[Supplementary material]

The chronology and function of a new circular mammoth-bone structure at Kostenki 11

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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 & 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: 209–12).

Kostenki 11 was discovered by A.N. Rogachev in 1951, but not subject to excavation until 1960–1965, when Rogachev exposed 150 m^2, 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 & 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 (Rogachev & Popov 1982; Popov *et al*. 2004). 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 m^2 of excavated occupation floor

(Rogachev & Popov 1982: 116–32; 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 approximately 9m in diameter and surrounded by five storage pits 1–2m in diameter and around 0.70m 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: 208–12). The depth of this floor, from what is determined to have been the ground surface at the time of occupation, ranges from 0.56m in the west (upslope) to 0.30m 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 0.50m 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 & Rogachev 1982: 123). No hearth was found inside the structure, although 65 burnt lithics were recovered in addition to 6kg 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 & 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). Slope-wash processes that had redeposited the finds down slope, however, heavily affected the material, 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 radiocarbon 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 2015, 2016). More than 72 radiocarbon dates for these Mezinian sites span a period from 21,000 to 12,000 radiocarbon years BP, but the majority fall between 15 500–14 000 radiocarbon years BP and this is argued on climatic and stratigraphic grounds to be the most likely timeframe for activity at these sites (Iakovleva & Djindjian 2005; Iakovleva 2016). Radiocarbon dates for Radomyshl' I of 19 000 and 19 600 BP 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 & 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 per cent. 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 (five 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%).

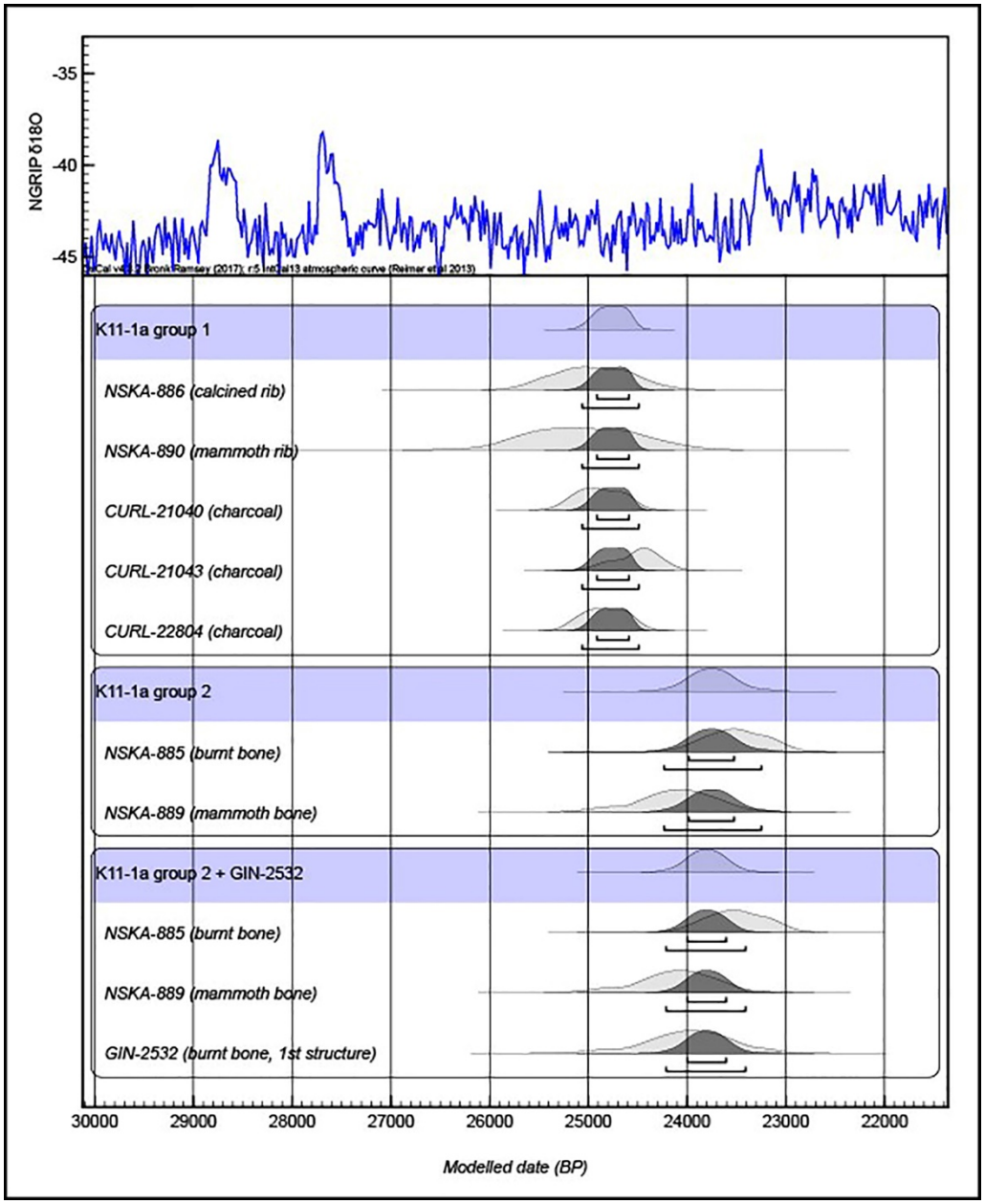

Figure S1. Plot produced in OxCal showing results of the Combine function analyses described in the text. Image prepared by A.J.E. Pryor.

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

Name	Unmodelled (BP)				Modelled (BP)				Indices	
	68.20% confidence		95.40% confidence		68.20% confidence		95.40% confidence			
	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 third mammoth-bone structure and a later phase occurring approximately 1000 years later that included activity at both the first and third 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 (Higham *et al*. 2006; van der Plicht & Palstra 2016). 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. We note, however, 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

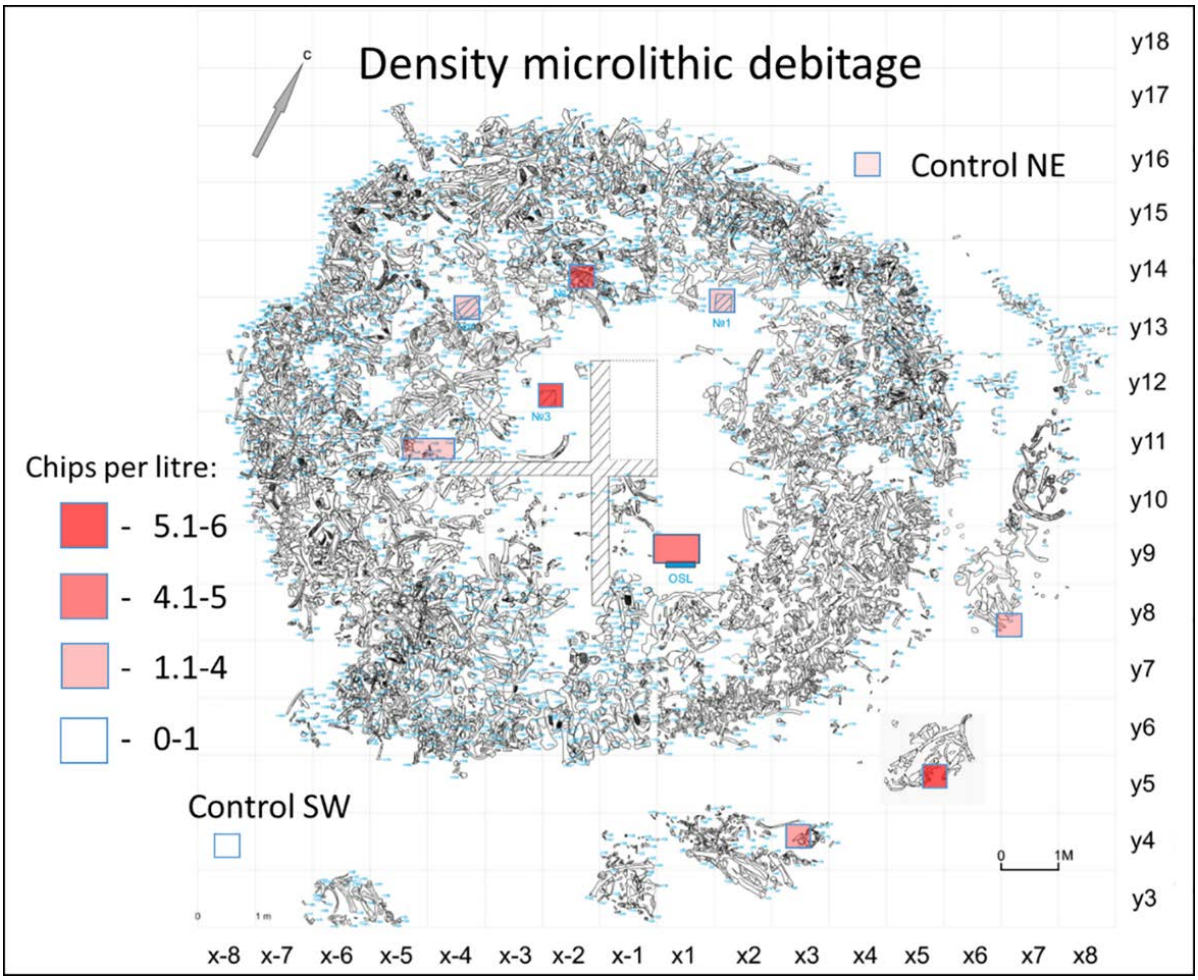

Figure S2. Graphical representation of lithic chip densities (plan by E.M. Ikonnikova & A.E. Dudin. Final image prepared by A.J.E. Pryor).

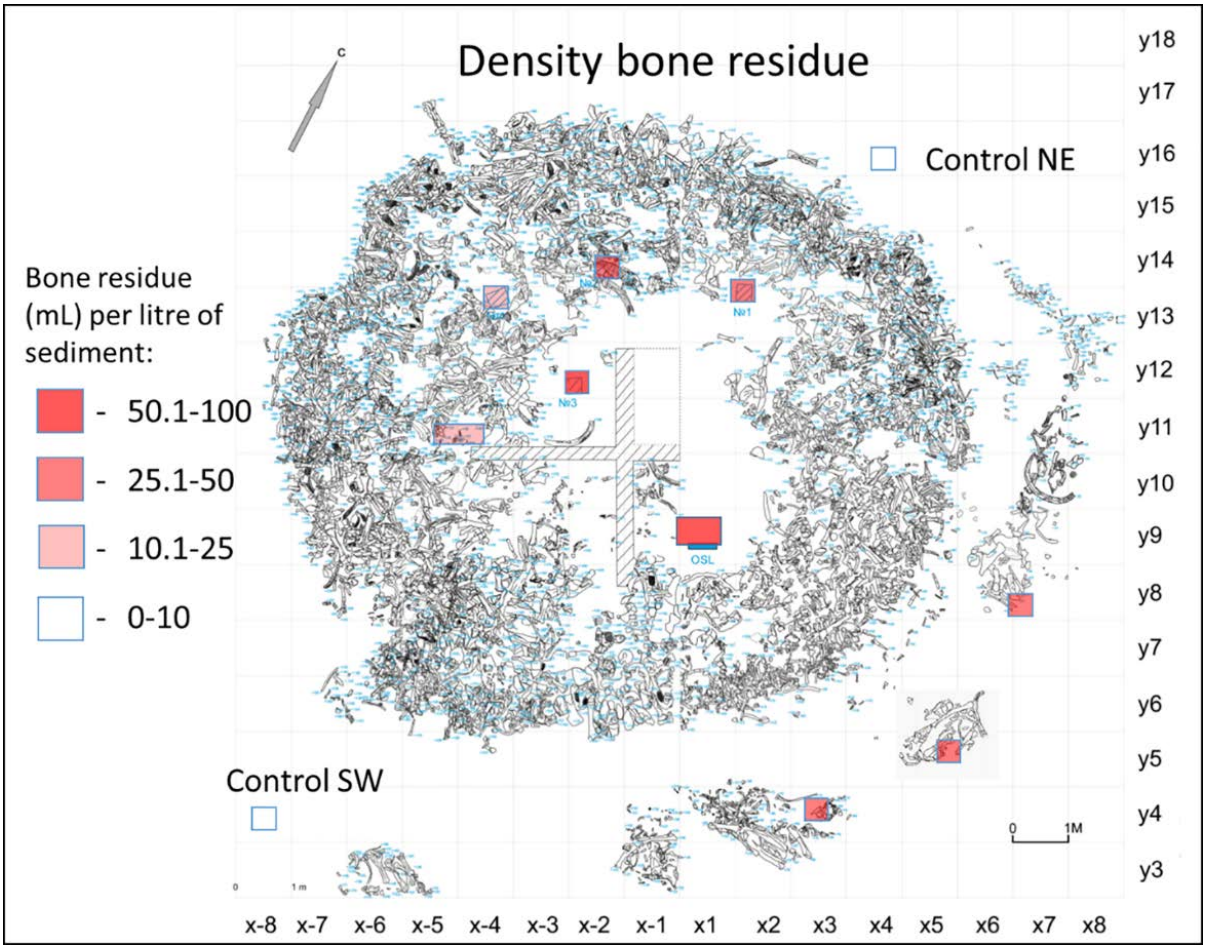

Figure S3. Graphical representation of burnt bone fragment densities (plan by E.M. Ikonnikova & A.E. Dudin; final image prepared by A.J.E. Pryor).

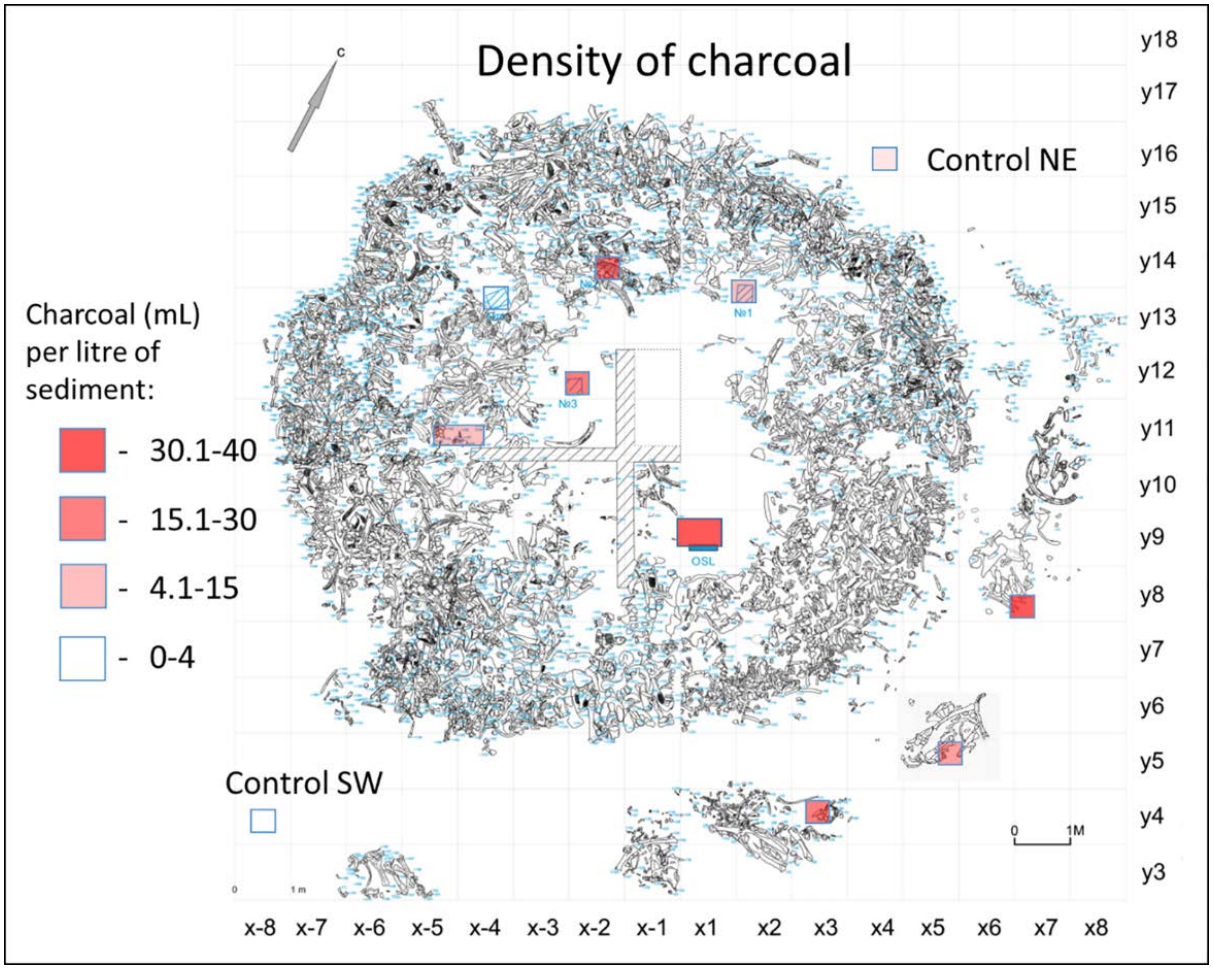

Figure S4. Graphical representation of charcoal densities (plan by E.M. Ikonnikova & A.E. Dudin; final image prepared by A.J.E. Pryor).

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. Image taken July 2017 (photograph: A.E. Dudin).

Figure S6. Photograph looking north towards the third circular mammoth-bone feature under excavation in summer 2015 (photograph: A.J.E. Pryor).

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