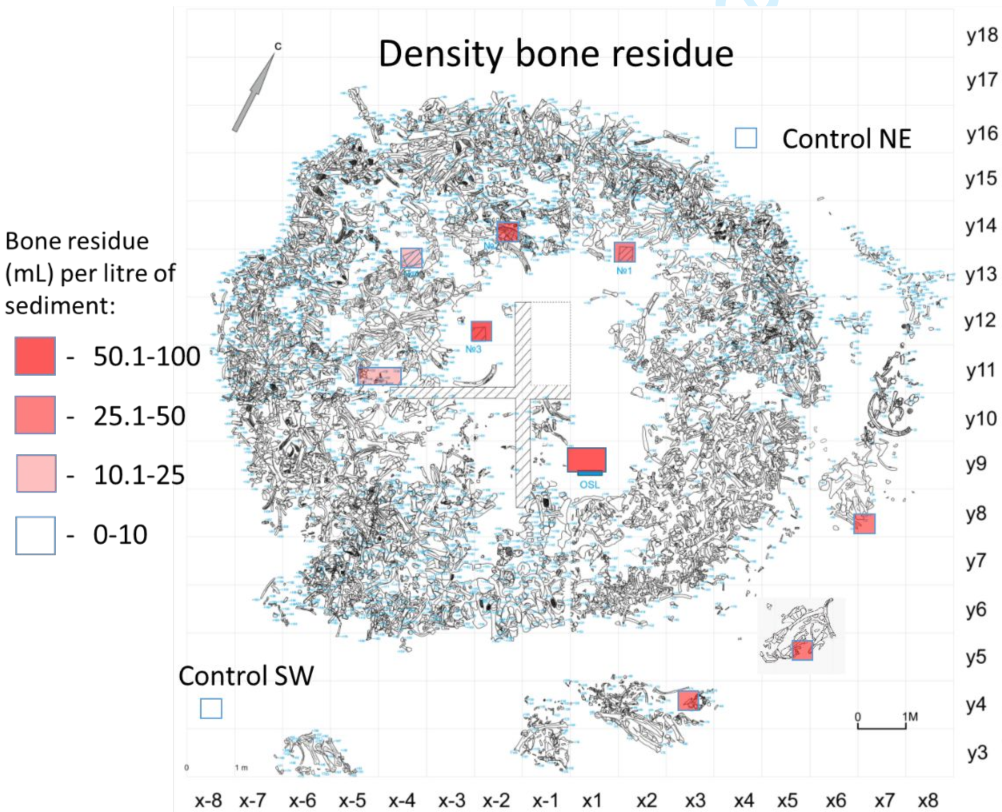
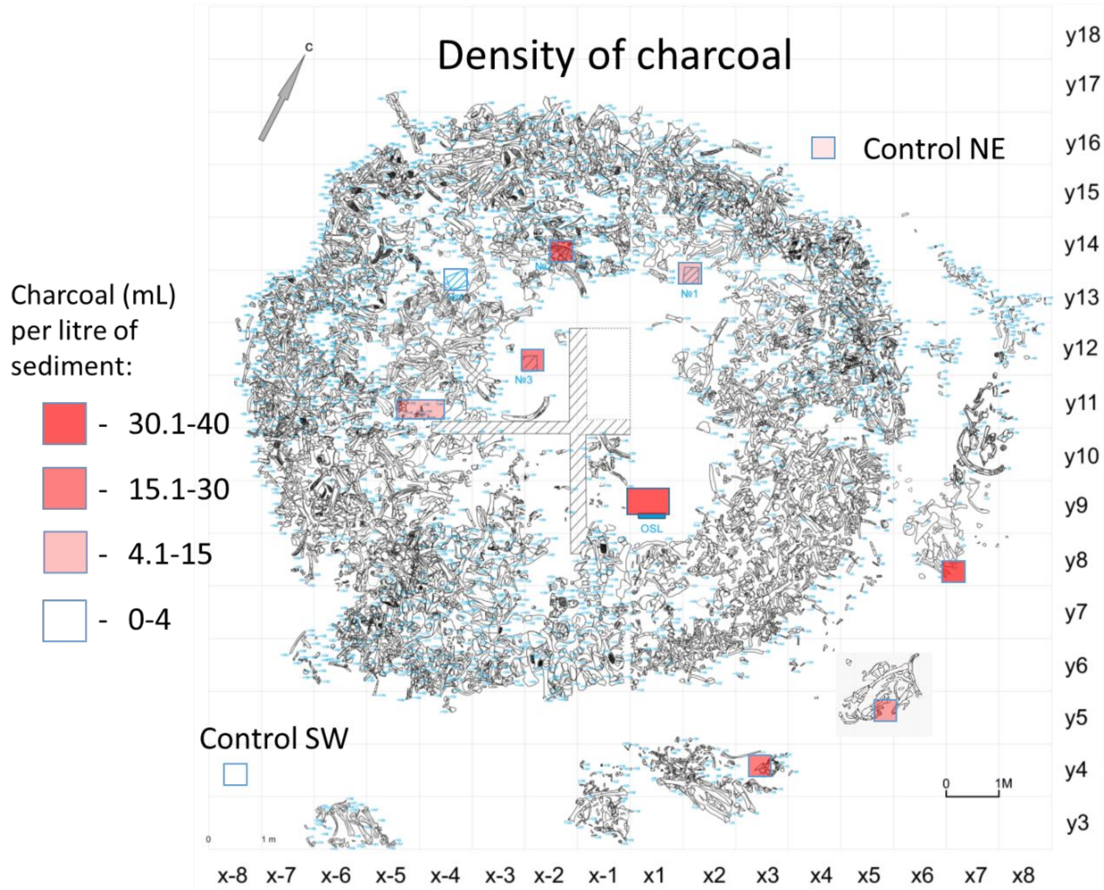


Figure S4: Graphical representation of charcoal densities.



Further images of the third circular mammoth bone structure at K11-Ia

Figure S5: Photograph taken from the museum roof, looking west towards the third mammoth bone structure. The two visible scales are 5m long each. Images taken July 2017. Image credit: A.E. Dudin.

Figure S6: Photograph looking north towards the third circular mammoth bone feature under excavation in summer 2015. Image credit: A.J.E. Pryor.

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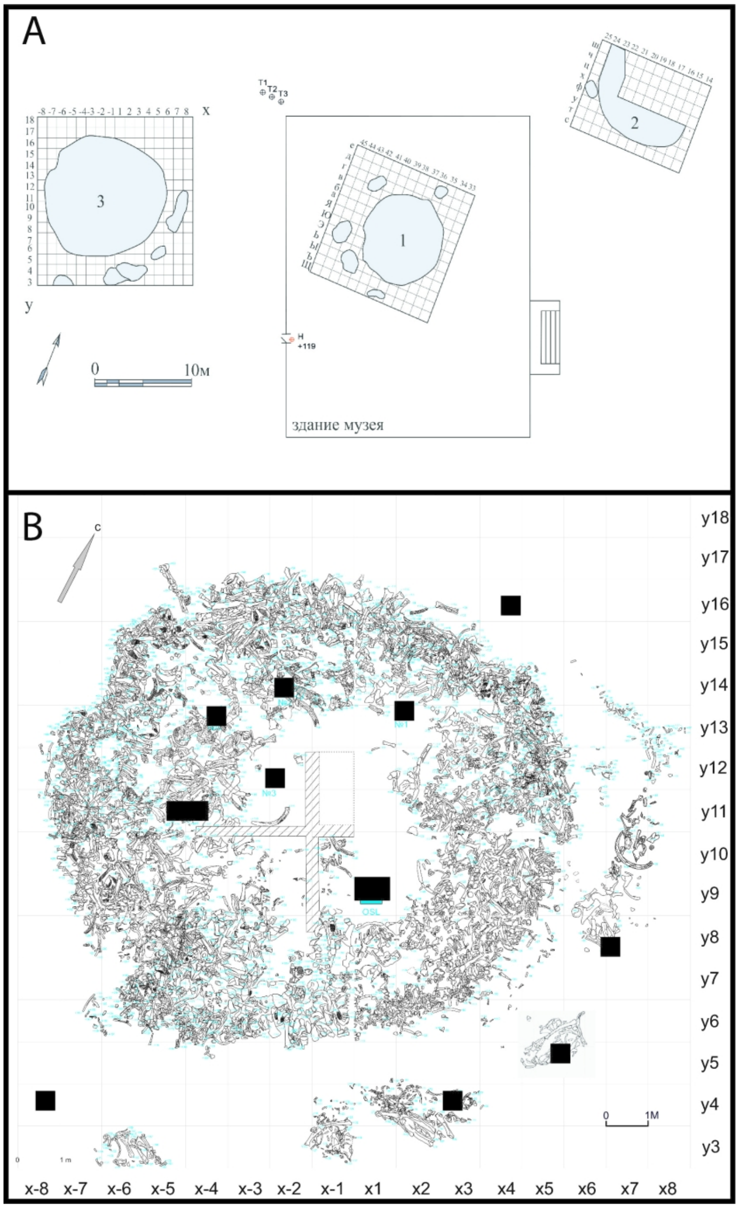
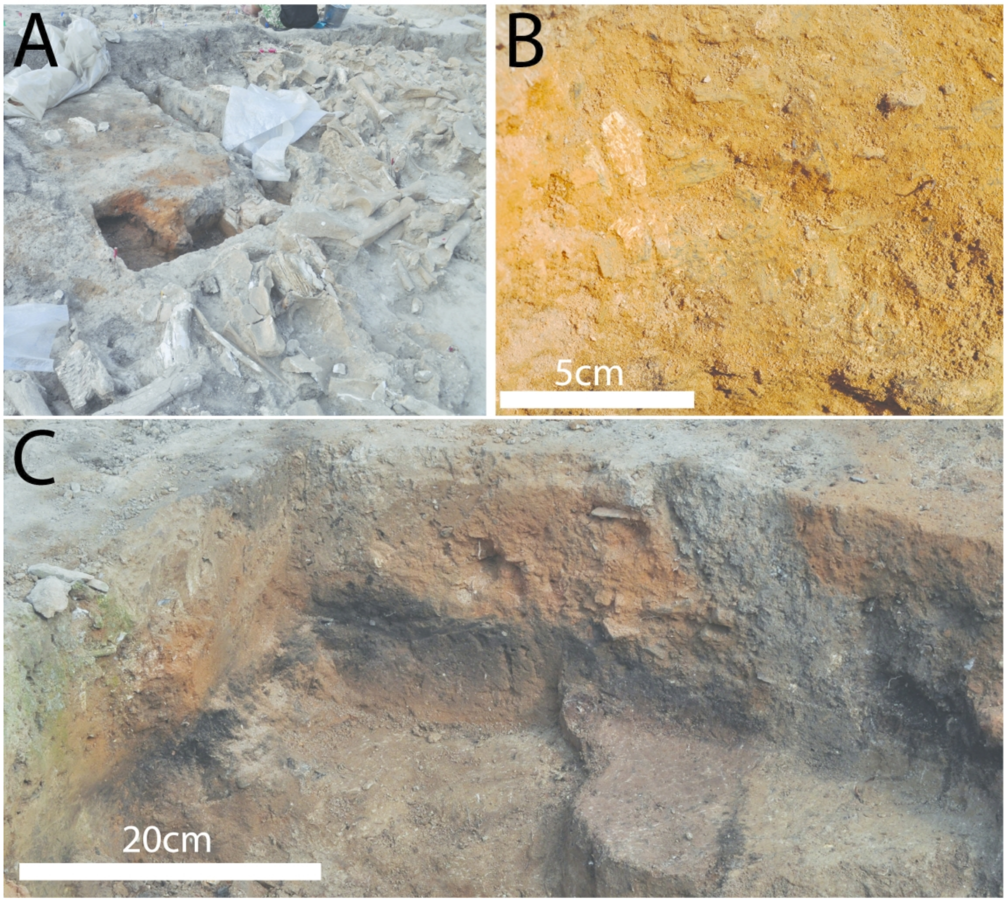


A) Relative locations of three mammoth bone features from Kostenki 11-Ia (Image credit: I.V. Fedyunin of LLC "Terra"). Feature 1 is preserved today in the Kostenki Museum.
B) Plan of the third mammoth bone structure as it appeared at the end of the 2015 excavation season. Sampling locations for floated sediments indicated by black rectangles.

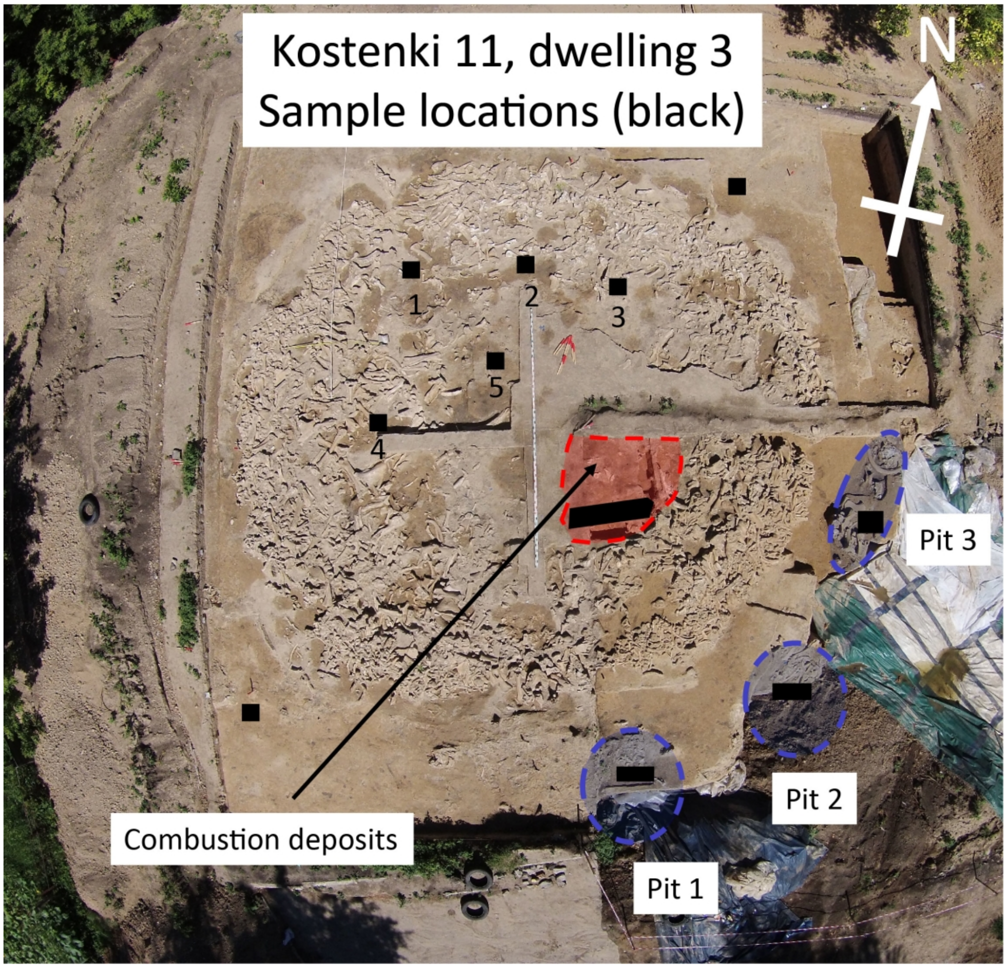
149x245mm (300 x 300 DPI)

Photograph taken from the museum roof in July 2017, looking north-west towards the third mammoth bone structure. The two visible scales are 5m long each. Image credit: A.E. Dudin.



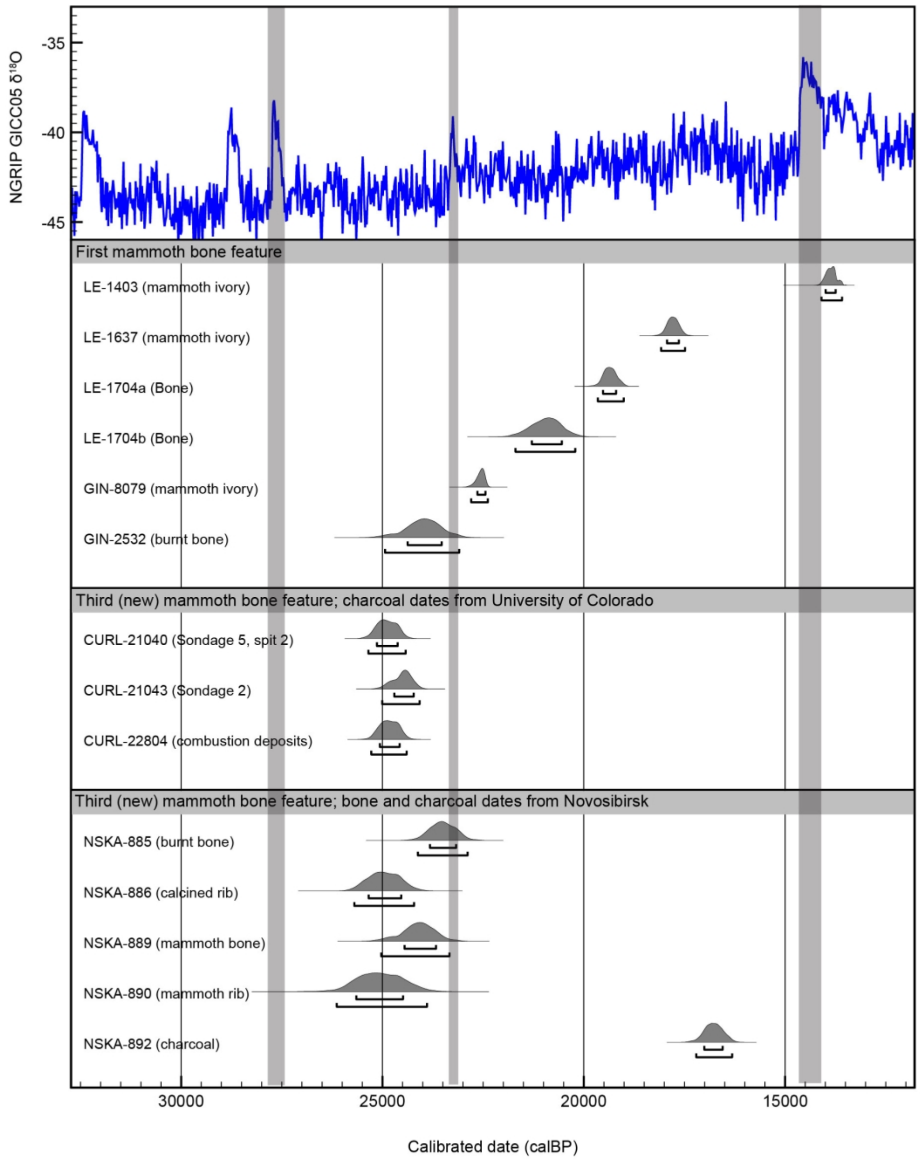
Images of the combustion deposits within the mammoth bone circle. A) View looking north towards the combustion deposits immediately prior to sample collection. B) Close-up of rubified layer showing densely packed charred bone fragments including white vitrified pieces. C) Cross-section of combustion feature part-way through excavation. The thick rubified layer overlies a thin black deposit that fades to sterile loess below. The pale sediments cutting through the rubified layer on the right hand side of the section result from animal burrowing. Just to the left of this a lithic is visible protruding from the section.

266x239mm (300 x 300 DPI)



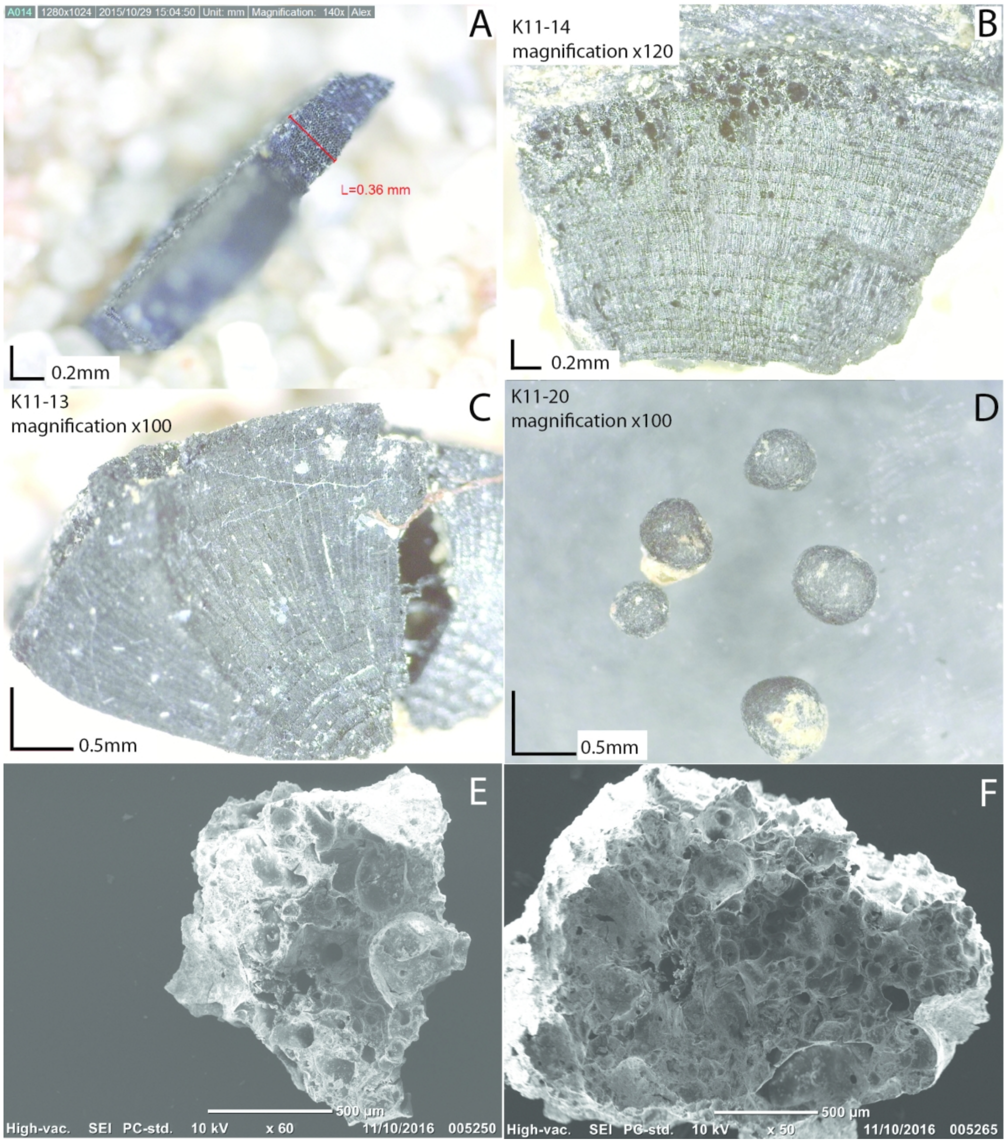
Aerial photograph of the new mammoth bone structure at Kostenki 11, taken using a drone during excavations in 2015 (image credit: A.Yu. Pustovalov and A.M. Rodionov). Location of the burnt deposits, pit features and sampling locations are shown.

198x190mm (300 x 300 DPI)



Old and new radiocarbon dates for Kostenki 11-Ia (Rogachev and Popov, 1982, Popov et al., 2004), calibrated in Oxcal version 4.3.2 using the IntCal13 calibration curve (Bronk Ramsey, 2009, Reimer et al., 2013). The δ18O curve from the NGRIP ice core is also shown. The new dates match closely with the oldest bone-based date measured on the first-discovered mammoth bone complex.

166x205mm (300 x 300 DPI)



Charred materials from Kostenki 11. A) Charcoal fragment a single growth ring wide; B) Most charcoal showed consistently narrow growth rings. In this fragment average ring width was 0.13 mm. C) Charcoal fragment with tight ring curvature deriving from the centre of the stem. Based on ring curvature the stem was at least 6 mm in diameter. D) Examples of seeds (currently unidentified). E and F) Scanning electron microscope images of charcoal fragments lacking cellular structure, tentatively identified as crushed soft plant tissue.

210x238mm (300 x 300 DPI)