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► **To cite this version:**

Rob Dinnis, Alexander A Bessudnov, Natasha Reynolds, Thibaut Deviese, Abi Pate, et al.. New data for the Early Upper Paleolithic of Kostenki (Russia). *Journal of Human Evolution*, 2019, 127, pp.21-40. 10.1016/j.jhevol.2018.11.012 . hal-01982049

HAL Id: hal-01982049

<https://hal.science/hal-01982049>

Submitted on 15 Jan 2019

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Post-print of article published in Journal of Human Evolution:

Dinnis, R., Bessudnov, A. A., Reynolds, N., Devière, T., Pate, A., Sablin, M. V., Sinitsyn, A. A. & Higham, T. 2019. New data for the Early Upper Paleolithic of Kostenki (Russia). *Journal of Human Evolution* 127: 21–40. <https://doi.org/10.1016/j.jhevol.2018.11.012>

New data for the Early Upper Paleolithic of Kostenki (Russia)

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Abstract

Several questions remain regarding the timing and nature of the Neanderthal-anatomically modern human (AMH) transition in Europe. The situation in Eastern Europe is generally less clear due to the relatively few sites and a dearth of reliable radiocarbon dates. Claims have been made for both notably early AMH and notably late Neanderthal presence, as well as for early AMH (Aurignacian) dispersal into the region from Central/Western Europe. The Kostenki-Borshchevo complex (European Russia) of Early Upper Paleolithic (EUP) sites offers high-quality data to address these questions. Here we revise the chronology and cultural status of the key sites of Kostenki 17 and Kostenki 14. The Kostenki 17/II lithic assemblage shares important features with Proto-Aurignacian material, strengthening an association with AMHs. New radiocarbon dates for Kostenki 17/II of ~41–40 ka cal BP agree with new dates for the recently excavated Kostenki 14/IVw, which shows some similarities to Kostenki 17/II. Dates of ≥ 41 ka cal BP from other Kostenki sites cannot be linked to diagnostic archaeological material, and therefore cannot be argued to date AMH occupation. Kostenki 14's Layer in Volcanic Ash assemblage, on the other hand, compares to Early Aurignacian material. New radiocarbon dates targeting diagnostic lithics date to 39–37 ka cal BP. Overall, Kostenki's early EUP is in good agreement with the archaeological record further west. Our results are therefore consistent with models predicting interregional penecontemporaneity of diagnostic EUP assemblages. Most importantly, our work highlights ongoing challenges for reliably radiocarbon dating the period. Dates for Kostenki 14 agreed with the samples' chronostratigraphic positions, but standard pre-treatment methods consistently produced incorrect ages for Kostenki 17/II. Extraction of hydroxyproline from bone collagen using prep-HPLC, however, yielded results consistent with the samples' chronostratigraphic position and with the layer's archaeological contents. This suggests that for some sites compound-specific techniques are required to build reliable radiocarbon chronologies.

Keywords: Early Upper Paleolithic; Anatomically modern humans; Radiocarbon dating; Kostenki; Eastern Europe; Bladelet technology

Introduction

Due to the overall paucity of diagnostic skeletal remains, the timing and nature of anatomically modern human (AMH) dispersal into Europe and the demise of Neanderthals is reconstructed largely via archaeological proxies, with different archaeological assemblage types taken to represent biologically distinct populations (e.g., Higham et al., 2014; Hublin, 2015; Kadowaki et al., 2015; Roussel et al., 2016; Teyssandier and Zilhão, 2018). The biological transition is broadly coeval with the appearance of Early Upper Paleolithic (EUP: ~37–30 ka BP¹; ~42–34 ka cal BP) assemblages, while preceding European Late Middle Paleolithic (LMP) assemblages are generally accepted as being made by Neanderthals.

The earliest assemblages generally agreed to be of AMH authorship are Proto- and Early Aurignacian (Zilhão, 2013; Higham et al., 2014; Nigst et al., 2014; Benazzi et al., 2015; Hublin, 2015; Kadowaki et al., 2015; Roussel et al., 2016; Teyssandier and Zilhão, 2018). The chronology of sites dating to this period is still the subject of active research, but broadly appears to fit the periods ~41–39 ka cal BP for Proto-Aurignacian and ~39–36 ka cal BP for Early Aurignacian sites (using IntCal13; Supplementary Online Material [SOM] S1, Fig. S1 and Table S1; Jöris and Street, 2008; Banks et al., 2013a,b; Wood et al., 2014).

Proto-Aurignacian lithic assemblages are characterized by: fully Upper Paleolithic blade(let) production (i.e., with platform abrasion and marginal percussion) employing unipolar strategies; production of relatively light blades; a strong emphasis on the production of large bladelets with straight or only slightly curved profiles; and a retouched bladelet assemblage characterized by marginal retouch, including examples of alternate/ventral retouch (i.e., Dufour subtype Dufour bladelets). These bladelets are thought to have served as

¹ Radiocarbon determinations are reported as conventional radiocarbon ages 'BP', with BP representing before 1950 AD. Calibrated radiocarbon ages are reported as ages 'cal BP'. We used OxCal 4.3 (Bronk Ramsey, 2009) and the IntCal13 calibration curve to calibrate the radiocarbon ages (Reimer et al., 2013).

component parts of hunting equipment (Broglia et al., 2005; O'Farrell, 2005; Normand et al., 2009), marking a tangible behavioral difference from preceding assemblages (Teyssandier and Zilhão, 2018). Early Aurignacian lithic assemblages differ from Proto-Aurignacian primarily in the prevalence of blades bearing heavy Aurignacian retouch, including strangulated/notched types, and the presence of smaller modified bladelets with curved but generally untwisted profiles, found in association with their parent wide-faced carinated cores.

Beyond the general consensus that Proto- and Early Aurignacian assemblages were created by AMHs, much remains unclear about how and when Neanderthal extinction and initial AMH occupation occurred. Substantial disagreements exist over: a) the attribution to AMH or Neanderthals of earlier or penecontemporary assemblages (Bohunician, Uluzzian, Châtelperronian, Streletskian, Spitsynian: Anikovich et al., 2007; Hoffecker, 2009; Benazzi et al., 2011; Müller et al., 2011; Zilhão, 2011; Hublin, 2015; Hoffecker et al., 2016; Vishnyatsky, 2016; Bataille, 2017); b) the validity of particular artifacts as markers of specific archaeological assemblages (and, by extension, of AMHs/Neanderthals; e.g., Slimak et al., 2011; Zwyns et al., 2012; Nigst et al., 2014; Moreau et al., 2015; Teyssandier and Zilhão, 2018); and the association of dated samples with diagnostic material (e.g., Nigst et al. 2014; Teyssandier and Zilhão 2018).

A more fundamental disagreement concerns the observability of directions and dynamics of dispersals from archaeological proxies given the current resolution of our chronometric methods. For some, the origins and spread of specific cultural phenomena are evident from the data (e.g., Higham et al., 2012, 2013; Nigst et al., 2014; Davies et al., 2015), while for others such perceived origins and spreads instead result from inconsistent and sometimes plainly erroneous data (e.g., Banks et al., 2013a,b; Teyssandier and Zilhão, 2018). The ongoing problems with accurately radiocarbon dating the period 50–30 ka cal BP lie at the

root of much of this debate (Higham 2011; Alex et al., 2017; Devièse et al., 2017; this paper). To address these issues, further reliable archaeological and chronometric data are needed, especially for regions whose archaeological records are less well understood. The present study tackles these outstanding questions with new work on the EUP of Eastern Europe.

The Neanderthal-AMH transition in Eastern Europe

Despite its position adjacent to putative routes of AMH dispersal into Europe, the timing and dynamics of the Neanderthal-AMH transition in Eastern Europe are currently particularly unclear. A paucity of sites on the East European Plain is compounded by serious problems with the radiocarbon chronologies of key sites and sequences (Dambon et al., 1996; Sinitsyn, 1996; Sinitsyn et al., 1997; Douka et al., 2010; Demidenko and Noiret, 2012a; Marom et al., 2012). Additionally, uncertainty surrounds the Streletskian, which includes assemblages seen as representing a ‘transitional’ industry of Eastern Europe (Vishnyatsky, 2016; Dinnis et al., 2018). Most researchers consider all Streletskian assemblages as indicators of AMHs, either directly (Vishnyatsky and Nehoroshev, 2004; Anikovich et al., 2007; Kozłowski, 2014; Otte, 2014; Hoffecker et al., 2016; Vishnyatsky, 2016) or through acculturation of Neanderthals by incoming AMHs (Anikovich, 1999; Cohen and Stepanchuk, 1999). However, early Streletskian sites contain no human skeletal evidence to support either premise.

Long-lasting Neanderthal refugia have been suggested for several areas. Slimak et al. (2011) argued for Neanderthal presence close to the Arctic Circle at ≤ 34 ka cal BP based on the perceived LMP nature of the Byzovaya lithic assemblage, although for Zwyns et al. (2012) the assemblage falls within the range of variation of the Streletskian and therefore does not indicate Neanderthal presence. To the south, claims for refugia in the Caucasus and Crimea (Ovchinnikov et al., 2000; Chabai, 2003) have been contradicted by more recent work (Adler et al., 2006, 2008; Jöris et al., 2011; Pinhasi et al., 2011).

At the same time, claims have been made for early AMH occupation, based largely on evidence from the Kostenki-Borshchevo site complex in the Middle Don region. Various EUP assemblages at Kostenki have been argued to mark AMH presence prior to 40 ka cal BP (Anikovich et al., 2007; Zwyns et al., 2012), although skeletal evidence to support this is sparse, fragmentary and ambiguous (Boriskovskii et al., 1982; Goebel, 2007; Zilhão, 2011; Sinitsyn, 2016a). If AMH authorship of all Streletskian assemblages is accepted, then recent radiocarbon dates for Layer V of Kostenki 1 (Haesaerts et al., 2017) ostensibly push AMH occupation at Kostenki back to ~45 ka cal BP (but see Discussion, below). With reference to more secure archaeological proxies, Hoffecker et al. (2016) have argued that AMHs using Aurignacian technology appeared later in Eastern Europe than in Central/Western Europe, with Proto-Aurignacian/Aurignacian assemblages from Kostenki and Siuren I (Crimea) representing an eastward dispersal.

Kostenki-Borshchevo

The Kostenki-Borshchevo complex (Voronezh region, Russia) includes numerous multilayered Upper Paleolithic sites and large archaeological assemblages, and offers a unique record of the Eastern European EUP. Nine of Kostenki-Borshchevo's 26 Upper Paleolithic sites have yielded at least one convincing EUP layer: Kostenki 1, 6, 8, 11, 12, 14, 17, and Borshchevo 4 and 5. The sites are positioned within and around a series of ravines that cut a chalk plateau meeting the western edge of the floodplain of the Don River (Fig. 1). The geological context of the Kostenki-Borshchevo archaeological deposits has been subject to considerable research and is now generally well understood (Rogachev, 1957; Lazukov, 1982; Holliday et al., 2007; Velichko et al., 2009; Sedov et al., 2010; Sinitsyn, 2014; Hoffecker et al., 2016). EUP material is found within, and between, two paleosol complexes: the Lower Humic Bed (LHB) and the stratigraphically higher Upper Humic Bed (UHB). At

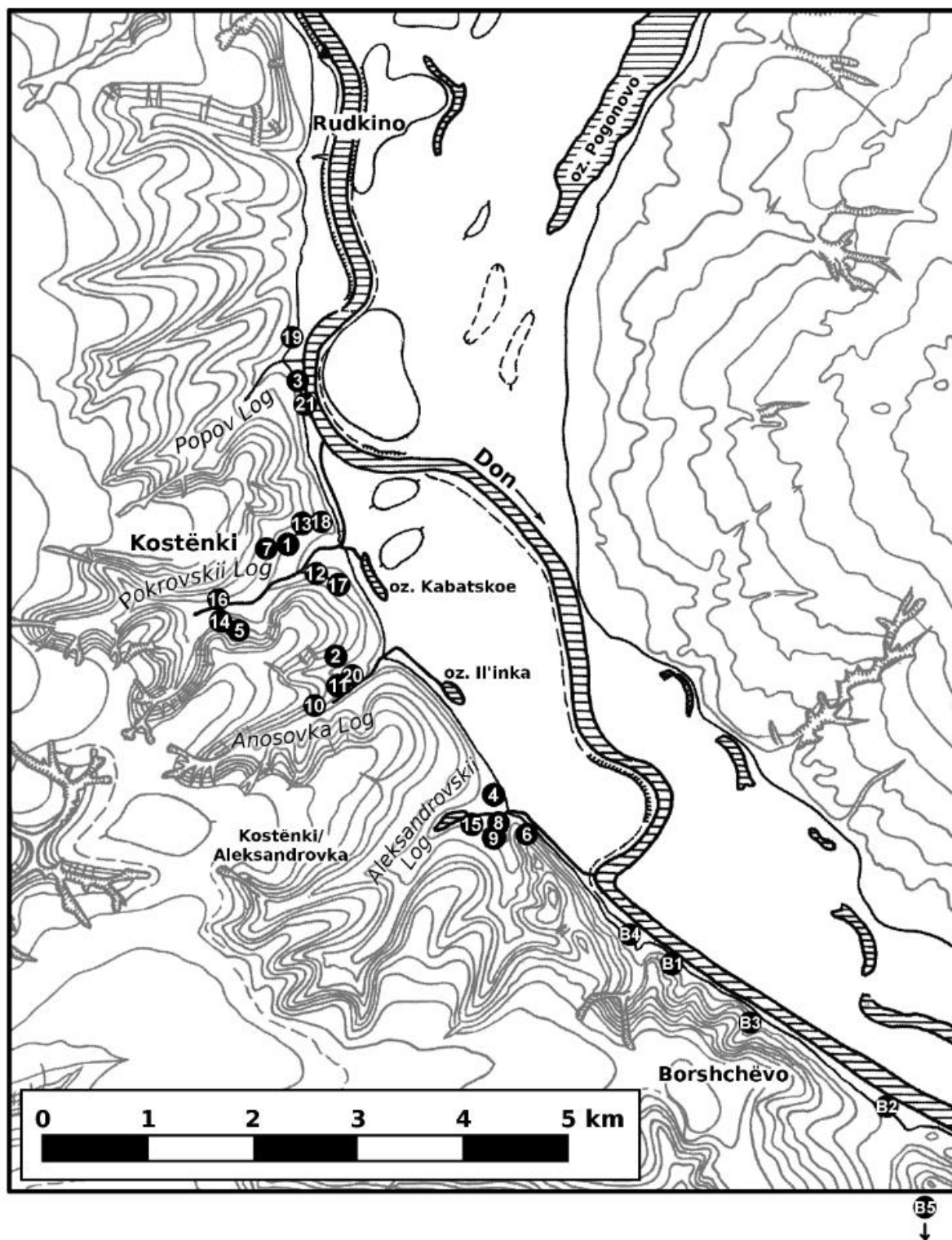


Figure 1. Location of the different sites within the Kostenki-Borshchevo complex. The Kostenki sites are marked as 1–21 and the Borshchevo sites as B1–B5.

some sites these paleosol complexes are separated by a layer containing lenses or concentrations of volcanic ash. This has been identified as the Campanian Ignimbrite (CI)/Y5 tephra, now dated according to a combined series of radiocarbon dates on charcoal to $34,290 \pm 90$ BP, or $\sim 39\text{--}38.5$ ka cal BP using IntCal 13 (Pyle et al., 2006; Giaccio et al., 2017).

The nature of the CI tephra differs between sites and between different areas of each site. At some sites it is visible to the naked eye as sometimes-large lenses (e.g., Kostenki 17, 6 and 14 (Praslov and Rogachev, 1982), whereas at others it is present as concentrations of ash visible only with the aid of microscopy (e.g., Kostenki 1 [Anikovitch/Dudin excavations]; Hoffecker et al., 2016). In some cases, most notably at Kostenki 6, the ash has clearly been redeposited (Rogachev, 1957). However, there is currently little to suggest that such processes have created inverted archaeological stratigraphies. The CI tephra therefore provides a crucial chronological marker. This is especially important because, despite the preservation of abundant bone and charcoal, successfully radiocarbon dating the Kostenki complex of sites has proved challenging (e.g., Damblon et al., 1996; Sinitsyn et al., 1997; Douka et al., 2010; Marom et al., 2012; Wood et al., 2012; Haesaerts et al., 2017; Reynolds et al., 2017).

Kostenki-Borshchevo therefore has the potential to provide high-resolution and, most importantly, verifiable radiocarbon chronologies. Furthermore, the presence of multiple sites means that the highest quality layers and areas can be targeted for analysis. This provides opportunities to circumvent the problems of mixing and/or ambiguity of archaeological material that exist at many EUP sites. Such high-quality data can help address not only questions regarding the timing of appearance of AMH-related archaeological material on the East European Plain, but also the fundamental issue of whether EUP cultural phenomena can be expected to display chronological clines between sites and regions. With these aims in

mind, we undertook a new technotypological and chronometric analysis of Kostenki-Borshchevo's most important EUP sites.

Early EUP assemblages at Kostenki 17, Kostenki 14 and Kostenki 1

Kostenki-Borshchevo's oldest EUP layers can be separated into those including retouched bladelets (or evidence for bladelet manufacture) and those characterized by Streletskian bifacial technology (Praslov and Rogachev, 1982; Anikovich, 1992, 2002; Bradley et al., 1995; Brantingham et al., 2004; Anikovich et al., 2007; Sinitsyn, 2014). Given the problematic nature of Kostenki's early Streletskian assemblages (see Discussion, below), the earliest assemblages that can be reasonably argued to have been created by AMHs are those with retouched bladelets from the sites of Kostenki 14, Kostenki 1 and Kostenki 17.

Kostenki 17 The main excavations at Kostenki 17 were undertaken by P.I. Boriskovskii in 1953 and 1955 (Boriskovskii, 1963; Boriskovskii et al., 1982; Fig. 2). Boriskovskii discovered two archaeological layers: the stratigraphically higher Layer I, positioned in the UHB; and the underlying and archaeologically richer Layer II, found in the top of the LHB, ~6 m below the modern-day surface. Layer II was stratigraphically separated from Layer I by ~3 m of archaeologically sterile deposits. Within these sterile deposits, roughly halfway between Layers I and II, was a layer containing lenses of volcanic ash. Boriskovskii excavated Layer II over an area of 60 m² (Boriskovskii, 1963). Small areas of the archaeological layer or contemporary deposits have been excavated since then (Rogachev, 1963; Praslov et al., 1980; Bessudnov, 2008), most recently in 2017–2018 by one of us (A.B.; Bessudnov et al., 2018). However, Boriskovskii's collection still constitutes ~90% of the archaeological material excavated from this layer.



Figure 2. Excavation of Kostenki 17/I in 1953. Photo: Institute for the History of Material Culture, Russian Academy of Sciences (IIMK RAN), archive reference O.1958-67.

Finds in Layer II were generally limited to a gently sloping 20–30 cm-thick horizon (Boriskovskii, 1963; Velichko, 1963). Boriskovskii (1963) and Velichko (1963) both considered the layer's contents to be mostly in situ, and subject to only minor downslope redeposition. The layer's lithic assemblage appeared unrolled and unweathered, and contained very small chips as well as larger pieces. In some places the layer was stained with red ocher, and concentrations of charcoal and ash in the NE and SW corners were interpreted as remnants of two hearths >1 m in diameter, around which lay concentrations of archaeological material. In the central part of the trench were horse vertebrae and limb bones in anatomical position (Boriskovskii, 1963; Boriskovskii et al., 1982).

Boriskovskii recovered a large lithic assemblage of ~10,000 pieces (Table 1), as well as a modest osseous tool assemblage of two awls made from arctic fox (or hare) ulnae and several fragmentary bone/ivory objects. The abundance of archaeological material within a relatively small excavated area led Boriskovskii (1963) to interpret the layer as evidence for a long-term settlement. Given the assemblage's size it may well represent a palimpsest of multiple phases of activity. Boriskovskii also found pendants made from fossil shells, carved stone and belemnites, along with a group of 37 fox canines perforated by rotary biconical drilling (SOM Files S1 and S2; Boriskovskii, 1963; Boriskovskii et al., 1982). The faunal assemblage comprised wolf, mammoth, horse, reindeer, bison and wolverine, with arctic fox represented by 37 pendants (Vereshagin and Kuz'mina, 1977; Boriskovskii et al., 1982). A single human molar found in the layer was tentatively attributed to *Homo sapiens* (Boriskovskii et al., 1982; Gerasimova et al., 2007), but it has never been the subject of complete study and for some researchers it is undiagnostic (e.g., Goebel, 2007; Zilhão, 2011).

Kostenki 17/II is usually referred to as 'Spitsynian', after the site's alternative name, Spitsynskaia. The only other assemblage to have frequently been described as Spitsynian is Layer II of Kostenki 12 (Anikovich, 1992; Anikovich et al., 2008; but see Sinitsyn, 2014). The use of this locally specific taxon highlights the historic difficulty of finding parallels for the assemblage outside Kostenki. Early comparisons (Chernysh, 1959; Boriskovskii, 1963) were made with assemblages now known to be much younger. Due to a perceived prevalence of heavily retouched blades, Grigor'ev (1968) and later Anikovich (2000; Anikovich et al., 2008) saw similarities with Aurignacian assemblages. However, it is important to note that when making this comparison the latter authors relied heavily on the small assemblage from Kostenki 12/II, which in our view is a mixed assemblage that probably includes Aurignacian artifacts. Boriskovskii's (1963) description of the Kostenki 17/II assemblage does not suggest the presence of aggressive, scaled/stepped Aurignacian-type edge retouch. Other researchers

saw similarities to Gravettian material in the Kostenki 17/II assemblage, and suggested that the earlier age of Kostenki 17/II meant it represented the ancestor of later Gravettian assemblages (Kozłowski, 1986). More recently, Hoffecker and Holliday (2014) have referred to the assemblage as ‘Proto-Gravettian’, suggesting it represents a dispersal of AMHs into Eastern Europe different from, but broadly coeval with, an AMH Proto-Aurignacian dispersal around the Mediterranean. Others have stressed the lack of diagnostic elements that allow Kostenki 17/II to be described as either Aurignacian (e.g., Sinitsyn, 1997; Kozłowski and Otte, 2000; Demidenko, 2004; Vishnyatsky and Nehoroshev, 2004; Monigal et al., 2006; Usik et al., 2006) or Gravettian (Sinitsyn, 1997; Anikovich, 1992, 2000; Anikovich et al., 2008).

Despite these disagreements, the Kostenki 17/II assemblage is usually seen as evidence for AMHs at Kostenki; however, as Zilhão (2011) has argued, further evidence beyond its Upper Paleolithic nature is needed to warrant this conclusion. The position of Layer II below the CI tephra implies an age older than 39–38.5 ka cal BP (CI tephra = $34,290 \pm 90$ BP following Giaccio et al., 2017), but radiocarbon dates for the layer are either inconsistent with this or inconclusive (Table 2). One bone produced a date of $32,780 \pm 300$ BP (LE-1436; i.e., younger than the tephra), while two dates from charcoal overlap with the tephra age but have notably large standard errors: $32,200 \pm 2000/1600$ BP (GrN-10512) and $36,780 \pm 1700/1400$ BP (GrN-12596).

Kostenki 14 and Kostenki 1 Early EUP archaeological assemblages with retouched bladelets have also been found at the better-known sites of Kostenki 14 and Kostenki 1.

As at Kostenki 17/II, the lowest layers of Kostenki 14 have been found within the LHB. Layer IVb is found in the eastern part of Kostenki 14. It comprises archaeological material deposited on the sloping sides of a paleogully and in the gully’s base. The layer contained Upper Paleolithic lithic and osseous tool assemblages, a series of perforated shells, and a

single human tooth, thought to be AMH (Sinitsyn, 2016a). Recently published dates for Layer IVb of ~36.5–34 ka BP (Douka and Higham, 2017) are consistent with the material's chronostratigraphic position beneath the CI tephra.

On the western side of Kostenki 14 the lowermost identified archaeological layer is Layer IVw (the 'w' refers to its western location). During its 2010–2015 excavation it was subdivided into IVw1 and the stratigraphically lower IVw2, which in some places were separated by a thin sterile layer and elsewhere were directly superimposed on one another, but are thought to reflect the same occupation horizon. Layer IVw2 is interpreted as the in situ remains of settlement activity, and Layer IVw1 as containing material that has been displaced downslope. Evidence for the undisturbed nature of Layer IVw2 includes a series of hare hindlimb bones found in anatomical position (Fig. 3). Layer IVw has yielded a series of pendants made from marine and freshwater mollusc shells and a lithic assemblage of ~3,000 pieces, including retouched bladelets. Although the lithic collection awaits full study, initial observations suggest some similarities with Kostenki 17/II (explained in Results, below).

Another layer at Kostenki 14, the Layer in Volcanic Ash (henceforth LVA), is stratigraphically higher than Layer IVw. Archaeological material in this layer has been subject to variable levels of postdepositional downslope displacement. Despite its apparent association with the CI tephra ($=34,290 \pm 90$ BP following Giaccio et al., 2017), published radiocarbon dates for the layer range from 20–35 ka BP (Table 3). Kostenki 14/LVA's small lithic assemblage contains diagnostically Aurignacian retouched bladelets, including Dufour bladelets (Sinitsyn, 2003). The retouched bladelets are 1–3 cm long and have curved but generally untwisted profiles. This kind of bladelet is typical of Early Aurignacian assemblages elsewhere in Europe (Pelegrin and O'Farrell, 2005; Le Brun-Ricalens et al., 2005; Michel, 2010; Chiotti et al., 2015; Bourrillon et al., 2017; Teyssandier and Zilhão, 2018).



Figure 3. 2015 excavation of Kostenki 14/IVw2 (top) and close up of articulated hare hindlimb bones (bottom).
Photos: A. Sinitsyn.

The Kostenki 14/LVA retouched bladelets are similar in their size and morphology to those from the Aurignacian assemblage of Kostenki 1/III (Sinitsyn, 1993, 2003), which was found within, and beneath, a buried soil that correlates to the UHB (Rogachev, 1957; Hoffecker and Holliday, 2014; Hoffecker et al., 2016). The Kostenki 1/III assemblage is larger than the Kostenki 14/LVA assemblage and contains carinated-scrapers with

debitage faces sufficiently wide that bladelets produced were not systematically twisted (Fig. 4). It also contains pieces bearing heavy Aurignacian-type retouch, including one typical strangulated blade (Hahn, 1970; Sinitsyn, 1993; Fig. 4, bottom left). These features are characteristic of Early Aurignacian assemblages (Chiotti, 2005; Teyssandier and Zilhão, 2018).

Materials and methods

In order to revise the chronology of Kostenki's EUP retouched bladelet assemblages, we undertook new radiocarbon dating of Kostenki 17/II, Kostenki 14/IVw and Kostenki 14/LVA. We also undertook a new analysis of the Spitsynian lithic assemblage from Kostenki 17/II, to clarify its status as different from other known EUP assemblages. We focused particularly on the layer's retouched bladelets because these are the most diagnostic and chronoculturally sensitive aspect of EUP lithic assemblages (e.g., Bon, 2002; Bon and Bodu, 2002; Bordes, 2005; Le Brun-Ricalens et al., 2005; Demidenko and Noiret, 2012b; Nigst et al., 2014; Dinnis and Flas, 2016; Falcucci et al., 2017; Tafelmaier, 2017).

Radiocarbon dating

Sampling was carried out on bones from Kostenki 14/LVA housed at the Institute for the History of Material Culture, Saint Petersburg, Russia. We targeted bones from the area where diagnostic Aurignacian material (i.e., the retouched bladelets) was found due to the complex depositional nature of the layer. Twenty-three of the layer's 24 retouched bladelets/fragments derive from a 15 m² area, and together they form a coherent group consistent in their technological features and artifact condition. Of these 23, 18 were found within a 2 m² area. We therefore sampled four horse bones found in these two squares or squares immediately adjacent during the 2000 and 2003 excavations.

For Kostenki 17/II, we sampled two fox tooth pendants housed at the Institute for the History of Material Culture (Saint Petersburg, Russia) and three wolf bones housed at the Zoological Institute (Saint Petersburg, Russia). All of this material comes from Boriskovskii's excavations.

We also sampled three hare bones from Kostenki 14/IVw, because of its potential similarity to Kostenki 17/II. The bones were all excavated from Layer IVw2 in 2015, and are housed in the Institute for the History of Material Culture.

Two different methods were used to prepare the samples for accelerator mass spectrometry (AMS) dating. First, samples were pretreated following the routine procedure at the Oxford Radiocarbon Accelerator Unit (ORAU) as described by Brock et al. (2010). This comprised decalcification in acid, a base wash, reacidification, gelatinization and ultrafiltration (coded 'AF' in the ORAU). Samples that had been preserved with glues, or samples for which we did not have complete knowledge of their post-excavation history, were washed with solvents (acetone, methanol and chloroform) prior to AF treatment (coded 'AF*' in the ORAU). Second, following the problems we encountered removing likely contaminants using this method (described below), some of the Kostenki 17 samples were also redated using the single amino acid radiocarbon dating method optimized at the ORAU (Devièse et al., 2018). This method involves separation of the underivatized amino acids from hydrolyzed bone collagen samples using preparative high-performance liquid chromatography (Prep-HPLC). The amino acid hydroxyproline, found almost uniquely in mammalian collagen, was isolated by Prep-HPLC, combusted, graphitized and AMS dated. This pretreatment approach (coded 'HYP' in the ORAU) is the most efficient available technique to remove contaminants including, but not limited to, conservation materials (with the exception of collagen-based glue). The technique has been applied successfully to a small

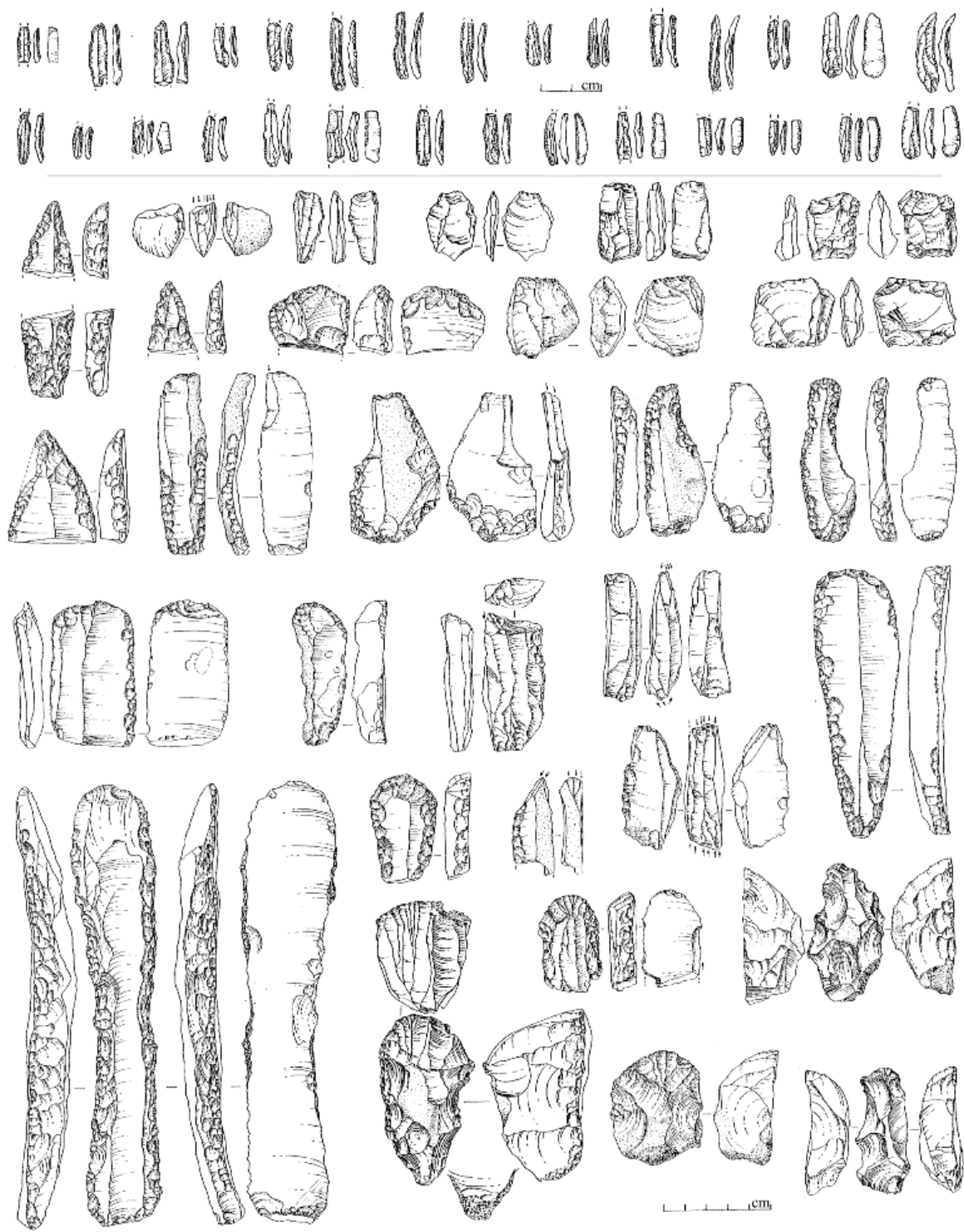


Figure 4. Lithic artifacts from the Aurignacian of Kostenki 1/III (reproduced from Sinitsyn, 1993).

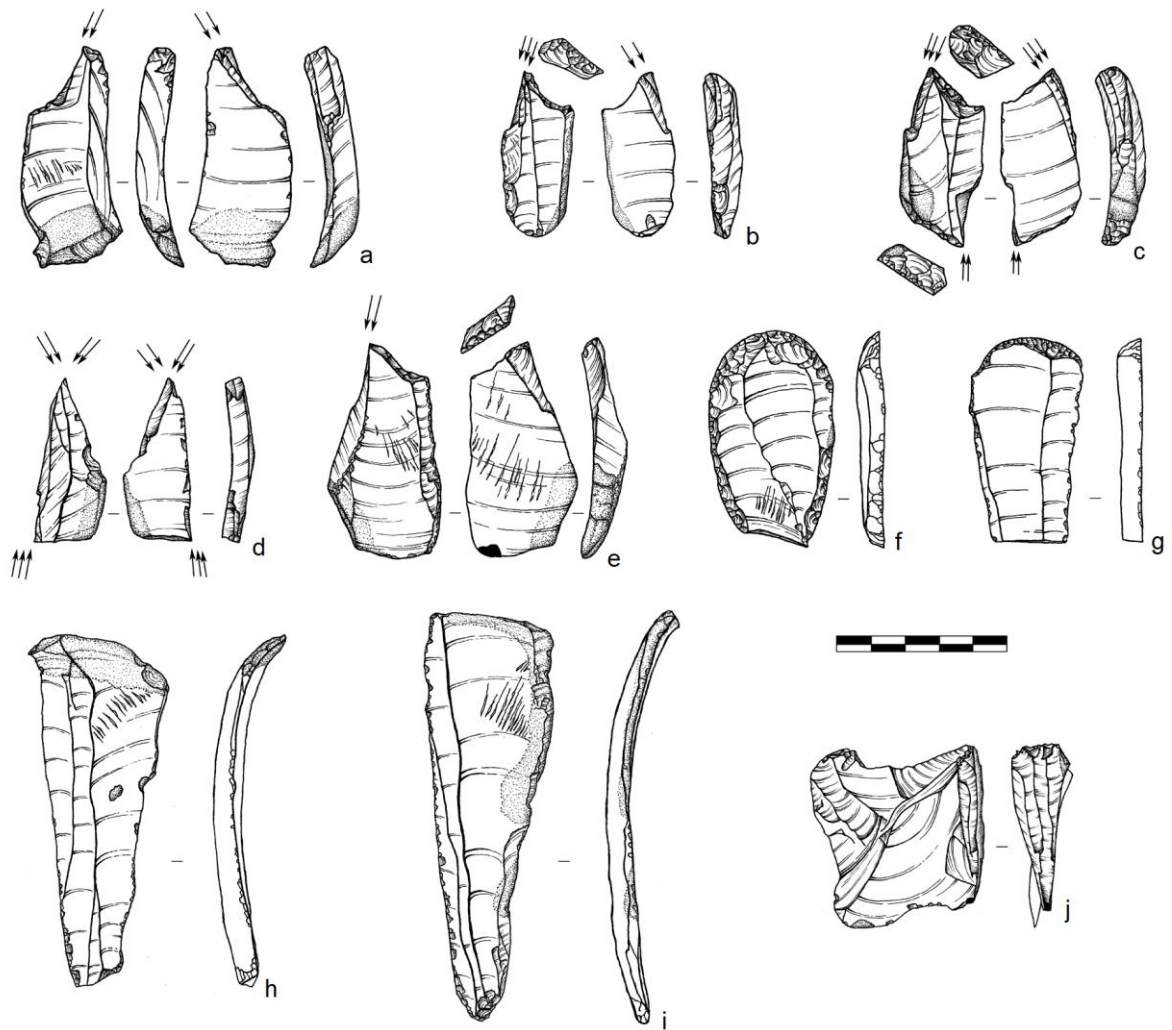


Figure 5. Part of the studied Kostenki 17/II lithic assemblage: burins (a-e), endscrapers (f, g), large blades (h, i) and bladelet core (j). Scale bar = 5cm.

number of contaminated Paleolithic bone samples (e.g., Bourrillon et al., 2017; Devière et al., 2017; Reynolds et al., 2017).

Kostenki 17/II lithic analysis

To reassess the Kostenki 17/II assemblage we studied the entire available part of Boriskovskii's lithic collection ($n = 191$ pieces). The assemblage was composed of retouched pieces, cores and a very small proportion of the unretouched debitage, including larger blades

and blade fragments (Fig. 5). Based on Boriskovskii's (1963) counts (Table 1) we estimate that we had access to roughly two-thirds of his total retouched assemblage, and that simple edge-retouched blades/fragments are underrepresented in our study. The whereabouts of the remainder of Boriskovskii's Layer II collection, including the vast majority of unretouched pieces, is currently unknown. Our study primarily utilized standard typological analysis, with technological and raw material characteristics noted where discernible. The material studied is housed at the Institute for the History of Material Culture. In addition, we consulted documentary material from Boriskovskii's excavations housed in the Institute's archive.

Results

Radiocarbon dating

Kostenki 17/II Five new radiocarbon dates were produced from the fox tooth pendants (sample codes: K2014/1 and K2014/2) and wolf bones (sample codes: K17-01, K17-02 and K17-03). The former were visibly covered by conservation materials, so we applied the AF* pretreatment. There was no indication that preservatives had been applied to the wolf bones, but, as the curatorial history of the specimens was unknown, we also applied the same pretreatment to these samples. The two pendants produced ages of $26,830 \pm 250$ BP (OxA-30824) and $25,480 \pm 220$ BP (OxA-30825), while the three bones K17-01, K17-02 and K17-03 were dated to $32,350 \pm 450$ BP (OxA-32594), $31,250 \pm 400$ BP (OxA-32595) and $33,050 \pm 500$ BP (OxA-32596), respectively (Table 4; SOM Table S2).

All five dates are younger than the age assigned for the CI tephra, and are therefore incompatible with their chronostratigraphic position within the Kostenki 17 sequence. Furthermore, the range of ages produced was incompatible with the nature of the archaeological material from the layer. The similarity of the group of fox tooth pendants and their find locations suggest strongly that they constitute a single (contemporary) group of

artifacts (Boriskovskii, 1963), but the two dates produced are significantly different. More generally, the large spread of these five dates is contradicted by the technotypological coherence of the layer's lithic material, which indicates that the layer relates to activity over a short period of time (see, e.g., Chiotti, 2005; Michel, 2010; Dinnis and Flas, 2016).

We hypothesized that the erroneous radiocarbon results may have been due to some contaminant that cannot be removed by routine AF* pretreatment, and carried out further dating work. Two of the wolf bones (K17-01 and K17-03) were redated using the HYP method, using the surplus collagen obtained during the original AF* treatment along with additional collagen obtained by resampling the bones. K17-01 was dated using the HYP method to $35,650 \pm 690$ BP (OxA-X-2677-56) and K17-03 to $36,020 \pm 740$ BP (OxA-X-2677-57). Although there was some surplus collagen available for each of the fox tooth pendant samples, the amounts were individually insufficient for application of the HYP method, and no material was available for resampling. A third HYP date was therefore produced using the combined surplus collagen from the two fox tooth pendant samples. Although combining collagen from two different pendants is not ideal, their archaeological context, described above, strongly suggest that they are contemporary. The combined sample from the two pendants was used to produced a HYP date of $35,840 \pm 520$ BP (OxA-X-2717-26). The three new results of ~36–35.5 ka BP are internally consistent and consistent with the layer's chronostratigraphic position beneath the CI tephra (Table 4; Fig. 6).

Kostenki 14/IVw Samples from this layer were prepared using the standard AF procedure because the post-excavation history of all the sampled bones is known precisely, and no conservation treatment has been applied to them. The three dated bones produced results of ~36.5–35.5 ka BP (Table 5; Fig. 6; SOM Table S3). The accuracy of these results is supported by their internal consistency and their agreement with Kostenki 14/IVw's

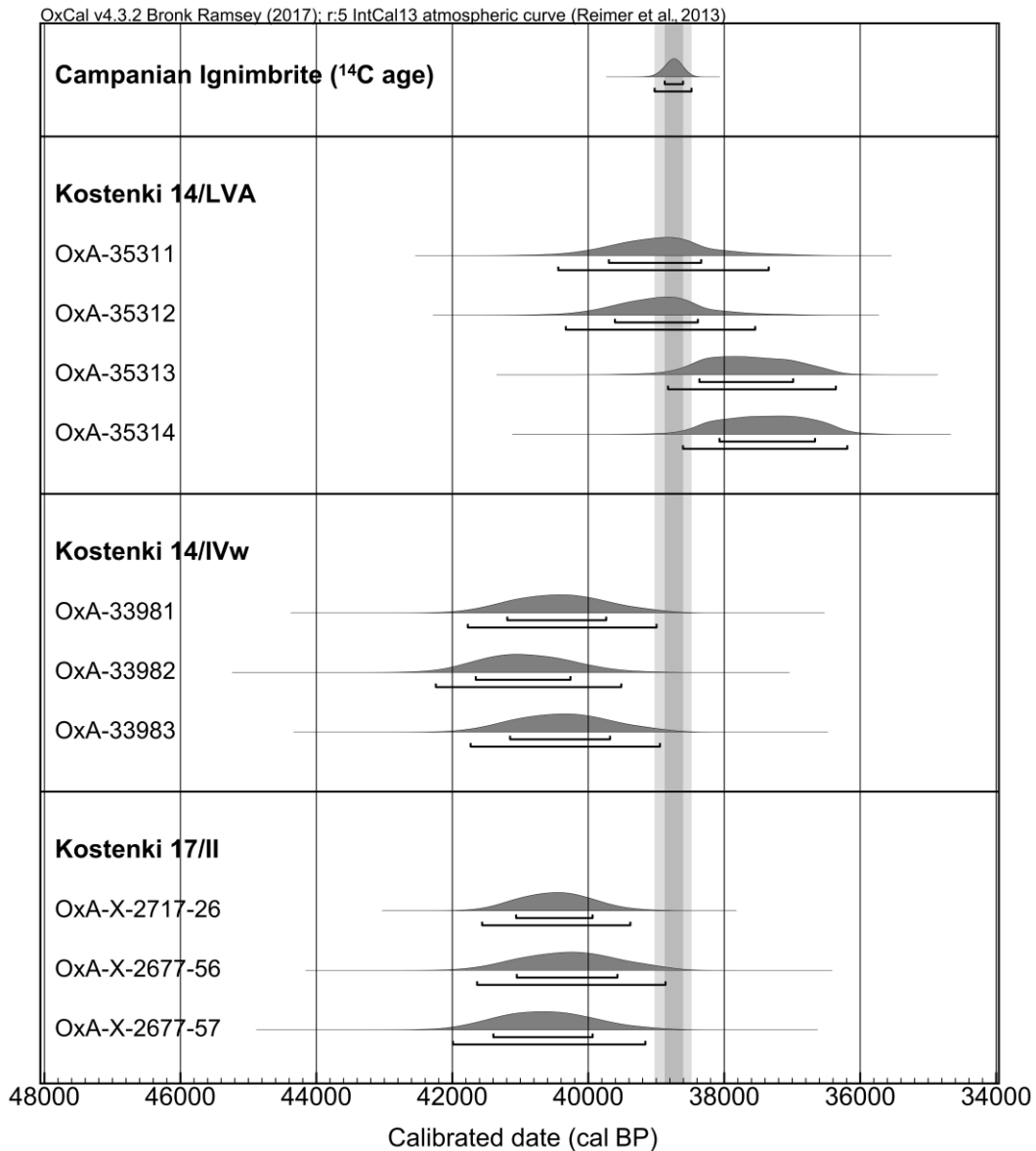


Figure 6. Calibrated ages for new radiocarbon dates from Kostenki 17/II (HYP dates only), Kostenki 14/IVw and Kostenki 14/LVA. The figure includes the age of the CI tephra following Giaccio et al. (2017).

chronostratigraphic position beneath the CI tephra (Table 5; Fig. 6). We also note their agreement with our HYP dates from Kostenki 17/II.

Kostenki 14/LVA Although we have a good knowledge of the curatorial history of the sampled material, we are aware that many people have examined it in the years since its excavation. As a precaution, we therefore applied the AF* pretreatment. The results of

34,400 ± 600 BP (OxA-35311), 34,400 ± 550 BP (OxA-35312), 33,400 ± 500 BP (OxA-35313) and 33,150 ± 500 BP (OxA-35314) are statistically indistinguishable from one another (mean 33,760 ± 266 BP; $T' = 4.5$, $df = 3$; $\chi^2 = 7.81$). Two of the determinations (OxA-35311 and -35312) overlap with the age ascribed to the CI tephra (Table 6; Fig. 6; SOM Table S4). The other two are statistically significantly younger, since their calibrated probability distributions do not overlap with 0 at 95.4% probability when we plot an OxCal Difference function comparing them with the calendar age of the CI. Overall, our results suggest that the archaeological material dates to the same time as the CI tephra or somewhat later. Either scenario is consistent with the site's stratigraphy as presently understood.

Kostenki 17/II lithic analysis

Raw materials/condition The assemblage that we studied from this site is dominated by flint (97%, $n = 186$ of 191), which is black, dark gray, dark brown or, more rarely, light brown in color. Some large blades (≥ 20 mm width) retain fresh cortex, suggesting they derive from large nodules extracted from a primary source. The origin(s) of the flint found at Kostenki is uncertain, but is thought to be at least 25 km distant, and possibly much farther (Boriskovskii, 1963; Yurgenson et al., 2012). Most material is unpatinated or lightly patinated to light gray or white. As was noted by Boriskovskii (1963), the overall assemblage is uniformly fresh in condition with only minimal edge damage and abrasion. This is consistent with it having undergone only minor postdepositional movement.

Blade production The assemblage includes 10 blade cores, of which one has been exploited as a bladelet core before discard. All are black or dark gray flint. Seven cores bear two or more flaking surfaces but only one has two opposite striking platforms, and in this case the second platform appears to have functioned only to maintain the core's longitudinal convexity (SOM File S3). General core morphology therefore indicates unipolar blade

production. This is consistent with the dorsal/ventral scar pattern seen on the blades/blade segments and the curved profile of the large blades/segments (Fig. 5).

The dimensions of the studied blades/blade segments (Fig. 5) show that they were made on cores that were originally large in size. One group of complete/near-complete blades (Boriskovskii's 'large' blades; Table 1; Fig. 5h, i; SOM File S4) are ≥ 10 cm long and up to 38 mm wide, and many of the retouched pieces are made on portions of similarly large blades (Fig. 5; see also Boriskovskii, 1963). However, it should be noted that these pieces are disproportionately large in comparison to other blades described by Boriskovskii (1963) and in comparison with the final blade(let) removal negatives on the studied cores, whose widths range from 9–20 mm. The lateral edges of the studied blades are generally straight and parallel/subparallel.

Thirteen large unmodified, retouched or crested blades retain their butts. Nine are faceted, with one showing dedicated isolation of the striking point (sensu Giria, 1997; see Dinnis et al., 2017). The remaining four are plain. Despite these blades' size, their butts are relatively small (average thickness 3 mm, $n = 13$). Preparatory abrasion of the core edge is discernible on 85% of them ($n = 11$), and 85% ($n = 11$) are lipped. Bulbs of percussion are diffuse. Together these features indicate marginal percussion using a soft and possibly organic hammer (Pelegrin, 2000, 2012).

Burin-cores and bladelet production The Kostenki 17/II retouched assemblage is dominated by burins, and particularly burins on truncation (Table 1). The assemblage that we studied contains 138 burins, of which 32 are double. Their blanks are mostly blades/blade segments (79%; $n = 109$ of 138), although large flakes and core preparation/maintenance pieces (e.g., crested blades, core tablets) were also used (11%; $n = 15$). The platforms for burin removals were generally created by steep, oblique/concave retouched truncations (Tables 7 and 8; Fig. 5; SOM Files S5 and S6). Most burins are multifaceted, with 76% of burin tips having two or

more facets ($n = 130$ of 170). The maximum number of facets is six (4%, $n = 6$ of 170) and the mean number is 3.8.

This prevalence of burins suggests activity specialism at Kostenki 17. Boriskovskii (1963) noted usewear on some examples and suggested they may have served to pierce bone and other more malleable materials. However, prior to their discard many of these artifacts were apparently exploited as cores (e.g., Fig. 5a–c; SOM Files S5 and S6), an observation also made by Bataille (2013; see also comments by Boriskovskii, 1963). The incompleteness of the assemblage precludes confident assessment of the proportion that served as cores. However, we broadly agree with Bataille (2013), who concluded that ~20 of the Kostenki 17/II burins have convincing burin-core morphology but that the true number of burin-cores in the collection is higher, and that bladelet production from burin-cores is the main focus of stone-working activity evident at the site. One bladelet core formed on the edge of a large flake (Fig. 5j) is conceptually comparable to the burin-cores.

Bladelet production, like blade production, followed a unipolar reduction strategy. Four modified bladelets and two burin spalls retain their butts: they are small (all <2 mm), bear evidence of core abrasion ($n = 5$ of 6) and are sometimes lipped (2 of 6). This suggests soft hammer percussion.

Retouched/modified bladelets The studied Kostenki 17/II assemblage contains six modified bladelets, of which five are complete/near-complete (Fig. 7; Table 9). All are straight in profile or only slightly curved. Four are made from the layer's predominant black/dark gray flint and bear mostly semiabrupt, marginal, dorsal retouch. Two of these four (Fig. 7c, e) demonstrably derive from burin-cores. The remaining two (Fig. 7a, f; SOM File S7) have semiabrupt inverse marginal retouch along their right edge and direct retouch on their left edge, thereby fulfilling the criteria of Dufour bladelets of Dufour subtype (Demars and Laurent, 1992). Although the raw material/patination of both is atypical for the layer (Table

9), there is no stratigraphic or technological reason to dissociate them from the layer (SOM S2 and Fig. S2).



Figure 7. Kostenki 17/II modified bladelets: artifact numbers 1024 (a), 545 (b), 745 (c) 894 (d), 573 (e) and 188 (f). Scale bar = 5cm.

Although this is only a small sample, we can note technological similarities with Proto-Aurignacian retouched bladelets from, e.g., Isturitz, Grotte du Renne and Les Cottés in France, Fumane in Italy, Kozarnika in Bulgaria, and Siuren I in Crimea (Perpère and Schmider, 2002; Sirakov et al., 2007; Normand et al., 2009; Tsanova et al., 2012; Falcucci et al., 2018). This includes: unipolar production employing core abrasion and marginal percussion; straight/slightly curved profiles; and similar size (Table 10). Examples with alternate retouch also show similarity in the lateralization of ventral/dorsal retouch on the right/left edges respectively, and the more invasive and uniform ventral retouch relative to dorsal retouch. The clearest point of difference with these Proto-Aurignacian modified bladelet assemblages is the use of the truncation-burin-core method of bladelet manufacture

at Kostenki 17, which may help to explain the overall comparatively thicker blanks found there (Table 10).

In comparable EUP assemblages elsewhere most retouched bladelets are highly fragmentary. Falcucci et al. (2018) found that >95% of examples in the Proto-Aurignacian collections from Les Cottés, Isturitz and Fumane were fragments. We can therefore infer that the six bladelets in Figure 7 represent only the most complete modified bladelets from the layer, and that many more fragments exist in the unstudied part of the collection. Despite this, we conclude that these six artifacts can be considered technologically representative of bladelet manufacture in the layer. First, their form and size agree well with the layer's burin-cores. Second, although we acknowledge the selected nature of the studied assemblage, we should presume that other types of retouched bladelet were not missed during excavation. Rogachev recovered a series of smaller retouched bladelets from Kostenki 1 in 1951, and Boriskovskii would therefore have been aware of the potential for similarly small pieces prior to his Kostenki 17 excavations. Boriskovskii (1963; see Table 1) also recorded ~7,000 small retouch flakes and chips during his excavations, demonstrating a good rate of recovery of very small artifacts.

Comparisons with Kostenki 14 and Kostenki 1 retouched bladelet assemblages As described above, the lowest layers of Kostenki 14 (Layers IVb and IVw) are, like Kostenki 17/II, found in the LHB. Bladelet cores from Kostenki 14/IVb are unlike those that characterize Kostenki 17/II, and the lithic raw material profile of Layer IVb shows a notably greater prevalence of local colored flint than Kostenki 17/II (Bataille, 2013; Sinitsyn, 2014).

Rather, as noted above, Kostenki 17/II is more similar to Kostenki 14/IVw. The Kostenki 14/IVw assemblage is, like that of Kostenki 17/II, dominated by imported flint, with a minimal amount of brown/yellow flint, chert and quartzite. Burins apparently served as cores

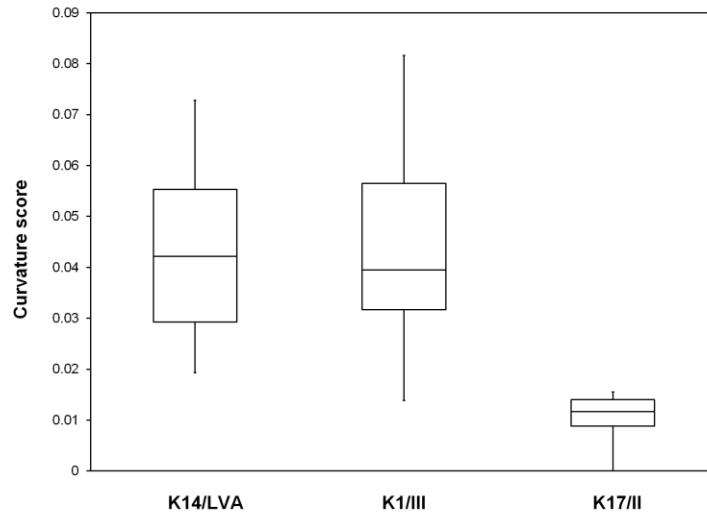


Figure 8. Box plot showing bladelet curvature scores for modified bladelets/fragments from Kostenki 14/LVA ($n = 16$), Kostenki 1/III ($n = 23$) and Kostenki 17/II ($n = 6$). The whiskers denote the range of values and the boxes denote the first to third quartiles. The line within each box represents the second quartile (median). Curvature score calculated as maximum deviation from straight (to nearest 0.1 mm) / length (to nearest 0.1 mm). Fragments too small to allow measurements excluded. All measurements taken with digital calipers.

for the production of bladelets. So far, nine fragmentary modified bladelets/burin spalls have been identified from Layer IVw (four from IVw1 and five from IVw2), of which at least five derive from burin-cores. All bear abrupt/semiabrupt marginal dorsal retouch, in five cases bilateral and in four cases on one edge only. However, unlike at Kostenki 17/II, none bears ventral retouch.

The assemblages from Kostenki 14/LVA and Kostenki 1/III are chronostratigraphically later than Kostenki 17/II, and the modified bladelets found in these two assemblages differ from the Kostenki 17/II examples. They are shorter (1–3 cm long) and have comparatively curved profiles (Fig. 8). Furthermore, the carinated-scraper cores used to produce this type of bladelet are absent from Kostenki 17/II.

Discussion

Radiocarbon dating the EUP and problematic bone dates from Kostenki

The difficulty in consistently producing accurate radiocarbon dates for the period 50–30 ka BP is now well established. The primary problem appears to be incomplete removal of exogenous carbon, which, when present in even very small amounts, tends to render radiocarbon measurements younger than the real age of the dated specimen (Higham et al., 2006, 2009; Jacobi et al., 2006; Brock and Higham 2009; Marom et al., 2012; Bird et al., 2014; Nalawade-Chavan et al., 2014; Wood, 2015; Alex et al., 2017; Bourrillon et al., 2017; Devièse et al., 2017; Reynolds et al. 2017; Sikora et al., 2017). Although the situation has improved over the last decade, the radiocarbon record for the LMP and EUP is still clearly problematic. Eastern Europe's most important EUP sites seem particularly badly affected. Considerable problems with the radiocarbon chronologies of Kostenki and Sungir' have been demonstrated to be the result of incomplete removal of contaminant exogenous carbon (Damblon et al., 1996; Sinitsyn, 1996; Sinitsyn et al., 1997; Douka et al., 2010; Marom et al., 2012; Reynolds et al., 2017). Similar issues probably also explain the problematic dates for the generally well-stratified EUP material from Siuren I (Demidenko and Noiret, 2012a).

At Kostenki, dates on bone have often proved particularly incompatible with their chronostratigraphic positions (Damblon et al., 1996; Sinitsyn et al., 1997). Only in the last few years have bones stratified within the LHB produced radiocarbon ages consistent with their position below the CI tephra (Douka and Higham, 2017; this paper). Our results highlight ongoing problems. Radiocarbon dates produced for Kostenki 14's EUP layers (Tables 5 and 6; Fig. 6) using a collagen ultrafiltration pretreatment are internally consistent and agree well with their chronostratigraphic position relative to the CI tephra. Douka and Higham's (2017) new dates for Kostenki 14, including those on bone, similarly agree with

this chronostratigraphy. In contrast, however, bone dates for Kostenki 17/II produced using the same methods are erroneously young (Table 4).

How might we explain this discrepancy? The problems at Kostenki 17 potentially stem from post-excavation chemical treatment of bone/teeth. The new and apparently accurate bone dates for Kostenki 14 (Tables 5 and 6; Douka and Higham, 2017) were all produced from specimens excavated over the past two decades, and it is highly unlikely that any were treated with preservatives. Dated material from Kostenki 17, on the other hand, was excavated in the 1950s, and has a less clear post-excavation history. The dated pendants (OxA-30824 and OxA-30825), which initially produced radiocarbon ages ~10,000 radiocarbon years too young, were visibly glued (Table 4). Other visibly glued specimens from mid-20th century collections at Kostenki have likewise produced erroneously young ages (Marom et al., 2012; Reynolds et al., 2017). However, the Kostenki 17 wolf bones, whose initial radiocarbon ages were 5000–3000 radiocarbon years too young, bear no evidence of treatment (Table 4). This, of course, does not mean that they were not treated, and not enough is known of Kostenki's mid-20th century excavation and curatorial protocols to rule out routine treatment of bones, perhaps even at the point of excavation. Further dating work on Kostenki's EUP-age bone is in progress, and early indications are that mid-20th century collections from other Kostenki sites can produce similarly incorrect results. Further work will be undertaken to determine whether we can in fact identify evidence for conservation treatment on the bones.

Alternatively, given that the wolf bones from Kostenki 17 show no sign of post-excavation chemical treatment, then other reasons for the erroneous radiocarbon dates must be considered. A useful comparison is found in Bourrillon et al.'s (2017) results for untreated bones associated with Early Aurignacian material at Abri Blanchard. Here too, standard methods (i.e., AF) produced ages that appear too young for the associated archaeological

material. When redated using HYP pretreatment, the same bones yielded results that were 2500–4500 radiocarbon years older. This is consistent with contamination with younger carbon. Bourrillon et al. (2017) suggested that exogenous carbon may have derived from humates carried in groundwater, which could have cross-linked with collagen and become impossible to remove completely using standard pretreatment methods. Support for this comes from the adjacent site of Abri Castanet, where untreated bones associated with comparable archaeological material and similar (post)depositional circumstances also produced dates inconsistent with those for other Early Aurignacian assemblages nearby (Higham et al., 2011; White et al., 2012). If a similar mechanism has affected bones at Kostenki, it need not necessarily apply consistently to all Kostenki sites: Kostenki 17 is positioned in the main river valley whereas Kostenki 14 lies on the slope of a tributary ravine, and they will certainly have experienced different (post)depositional processes. The explanation offered for the incorrect dates from Abri Blanchard could therefore also explain the unreliability of dates from Kostenki 17 compared to Kostenki 14. One further factor to note is the open-air or near open-air nature of all these sites. Zilhão and d’Errico (2003) and Mellars (2006a) have previously suggested that radiocarbon dates of bone from inside caves and outside on porches exhibit markedly different results, with the latter often more significantly underestimating the real age.

More work is required to explore how widespread these anomalies might be, but currently we recommend caution in building radiocarbon chronologies for the LMP and EUP at single sites when radiocarbon dates produced cannot be verified or supported by other chronological information (e.g., inter-site stratigraphic correlations, other radiometric methods: see d’Errico and Banks, 2015). For Kostenki 17/II, our three initial dates of 33–31 ka BP for the wolf bones (Table 4) were in good agreement with a bone date produced previously at the Saint Petersburg laboratory and with one of the two dates on charcoal from the Groningen

laboratory (Table 2). The wolf bones were not visibly treated and there is no indication from the sample measurements (e.g., C:N ratios) that these dates are questionable. However, the position of the layer beneath the CI tephra and subsequent redating using HYP pretreatment confirm that these dates are significant underestimates of the true age of the samples. Such a wealth of supporting evidence is obviously rarely available for LMP/EUP sites; therefore, given that they are less sensitive to such site-specific problems, models built on regional or supraregional data (e.g., Jöris et al., 2011; Banks et al., 2013a; Alex et al., 2017) are more appropriate to diagnose chronology.

Whatever it was that caused our initial, erroneous dates for Kostenki 17/II, the dates subsequently produced using HYP pretreatment appear to be reliable, as they ought to be given that they are on compound-specific single amino acid fractions (Table 4). As with previous applications of the method, they are internally consistent, consistent with independent stratigraphic markers and are in line with expectations based on associated archaeological material (Marom et al., 2012; Nalawade-Chavan et al., 2014; Bourrillon et al., 2017; Devière et al., 2017; Reynolds et al., 2017).

Streletskian early AMHs at Kostenki?

Our results for the well-stratified layers Kostenki 17/II and Kostenki 14/IVw show that these two typically Upper Paleolithic assemblages (i.e., with ‘Upper Paleolithic’ blade/bladelet production and personal ornaments) at Kostenki date to ~36 ka BP (≈41 ka cal BP). This age is close to the older of the dates recently produced for the Upper Paleolithic assemblage from Kostenki 14/IVb (Douka and Higham, 2017), which occupies a similar stratigraphic position to Layer IVw.

Other layers at Kostenki are also thought to predate the CI tephra, most notably Layer III of Kostenki 12 and Layer V of Kostenki 1, where radiocarbon and OSL dates suggest an age

equal to or in excess of 41 ka cal BP (Praslov and Rogachev, 1982; Holliday et al., 2007; Levkovskaya et al., 2015; Haesearts et al., 2017). Both assemblages are usually referred to as Streletskian (e.g., Rogachev, 1957; Bradley et al., 1995; Anikovich et al., 2004; Bosinski, 2013; Sinitsyn, 2014), with a mixture of Upper and Middle Paleolithic characteristics (Anikovich, 2002; Anikovich et al., 2004; Bataille, 2013, 2016). Both have been argued to be evidence for early AMHs on the East European Plain (e.g., Vishnyatsky and Nehoroshev, 2004; Kozłowski, 2014; Otte, 2014; Hoffecker et al., 2016; Vishnyatsky, 2016).

Unlike Kostenki 17/II and Kostenki 14/IVw, however, neither Kostenki 12/III nor Kostenki 1/V can be considered per se as well-stratified/unmixed and well-dated. Kostenki 12/III was found within the LHB, but was positioned differently within it in different parts of the site (Rogachev, 1957; Anikovich et al., 2004; Levkovskaya et al., 2015). In northern (downslope) parts of the site, excavated in the 1950s and early 1960s, it was recognized that Layer III and the overlying Layer II were conflated over most of the excavated area, with lithic material separated into the two layers only post-excavation (Rogachev, 1957; Anikovich, 1977; Rogachev and Anikovich, 1982). More recent excavations in the site's southern (upslope) part have amply demonstrated that Layer III has been redeposited (Anikovich et al., 2004; Hoffecker et al., 2005, 2010; Holliday et al., 2007). Importantly, the condition of the horse bones found in the layer differs from that of the reindeer bones, indicating that they have different depositional histories. For Hoffecker and colleagues (Hoffecker et al., 2010; Hoffecker and Holliday, 2014) this is evidence that they were deposited at different times. Clearly the associated lithic assemblage cannot be presumed to be unmixed, particularly given its marked technotypological variation relative to the assemblages from the well-stratified Kostenki 14/IVw and Kostenki 17/II (Praslov and Rogachev, 1982; Anikovich et al., 2004; Bataille, 2013).

Kostenki 1/V poses different problems. Rogachev's 1948-53 Layer V excavations yielded an apparently well-stratified lithic assemblage that included diagnostic Streletskian points (Rogachev, 1957; Rogachev et al., 1982; Hoffecker et al., 2016). However, the material found in Layer V during more recent work beyond Rogachev's excavation area is meager and mostly undiagnostic (Anikovich et al., 2008; Hoffecker et al., 2010, 2016). Unfortunately, all luminescence/radiocarbon dates for the layer come from excavations later than Rogachev's (Anikovich et al., 2007; Hoffecker et al., 2016; Haesaerts et al., 2017), and they cannot confidently be associated with Rogachev's finds. This includes the radiocarbon dates of >42 ka BP recently produced by Haesaerts et al. (2017). All diagnostic Streletskian points attributed to Kostenki 1/V come from the northern excavation area, whereas Haesaerts et al.'s (2017) dates are for samples from the southern excavation area, which is separated from the northern area by an unexcavated zone. This situation is exacerbated by the recent recognition that a part of Layer V in the southern excavation area, adjacent to where Haesaerts et al.'s (2017) dated samples came from, actually consists of more than one observable layer (Hoffecker et al., 2016). Haesaerts et al.'s (2017) dates therefore cannot be securely associated with the Layer V Streletskian assemblage found by Rogachev.

Since these radiocarbon dates from Kostenki 12/III and Kostenki 1/V cannot be confidently associated with diagnostic archaeological material, they cannot be argued to date Streletskian assemblages, and therefore cannot be attributed to AMHs. Further still, the blanket association between Streletskian assemblages and AMHs is itself problematic, given the high degree of variability and long chronological range found among Streletskian assemblages. While marked technotypological variety is usually implicitly accepted as representative of high diversity in Streletskian stone-working behaviors over a short period of time (e.g., see Bradley et al., 1995; Anikovich, 2002; Anikovich et al., 2004; Zwyns et al., 2012; Bosinski, 2013), in at least some cases it is equally if not more likely to result from

mixing of material from different occupation events. It follows that some material in Kostenki's early Streletskian layers potentially reflects Neanderthal and not AMH activity.

The place of the Spitsynian in the western Eurasian Early Upper Paleolithic

The presence of pendants, bone tools and typically Upper Paleolithic blade/bladelet production and tool forms in the Kostenki 17/II assemblage has led to the general recognition that it is fully Upper Paleolithic and unrelated to LMP assemblages. However, finding analogies for the assemblage beyond Kostenki has proved difficult. Its typological and technological profile does not suggest a relationship with 'transitional' Eastern/Central European Streletskian or Szeletian (Allsworth-Jones, 1986, 1990; Bradley et al., 1995; Bataille, 2013; Mester, 2014). The fully Upper Paleolithic nature of the blade production and the importance of bladelet production marks it as different from the Near Eastern Initial Upper Paleolithic and the Central European Bohunician assemblages (Škrdla and Rychtaříková, 2012; Škrdla, 2014), as well as from the comparable industry from Layer II of Korolevo II in western Ukraine (Monigal et al., 2006; Usik et al., 2006). The absence of curved and/or twisted bladelet production distinguishes Kostenki 17/II from Aurignacian assemblages *sensu stricto* (i.e., excluding Proto-Aurignacian). Kostenki 17/II has also not yielded the steeply and invasively backed pieces that characterise Gravettian assemblages (Noiret, 2013). Furthermore, Early Gravettian sites across Europe, including at Kostenki, are close to 10 kyr younger than Kostenki's Spitsynian assemblages (Jöris et al., 2010; Higham et al., 2011; Reynolds et al., 2015). Any perceived link between the two should therefore be rejected.

One potential analogue for Kostenki's Spitsynian assemblages comes from the EUP Layer 3 of Sokyrnytsa I Area A in western Ukraine (Usik et al., 2006; Bataille, 2013): as at Kostenki 17/II there is evidence for typically Upper Paleolithic blade/bladelet production,

burins are prevalent (including on concave truncations), carinates are absent, and bladelets with marginal dorsal retouch are present (Monigal et al., 2006; Usik et al., 2006; Bataille, 2013). Bataille (2013) has also suggested a possible link between Kostenki 17/II and EUP assemblages containing burins on truncation found in Layer 4c/4d of Ortvale Klde (Adler et al., 2006, 2008) and Layer D of Dzudzuana Cave (Bar-Yosef et al., 2011) in the Caucasus. Further study of burins and bladelet production at these sites would help to assess these proposed similarities, although we can note that, in contrast to Kostenki 17/II, no Dufour bladelets have been described for any of these assemblages. Further south, the Ksar Akil Phase 3 assemblage (\approx layers XIII-XI of the 1938 excavation) is, like Kostenki 17/II, characterized by Upper Paleolithic blade/bladelet production and is dominated by burins, including multifaceted burins on truncation (Bergman, 1988; Williams and Bergman, 2010). However, unlike Ksar Akil Phase 3, the studied Kostenki 17 assemblage is not characterized by twisted blades/bladelets.

Most significantly, the presence of Dufour (Dufour subtype) bladelets at Kostenki 17/II invites comparison with European Proto-Aurignacian assemblages and comparable EUP facies in the Levant (i.e., Ksar Akil Phase 4 [\approx layers X-IX of the 1938 excavation]; Mellars, 2006b; Demidenko, 2012; Kadowaki et al., 2015). No Proto-Aurignacian material has so far been identified on the East European Plain, but several candidate assemblages have been described at its margins (Demidenko, 2004, 2009). The most important of these is from Siuren I in Crimea (Lower Layer of 1920s excavations, Units H/G 1990s excavations), \sim 800 km south west of Kostenki. This lithic assemblage contains evidence for the production of bladelets with straight or only slightly curved profiles, with Dufour (Dufour subtype) bladelets and Krems points found among the retouched assemblage. Bladelets were produced from dedicated bladelet cores (Demidenko and Noiret, 2012b). Radiocarbon dates and the assemblage's stratigraphic position beneath later Aurignacian material confirm its MIS 3 age,

but the radiocarbon data are too problematic to give a more precise chronology (Demidenko and Noiret, 2012a). The small, open-air surface collection from Chulek I, at the mouth of the Don River ~500 km south of Kostenki, is similar to the Siuren I Proto-Aurignacian assemblage. Twelve of the site's 39 retouched bladelets have been classified as Dufour (Dufour subtype; Demidenko, 2009). The retouched assemblage contains a relatively high proportion of burins (33%; $n = 33$ of 100) but these do not appear to have served as cores (Demidenko, 2009; Y. Demidenko, pers. comm. 2017). In the Northern Caucasus, the larger open-air site of Shirokii Mys is undated, but may also be compared to the Siuren I assemblage on technotypological grounds (Shchelinskiy, 2007). Of a group of 697 retouched bladelets found at Shirokii Mys, Demidenko (2009) described 15% ($n = 104$) as typical Dufour (Dufour subtype) bladelets, and a further 9% ($n = 61$) as Krems points. Bladelet production was from dedicated subpyramidal and subcylindrical cores, with a few carinated bladelet cores also represented (Demidenko, 2009). In addition, the lower layer from the nearby Kamennomostskaya Cave yielded a mixture of Micoquian and Upper Paleolithic material including Dufour bladelets. Bladelets were produced from dedicated prismatic bladelet cores and from the edge of large flakes (Demidenko, 2009). To the west, Beregov I in the Transcarpathia region of Ukraine has been described as Proto-Aurignacian (Usik, 2008; Usik et al., 2013), as have several sites west of the Black Sea (e.g., Kozarnika VII, Tincova, Românești-Dumbrăvița I; Sirakov et al., 2007; Demidenko and Noiret, 2012b; Tsanova et al., 2012, Schmidt et al., 2013).

A significant degree of variability is now evident in these and other assemblages described as Proto-Aurignacian. Bladelet production proceeded either from blade cores, dedicated bladelet cores, or along the edge of large flakes, which were sometimes configured as burin-cores (Bon, 2002; Bon and Bodu, 2002; Bordes, 2005; Demidenko, 2009; Porraz et al., 2010; Demidenko and Noiret, 2012b; Tsanova et al., 2012; Bataille, 2016; Falcucci et al., 2017;

Tafelmaier, 2017). However, despite this variation, these assemblages all share two features: significant evidence for relatively large modified bladelets with straight or only slightly curved profiles, and the presence of Dufour (Dufour subtype) bladelets among the retouched assemblage (Demidenko and Noiret, 2012b; Anderson et al., 2015; Falcucci et al., 2018). Although Kostenki 17/II shows some clear differences from these other assemblages—most notably in the production of large blades and the truncation-burin-core method of bladelet manufacture—both of these features are present. For this reason, it should be viewed as a local variant of the Proto-Aurignacian elsewhere. This is consistent with the shared chronological position of Kostenki 17/II and Proto-Aurignacian assemblages (Table 4). In addition, evidence from Kostenki 14 directly links Kostenki with areas with/near to Proto-Aurignacian occupation around this time: a perforated Columbella shell from Layer IVb derives from the Mediterranean Basin, and several perforated shells from Layer IVw are probably from the Black Sea region (Sinitsyn, 2016b).

The Proto-Aurignacian features of the Kostenki 17/II assemblage support the hypothesis that it represents early AMHs, and therefore AMH occupation of the Middle Don region by ~36 ka BP (41 ka cal BP), when Proto-Aurignacian sites evidence early AMH occupation elsewhere in Europe. A Proto-Aurignacian-like assemblage at Kostenki not only extends the known geographical limits of this assemblage type into the East European Plain, but also extends the known range northwards. This is significant given the often-noted southern European distribution of Proto-Aurignacian sites (Mellars, 2006b; Demidenko and Noiret, 2012b; Roussel et al., 2016; Demidenko and Haulk, 2017). In Western Europe, the Proto-Aurignacian Layer VII of Grotte du Renne (Schmider, 2002) lies at ~47.5 °N, while Beg ar C'hastel (~48.5 °N; Giot et al., 1975), and a possible Proto-Aurignacian component in the mixed assemblage from Spy Cave (~50.5 °N; Flas et al., 2012) may suggest a more northerly

limit. In Eastern Europe, the northernmost site described as Proto-Aurignacian is Chulek I (~48 °N). At ~51.5 °N, Kostenki is further north than any of these.

Early Upper Paleolithic chronocultural succession at Kostenki and across Europe

As discussed, our interpretation of the Kostenki 17/II assemblage as a local Proto-Aurignacian variant is consistent with the fact that both apparently date to the same period. With regard more generally to Kostenki's early EUP retouched bladelet assemblages, our results strengthen the chronological and cultural separation of the Kostenki 17/II Spitsynian material from the younger, typically Early Aurignacian material found in Kostenki 14/LVA and Kostenki 1/III.

Our new radiocarbon dates of 34.5–33 ka BP (39–37 ka cal BP) for the Aurignacian of Kostenki 14/LVA support an age close to (and possibly slightly younger than) the Campanian Ignimbrite/Y5 tephra (Table 6; Fig. 6). This is in good agreement with the age of other European Early Aurignacian assemblages (Higham et al., 2011; Teyssandier and Zilhão, 2018; SOM S1).

With regard to Kostenki 1/III, Hoffecker et al. (2016) have recently published radiocarbon dates of 32.5–29 ka BP for the layer, although they were (understandably) reluctant to explicitly relate individual dates to the site's Aurignacian occupation. The recent excavations at Kostenki 1 have confirmed that Layer III probably represents multiple occupations (Hoffecker et al., 2016), and some newly excavated material attributed to the layer is thought to be unrelated to the Aurignacian assemblage found previously in Layer III (Anikovich et al., 2008). Therefore, it is impossible to know whether Hoffecker et al.'s (2016) dated samples relate to Kostenki 1's Aurignacian occupation. Given the strong similarities between the lithic material from Kostenki 14/LVA and the Aurignacian material from Kostenki 1/III, we suggest that our new dates of 34.5–33 ka BP for the former (Table 6), corroborated by

their association with the CI tephra, also provide the best available age estimate for Aurignacian material in Kostenki 1/III. This age would be consistent with the chronostratigraphic position of the Kostenki 1/III Aurignacian.

When considered together, the early EUP assemblages from Kostenki 1, Kostenki 14 and Kostenki 17 are therefore in good agreement—chronologically and in terms of the modified bladelets produced—with the archaeological record further west in Europe. Given the obvious problems with the radiocarbon chronology of Siuren I (Demidenko and Noiret, 2012a), an argument that Eastern European Aurignacian occupation represents a dispersal from Western Europe (Hoffecker et al., 2016) is difficult to sustain.

Furthermore, if it is accepted that the Spitsynian assemblage from Kostenki 17/II can be viewed as culturally linked to Proto-Aurignacian assemblages, then Kostenki can be added to the list of locations where material of this type stratigraphically underlies Early Aurignacian material (Banks et al., 2013b), with no inversions of this stratigraphic succession yet known. More broadly, if the chronology of the Proto-Aurignacian and Early Aurignacian of Banks et al. (2013a,b) is accepted, then our results support the view that the direction and speed of spread of EUP cultural changes within Europe are unobservable at the current resolution and efficacy of our dating methods (e.g., Banks et al., 2013b; Teyssandier and Zilhão, 2018). More work will no doubt bring greater clarity. In the meantime we suggest that, where radiocarbon dates contradict prevailing models, then the competing hypotheses should be evaluated according to the plausibility of their anthropological implications (Teyssandier and Zilhão, 2018).

Conclusions

This study provides, for the first time, high-resolution and reliable radiocarbon chronologies for key EUP lithic assemblages from Kostenki 17 and Kostenki 14. The dates

obtained are on samples from well-stratified areas of the sites and are consistent with their stratigraphic positions, including their relationships with the CI tephra, giving us confidence in the results.

Our results from Kostenki 17/II are evidence for AMH activity on the East European Plain by ~36 ka BP (41 ka cal BP), approximately contemporary with early AMH-associated Upper Paleolithic assemblages elsewhere in Europe. These results must therefore be incorporated into future models of the vector(s) of initial AMH dispersal into Europe, and provide an important counterpoint to prevailing models that are heavily focused on dispersal along the Danube or Mediterranean coast (Conard and Bolus, 2003; Mellars, 2006a,b; Hoffecker, 2009; Nigst et al., 2014; Benazzi et al., 2015; Chu, 2018). A potential earlier (Streletskian) AMH presence at Kostenki-Borshchevo is undemonstrated, due to the uncertainty of the Streletskian-AMH association and the inadequate connection between dated samples and diagnostic archaeological material at Kostenki's early Streletskian sites.

Our new study of Kostenki 17/II reveals important similarities with European Proto-Aurignacian assemblages and related material in the Near East. Fully 'Upper Paleolithic' blade and bladelet production at the site followed unipolar strategies, with large, straight-profiled bladelets produced from burin-cores. The frequency of burin-cores in the assemblage indicates the overall importance of bladelet (rather than blade) production. Most significantly, the extant modified bladelet assemblage includes previously overlooked Dufour (Dufour subtype) bladelets. We therefore interpret the Spitsynian material from Kostenki 17/II as a local variant of Proto-Aurignacian assemblages found further west. Our new radiocarbon dates of ~36 ka BP (40–41 ka cal BP) for Kostenki 17/II are consistent with this interpretation.

Lithic material from Kostenki 1/III and Kostenki 14/LVA is instead similar to Early Aurignacian assemblages from elsewhere in Europe. Our new radiocarbon dates for Kostenki

14/LVA of 34.5–33 ka BP (39–37 ka cal BP), on samples found close to diagnostically Aurignacian bladelets, are in good agreement with the age of similar bladelet assemblages found further west in Europe.

These early EUP assemblages at Kostenki therefore fit well into the overall European chronocultural framework and are consistent with models of the EUP that predict penecontemporaneity of diagnostic assemblage types across large geographic areas.

Finally, our work highlights ongoing problems with the radiocarbon dating of certain Paleolithic sites. Well-stratified contexts were targeted for dating work, so that samples could confidently be related to the archaeological occupation under investigation and an established chronostratigraphic sequence could be used to corroborate results. Using standard collagen purification methods we obtained dates for Kostenki 14 that agreed well with the stratigraphic position of assemblages relative to the CI tephra. However, the same methods produced results for Kostenki 17/II that consistently underestimated the age of the samples, in two cases by around 10,000 (radiocarbon) years. Subsequent redating of samples using HYP pretreatment produced ages compatible with their position below the CI tephra, and in agreement with expectations based on the layer's archaeological contents.

Our work shows that for bones treated with consolidants it is important to use compound-specific methods that exclude these types of contaminants. Our results may also indicate a problem with using standard radiocarbon dating techniques for some open-air sites, perhaps because bones are more likely to be exposed to exogenous soil humate contaminants in these contexts. Work to explore the influence of this continues. In the meantime, models that incorporate independent chronological markers, such as tephras, as well as regional and continental-scale archaeological and technotypological data, are key to the construction of robust chronological frameworks.

Acknowledgements

This research was supported by the Leverhulme Trust (RPG-2012-800). A.B.'s work was supported by grants RFBR 18-39-20009 and RSF 18-78-00136, and by state assignment 0184-2018-0012. NR was supported during the writing of this paper by a Postdoctoral Study Grant from the Fondation Fyssen and the European Union's Horizon 2020 research and innovation programme under Marie Skłodowska-Curie grant agreement No 747400. A.S. acknowledges grant RFBR 17-06-00319a and state assignment 0184-2018-0012, and we also acknowledge the participation of ZIN RAS (state assignment AAAA-A17-117022810195-3). The research that enabled the production of HYP radiocarbon dates came from the European Research Council under the European Union's Seventh Framework Programme (FP7/2007-2013); ERC grant 324139 "PalaeoChron", which also supported N.R., T.D. and T.H. We acknowledge support from the UK Natural Environment Research Council (NERC) for the Oxford node of the national NERC Radiocarbon Facility, and gratefully acknowledge all staff of the ORAU, especially Dan Comeskey for his work on HYP pretreatment. Many thanks are due to the numerous friends and colleagues with whom we have discussed the Kostenki EUP and to several colleagues who kindly offered comments on an earlier draft of this paper, as well as to the reviewers for their helpful comments. We are very grateful to William Banks for discussions, and Maria Medvedeva and Natalia Lazarevskaya for their generous help with the IIMK RAN archive material.

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Table 1

Boriskovskii's (1963) typological counts for lithic material from his 1953 and 1955 excavation of Kostenki 17/II. Boriskovskii's 'special' burin category refers to "burins with a working edge made by a combination of abrupt retouch on the distal edge and a series of thin vertical burin spalls" (Boriskovskii, 1963: 94; translation by A.B.). Note the two artifacts described as (atypical) Kostenki knives do not meet the revised technotypological criteria proposed for this artifact type (Klaric et al., 2015).

Type	Count
End-scrapers	22
Burins:	160
angle burins	4
dihedral burins	10
'special' type	30
burins on truncation	>100
Burin spalls	~600
Splintered pieces	9
'Transitional' type between splintered pieces and flat-faceted burins	15
Kostenki knives (atypical)	2
Points	11
'Large' blades	4
Retouched blades and blade fragments	110
Blades and their fragments	~200
Prismatic cores (+ fragments)	15 (+30)
Hammer-stones	2
Flakes	1800
Chips	7000
Total	9800 (sic)

Table 2

Previously published radiocarbon dates for Kostenki 17/II

Lab code	Sample	Result BP	Reference
LE-1436	Bone	32,780 ± 300	Svezhentsev and Popov, 1993; Sinitsyn et al., 1997
GrN-10512	Charcoal	32,200 ± 2000/1600	Svezhentsev and Popov, 1993; Sinitsyn et al., 1997
GrN-12596	Charcoal	36,780 ± 1700/1400	Svezhentsev and Popov, 1993; Sinitsyn et al., 1997

Table 3

Previously published radiocarbon dates for Kostenki 14/LVA.

Lab code	Sample	Result BP	Reference
GrA-18230	Bone	20,640 ± 170/160	Sinitsyn and Hoffecker, 2006
GrA-18053	Charcoal	32,420 ± 440/420	Sinitsyn and Hoffecker, 2006
OxA-19134	Shell	29,134 ± 140	Sinitsyn, 2014
OxA-19787	Charcoal	33,220 ± 220	Douka et al., 2010
OxA-19021 ^a	Charcoal	35,080 ± 240	Douka et al., 2010
OxA-26313	Bone	33,300 ± 300	Douka and Higham, 2017
OxA-26314	Bone	33,600 ± 300	Douka and Higham, 2017
OxA-X-2642-8	Bone	35,210 ± 400	Douka and Higham, 2017

^a Same sample as OxA-19787 using alternative pretreatment.

Table 4

New radiocarbon dates for Kostenki 17/II. The dates were calibrated against the IntCal13 curve using OxCal version 4.2 (Reimer et al., 2013; Bronk Ramsey, 2017). Technical details related to the sample pretreatment can be found in SOM Table S2. No other radiocarbon dates (or failed dates) were produced for this context in the course of this work.

Sample reference	Material	Species	Museum accession ref	Excavation info	Pretreatment code ^a	Result $\pm 1 \sigma$ SD	Cal BP $\pm 1 \sigma$ SD	Cal BP $\pm 2 \sigma$ SD	Lab code
K2014/1	Tooth	<i>Vulpes lagopus</i>	-	r101, 19	AF*	26,830 \pm 250 BP	31,130–30,810	31,280–30,630	OxA-30824
K2014/2	Tooth	<i>Vulpes lagopus</i>	-	65, 20	AF*	25,480 \pm 220 BP	29,910–29,250	30,300–29,010	OxA-30825
K17-01	Bone	<i>Canis lupus</i>	28468	-	AF*	32,350 \pm 450 BP	36,850–35,690	37,800–35,280	OxA-32594
K17-01	Bone	<i>Canis lupus</i>	28468	-	HYP	35,650 \pm 690 BP	41,060–39,570	41,640–38,860	OxA-X-2677-56

K17-02	Bone	<i>Canis lupus</i>	28468	-	AF*	31,250 ± 400 BP	35,560–34,760	36,060–34,460	OxA-32595
K17-03	Bone	<i>Canis lupus</i>	28468	-	AF*	33,050 ± 500 BP	37,920–36,510	38,540–36,100	OxA-32596
K17-03	Bone	<i>Canis lupus</i>	28468	-	HYP	36,020 ± 740 BP	41,400–39,930	42,000–39,160	OxA-X-2677-57
K2014/1 +	Tooth	<i>Vulpes lagopus</i>	N/A	N/A	HYP	35,840 ± 520 BP	41,070–39,930	41,570–39,380	OxA-X-2717-26
K2014/2									

^a Pretreatment code: AF = ultrafiltered collagen (an asterisk denotes samples that have been solvent washed prior to the AF treatment); HYP = extraction of hydroxyproline from hydrolyzed bone collagen (Brock et al., 2010; Devière et al., 2018). CRA is conventional radiocarbon age, expressed in years BP (Stuiver and Polach, 1977).

Table 5

New radiocarbon dates for Kostenki 14/IVw. Technical details related to the sample pretreatment can be found in SOM Table S3. See caption of Table 4 for details of the terms used. No other radiocarbon dates (or failed dates) were produced for this context in the course of this work.

Sample reference	Material	Species	Excavation info	Pretreatment code	Result $\pm 1 \sigma$ SD	Cal BP $\pm 1 \sigma$ SD	Cal BP $\pm 2 \sigma$ SD	Lab code
K14-03	Bone	<i>Lepus</i> sp.	П-34 н/у -250	AF	35,800 \pm 700 BP	41,200–39,730	41,780–38,990	OxA-33981
K14-04	Bone	<i>Lepus</i> sp.	П-37 яма, н/у -258	AF	36,350 \pm 750 BP	41,660–40,260	42,250–39,510	OxA-33982
K14-05	Bone	<i>Lepus</i> sp.	P-33 -247	AF	35,750 \pm 700 BP	41,150–39,680	41,740–38,940	OxA-33983

Table 6

New radiocarbon dates for Kostenki 14/LVA. Technical details related to the sample pretreatment can be found in SOM Table S4. See caption of Table 4 for details of the terms used. No other radiocarbon dates (or failed dates) were produced for this context in the course of this work.

Sample reference	Material	Species	Excavation info	Pretreatment code	Result $\pm 1 \sigma$ SD	Cal BP $\pm 1 \sigma$ SD	Cal BP $\pm 2 \sigma$ SD	Lab code
K14-11	Bone	<i>Equus ferus</i>	K-14-2000 M-74 (-204) Г.П.	AF*	34,400 \pm 600 BP	39,700–38,330	40,450–37,340	OxA-35311
K14-12	Bone	<i>Equus ferus</i>	K14-ГП-03 M-H76	AF*	34,400 \pm 550 BP	39,610–38,380	40,330–37,540	OxA-35312
K14-13	Bone	<i>Equus ferus</i>	K14-ГП-03 M77	AF*	33,400 \pm 500 BP	38,370–36,980	38,830–36,350	OxA-35313
K14-14	Bone	<i>Equus ferus</i>	K14-03-ГП M-76 (-196) вне зольной линзы	AF*	33,150 \pm 500 BP	38,070–36,660	38,610–36,190	OxA-35314

Table 7

Platform type for detachment of burin spalls for 138 burins (32 double) in the studied Kostenki 17/II assemblage.

Platform	Count
Break	20
Burin spall	9
Truncation	136
Unmodified edge	2
Indet.	3
Total	170

Table 8

Truncation type for truncation burin removal platforms in the studied Kostenki 17/II assemblage.

Truncation type	Count
Slightly concave	6
Indet.	2
Lateral	10
Concave	37
Oblique	76
End-scraper front	3
Straight	2
Total	136

Table 9

The six modified bladelets from Kostenki 17/II (see Fig. 7).

Artifact number	Portion	Raw material	Modification position/extent	Retouch type	Width (mm)	Thickness (mm)	Length (mm)	Core type	Notes
1024	Mesial	Brown chert	Right edge, ventral, proximal-mesial Left edge, dorsal, mesial-distal	Marginal, semiabrupt	6.3	1.5	24.7	Indet.	Near complete
545	Mesial-distal	Black flint	Right edge, dorsal, proximal-mesial	Marginal, low	7.1	2.0	33.9	Indet.	Few facets only (=use?); near complete
745	Proximal	Black flint	Right edge, ventral, proximal (removal of butt) Right edge, dorsal, proximal	Marginal, semiabrupt/abrupt	5.0	2.3	23.9	Burin	Burned; incomplete
894	Complete	Black flint	Right edge, dorsal,	Marginal,	5.9	2.7	24.7	Indet.	Hinge termination

593	Complete	Black flint	proximal Left edge, dorsal, proximal-mesial	semiabrupt Marginal, semiabrupt	5.8	1.8	25.1	Burin	Small distal burination
188	Proximal- Mesial	Indet. (heavily patinated)	Right edge, ventral, entire edge Left edge, dorsal, proximal,	Marginal, semiabrupt	7.7	3.1	25.2	Indet.	Tip broken; near complete

Table 10

Metrics for the Kostenki 17/II bladelets (Table 9) and retouched bladelets from the Proto-Aurignacian of Les Cottés and Isturitz (France) and Fumane (Italy); data from Falcucci et al. (2018).

	Site	Mean (mm)
Length	Fumane ($n = 85$)	26.6
	Isturitz ($n = 15$)	25.1
	Les Cottés ($n = 2$)	26.7
	Kostenki 17/II ($n = 5$)	26.7
Width	Fumane ($n = 1751$)	6.5
	Isturitz ($n = 963$)	5.3
	Les Cottés ($n = 150$)	6.8
	Kostenki 17/II ($n = 6$)	6.3
Thickness	Fumane ($n = 1751$)	1.7
	Isturitz ($n = 963$)	1.5
	Les Cottés ($n = 150$)	1.9
	Kostenki 17/II ($n = 6$)	2.2