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THE CHRONOLOGY OF EARLY MODERN HUMANS IN EASTERN EUROPE, SIBERIA AND EAST ASIA: RESULTS AND PROBLEMS

Abstract

This article presents an analytical review of the direct radiocarbon dating evidence of anatomically modern human fossil remains (early *Homo sapiens*) from Palaeolithic contexts in Eastern Europe, Siberia and East Asia, with a brief mention of other regions in Eurasia. One of the most ancient finds for entire Eurasia, which provided a direct radiocarbon date, is Ust'-Ishim in Western Siberia (ca. 45,000 years ago); in Eastern Europe, the earliest directly-dated *H. sapiens* fossils are Kostenki 14 and Kostenki 1 (ca. 35,500-37,400 years ago). For a number of finds (such as Kostenki 18, and human fossils from the site of Sungir), there are serious problems that need to be solved with help of new data. This is particularly clear for Sungir where 21 radiocarbon dates were obtained on different collagen fractions (bulk collagen; ultrafiltered collagen; and hydroxyproline), and dates, even of the same skeleton, often contradict each other. Prevailing methodological issues of radiocarbon dating bones, and the importance of possibilities to assess independently the results obtained, are also considered. When preservation of collagen (which can be controlled using a number of parameters) is good, dating of the bulk collagen fraction appears to be reliable. Claims that only specific amino acids (such as hydroxyproline) give accurate radiocarbon dates for bone are not strictly proven.

Keywords

Radiocarbon dating, anatomically modern human fossils, Palaeolithic, Eastern Europe, Siberia, East Asia

INTRODUCTION

Establishing a reliable chronology is an essential part of Palaeolithic research. The most common way to determine the age of ancient sites is the radiocarbon (^{14}C) dating method. At present, this method has been used to understand the main temporal patterns of the Upper Palaeolithic cultural complexes in northern Eurasia (e. g., Kuzmin, 2007; Anikovich et al., 2007; Kuzmin et al., 2011; Qu et al., 2013; Pitulko and Pavlova, 2016, 2020; Keates et al., 2019; Dinnis et al., 2019; Pavlova and Pitulko, 2020).

One of the directions in the study of the Upper Palaeolithic concerns the chronology of human fossils. Starting from about 40,000 calendar years ago (cal BP), practically only one species of hominin was distributed throughout Eurasia – anatomically modern humans (early modern *Homo sapiens*, *H. sapiens*; hereafter: EMHS). According to direct ^{14}C dating of Neanderthal fossils, they survived in Europe until ca. 35,400-38,800 cal BP (Kuzmin and Keates, 2014: 756) and possibly to ca. 40,600-44,200 cal BP only (see Devièse et al., 2021), and therefore Neanderthals for some time coexisted with modern humans.

The most reliable estimate for the antiquity of human fossils is their direct (i. e., obtained on bones and teeth of ancient humans) ^{14}C age determination; these data and their analysis are the focus of this article. A seminal paper by Street et al. (2006) clearly demonstrated the importance of such direction in Palaeolithic research. By acknowledging the pioneering role of Dr. Martin Street in this respect, here the main attention is given to Eastern Europe, Siberia, and East Asia, with a brief discussion of EMHS chronology for other parts

In: S. Gaudzinski-Windheuser · O. Jöris (Eds.), The Beef behind all Possible Pasts. The Tandem-*Festschrift* in Honour of Elaine Turner and Martin Street. Monographien des RGZM 157 (Mainz 2021). DOI: 10.11588/propylaeum.868.c11317

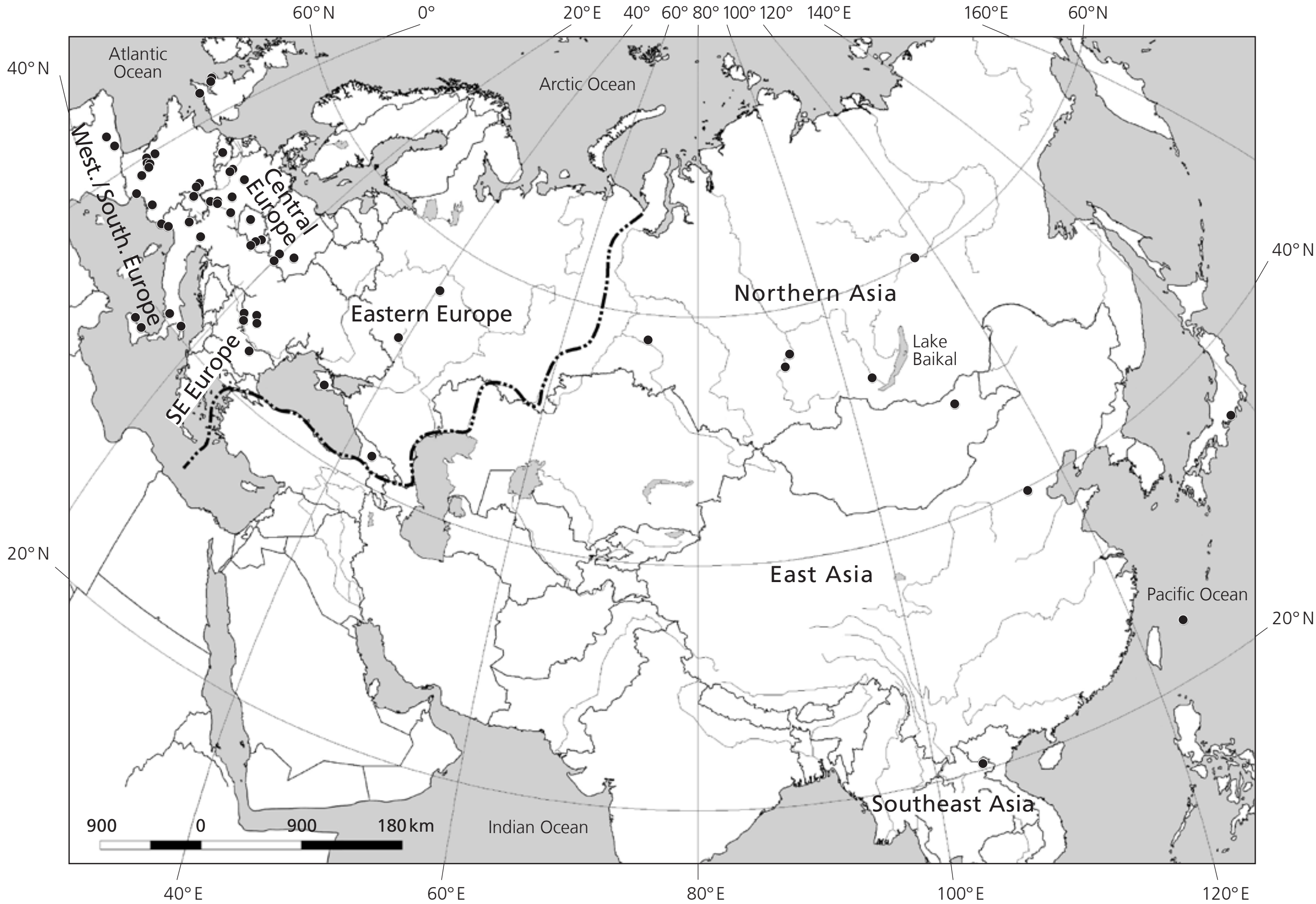

Fig. 1 Geographic distribution of early modern *H. sapiens* (EMHS) finds in Eurasia with direct ^{14}C dates (according to the data as of January 2021); names of locations are indicated in Kuzmin and Keates (2014).

of Eurasia. The importance of reliable age determination for EMHS fossils increased significantly after the accumulation of the initial "critical mass" of information on DNA of ancient hominins (see reviews: Nielsen et al., 2017; Skoglund and Mathieson, 2018; Yang and Fu, 2018).

MATERIALS AND METHODS

Currently (as of January 2021), about 120 direct ^{14}C dates have been published for EMHS fossils from Eurasia (**Fig. 1**; Kuzmin and Keates, 2014; see also: Formicola et al., 2005; Krause et al., 2007; Craig et al., 2010; Marom et al., 2012; Gazzoni et al., 2013; Fu et al., 2014, 2016; Kuzmin et al., 2014; Reynolds et al., 2017; Garralda et al., 2019; Devièse et al., 2019; Hublin et al., 2020; Kılınç et al., 2021). The geographical distribution of dated finds is not even (**Fig. 2**): Europe accounts for 88 % of the total (Western, Southern, Central and Southeastern Europe: 84 %; Eastern Europe: 4 %), and Asia for 12 %. Thus, Eastern Europe, Siberia and the neighbouring regions of Asia constitute 16 % of the ^{14}C-dated EMHS.

Until now, there has been no clear explanation for the phenomenon of the small number of EMHS fossils in Siberia and Eastern Europe; this problem is specifically discussed by Turner et al. (2013: 386-390). Reference to the insufficient degree of Palaeolithic research in Siberia compared to Western/Central Europe does not look convincing, because in southern Siberia systematic studies of the Palaeolithic have been carried out since 1871 when the very first Russian Palaeolithic site of 'Military Hospital' was discovered in the city of Irkutsk (Larichev et al., 1990).

Since the 1970s, collagen – the major organic part of the bone – has been used for ^{14}C dating of animal and human remains. Several methods are now employed to extract collagen from the raw bones/teeth/tusks: 1) dissolution of small pieces (up to 2-3 cm long) in a weak solution of hydrochloric acid (HCl) (e.g., Arslanov and Svezhentsev, 1993); the resulting material is often assigned as "bulk collagen"; 2) dissolution of powdered material in HCl (Longin, 1971); with a certain reservation, such material can also be called "bulk collagen"; 3) ultrafiltration, with extracted collagen passed through a filter with the size of holes small enough to allow only molecules with an atomic weight of less than 30,000 Daltons (atomic weight units) to go through; the remaining material with a weight greater than 30,000 Daltons is the subject of ^{14}C dating (Higham et al., 2006a; Brock et al., 2010); this can be classified as "ultrafiltered collagen"; 4) extraction of specific amino acids from collagen, mainly hydroxyproline (HYP) (McCullagh et al., 2010; Marom et al., 2012); this may be called "individual amino acids"; and 5) extraction of collagen using absorbent resins of the XAD-2 type (Stafford et al., 1988); this can be defined as "resin-purified collagen". The most widespread methods at present are numbers 1-3; in some cases, methods numbers 4-5 are used.

One of the most important aspects of ^{14}C dating Palaeolithic human bones and Late Pleistocene mammals is the quality assessment for the material dated. At present, certain criteria to estimate the suitability of extracted collagen have been developed (van Klinken, 1999; Brock et al., 2012): 1) the collagen content should ideally be more than 1 % weight (sometimes 0.5-1 % weight is sufficient); 2) the carbon content in collagen should be about 20-35 %, and the nitrogen content about 11-16 %; these values are approximate; 3) the atomic ratio of carbon to nitrogen (C:N) in collagen should be in the range of 2.9-3.6, and in some cases no more than 3.2-3.3; and 4) the ratios of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotopes in

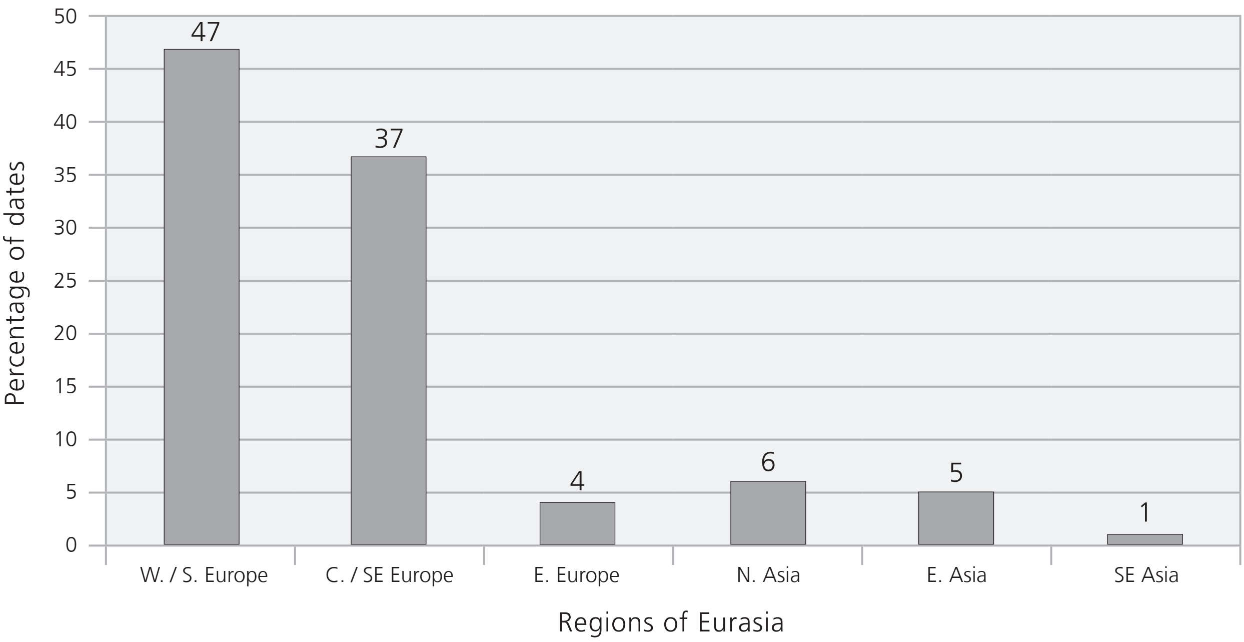

Fig. 2 Distribution of early modern *H. sapiens* (EMHS) ^{14}C dates by main regions of Eurasia (according to the data as of January 2021).

collagen for terrestrial organisms and humans should generally be within the ranges of -19‰ ÷ -22‰ (for $\delta^{13}C$), and +2‰ ÷ +12‰ (sometimes up to +17‰) (for $\delta^{15}N$). In cases when at least one of these criteria is not met, the ^{14}C date cannot be considered as reliable.

To compare the ^{14}C dates with the palaeoclimatic events of the Late Pleistocene – in particular, with the global climate fluctuations based on the Greenland ice core records – it is necessary to convert the ^{14}C ages into the calendar (astronomical) time scale. In order to do so, calibration software Calib Rev 7.0.4 (available at: http://calib.org/calib/), based on international standards (Reimer, 2020; Reimer et al., 2013), is used here. When performing the calibration, certain rules should be followed: 1) use a standard deviation of ± 2 sigma (σ); 2) round off the calibration results to the next 10 years; and 3) combine all the possible calendar intervals together. In this paper, mostly calibrated ^{14}C dates (expressed as "cal BP") are used; sometimes, uncalibrated ^{14}C ages (given as "BP") are also applied.

RESULTS

General chronology of early modern humans in Eurasia: a brief overview

The overall chronology of Pleistocene modern humans in Eurasia, based on direct ^{14}C age determinations, is shown in **Figure 3**. The oldest in Asia is the Ust'-Ishim human from West Siberia, dated to ca. 45,000 years ago (y.a.; hereafter "y.a." is the average value of the age intervals of calibrated ^{14}C dates). Another very early date for East Asia is Tianyuan Cave (northern China), about 39,500 y.a. In Europe, the oldest finds of early modern humans are dated to ca. 44,800 y.a. (Bacho Kiro, south-eastern Europe); ca. 37,800 y.a. (Kostenki 14, Eastern Europe); and ca. 35,400 y.a. (Kent's Cavern, Western/Southern Europe) (Kuzmin and Keates, 2014; Fu et al., 2014; Hublin et al., 2020).

As for the chronological relationship between EMHS in Eurasia and palaeoclimatic events of the second half of the Late Pleistocene (Seierstad et al., 2014; Rasmussen et al., 2014), the following patterns can be noted. Only a small number of EMHS finds corresponds to the time of the Last Glacial Maximum (LGM) (**Fig. 3**), currently dated to ca. 24,000-28,000 cal BP (Seierstad et al., 2014), or in a somewhat wider range to ca. 22,900-27,300 cal BP (Kuzmin and Keates, 2018). This undoubtedly reflects the fact that the Palaeolithic populations of Eurasia declined during the coldest and driest climatic conditions for the last 130,000 years. However, there is evidence of human habitation in the periglacial zone of Eastern Europe and southern Siberia during the LGM (Kuzmin, 2008; Kuzmin and Keates, 2005, 2013, 2018; Pitulko and Pavlova, 2020). In addition, a number of EMHS finds corresponds to other cold stages of the second half of the Late Pleistocene. For example, the Kostenki 1 skeleton dated to ca. 35,950 y.a. (mean calendar value of two ^{14}C dates) corresponds to the Greenland GS-8 cold interval (ca. 36,000 cal BP) (Kuzmin, 2019). Thus, Upper Palaeolithic people possessed a sufficient set of tools (dwellings; complex clothes made from sewn pieces of skin; cf. Gilligan, 2019), which allowed them to survive even in high latitudes.

In addition to the ^{14}C method, there are also direct age determinations of EMHS obtained by other techniques with a wider dating range (cf. Walker, 2005). The most reliable is the Uranium series (U-series) method, sometimes used in conjunction with Electron Spin Resonance dating (ESR). The oldest find of

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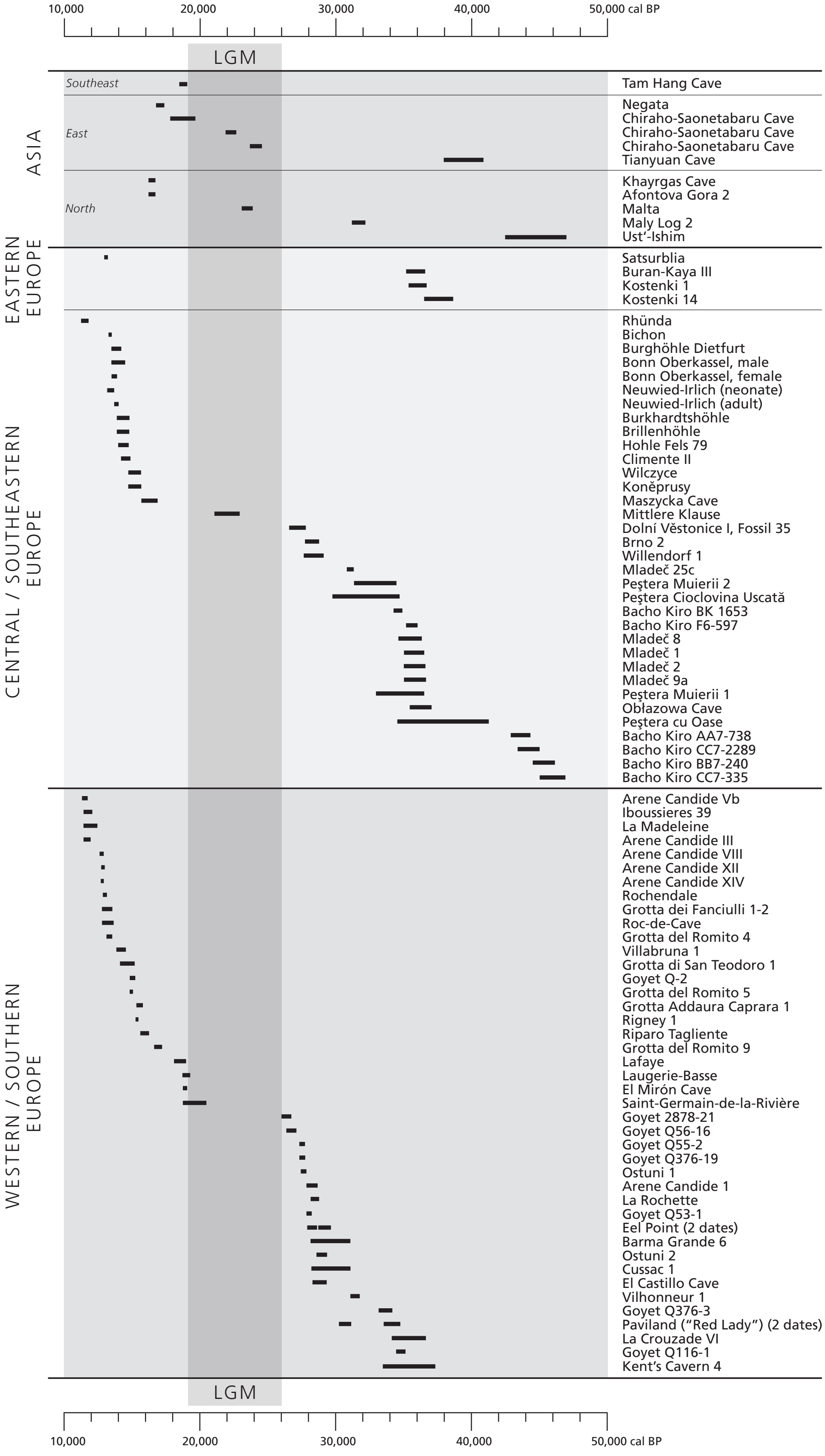
Fig. 3 General chronology of early modern *H. sapiens* (EMHS) in Eurasia based on direct ^{14}C dates (LGM Last Glacial Maximum); names of finds are indicated to the right. Data compiled after Kuzmin and Keates (2014), with additions.


10,000
20,000
30,000
40,000
50,000 cal BP
LGM
ASIA
Southeast
East
North
EASTERN EUROPE
CENTRAL / SOUTHEASTERN EUROPE
WESTERN / SOUTHERN EUROPE
Tam Hang Cave
Negata
Chiraho-Saonetabaru Cave
Chiraho-Saonetabaru Cave
Chiraho-Saonetabaru Cave
Tianyuan Cave
Khayrgas Cave
Afontova Gora 2
Malta
Maly Log 2
Ust'-Ishim
Satsurblia
Buran-Kaya III
Kostenki 1
Kostenki 14
Rhünda
Bichon
Burghöhle Dietfurt
Bonn Oberkassel, male
Bonn Oberkassel, female
Neuwied-Irlich (neonate)
Neuwied-Irlich (adult)
Burkhardtshöhle
Brillenhöhle
Hohle Fels 79
Climente II
Wilczyce
Koněprusy
Maszycka Cave
Mittlere Klause
Dolní Věstonice I, Fossil 35
Brno 2
Willendorf 1
Mladeč 25c
Peştera Muierii 2
Peştera Cioclovina Uscată
Bacho Kiro BK 1653
Bacho Kiro F6-597
Mladeč 8
Mladeč 1
Mladeč 2
Mladeč 9a
Peştera Muierii 1
Obłazowa Cave
Peştera cu Oase
Bacho Kiro AA7-738
Bacho Kiro CC7-2289
Bacho Kiro BB7-240
Bacho Kiro CC7-335
Arene Candide Vb
Iboussieres 39
La Madeleine
Arene Candide III
Arene Candide VIII
Arene Candide XII
Arene Candide XIV
Rochendale
Grotta dei Fanciulli 1-2
Roc-de-Cave
Grotta del Romito 4
Villabruna 1
Grotta di San Teodoro 1
Goyet Q-2
Grotta del Romito 5
Grotta Addaura Caprara 1
Rigney 1
Riparo Tagliente
Grotta del Romito 9
Lafaye
Laugerie-Basse
El Mirón Cave
Saint-Germain-de-la-Rivière
Goyet 2878-21
Goyet Q56-16
Goyet Q55-2
Goyet Q376-19
Ostuni 1
Arene Candide 1
La Rochette
Goyet Q53-1
Eel Point (2 dates)
Barma Grande 6
Ostuni 2
Cussac 1
El Castillo Cave
Vilhonneur 1
Goyet Q376-3
Paviland ("Red Lady") (2 dates)
La Crouzade VI
Goyet Q116-1
Kent's Cavern 4
LGM
10,000
20,000
30,000
40,000
50,000 cal BP

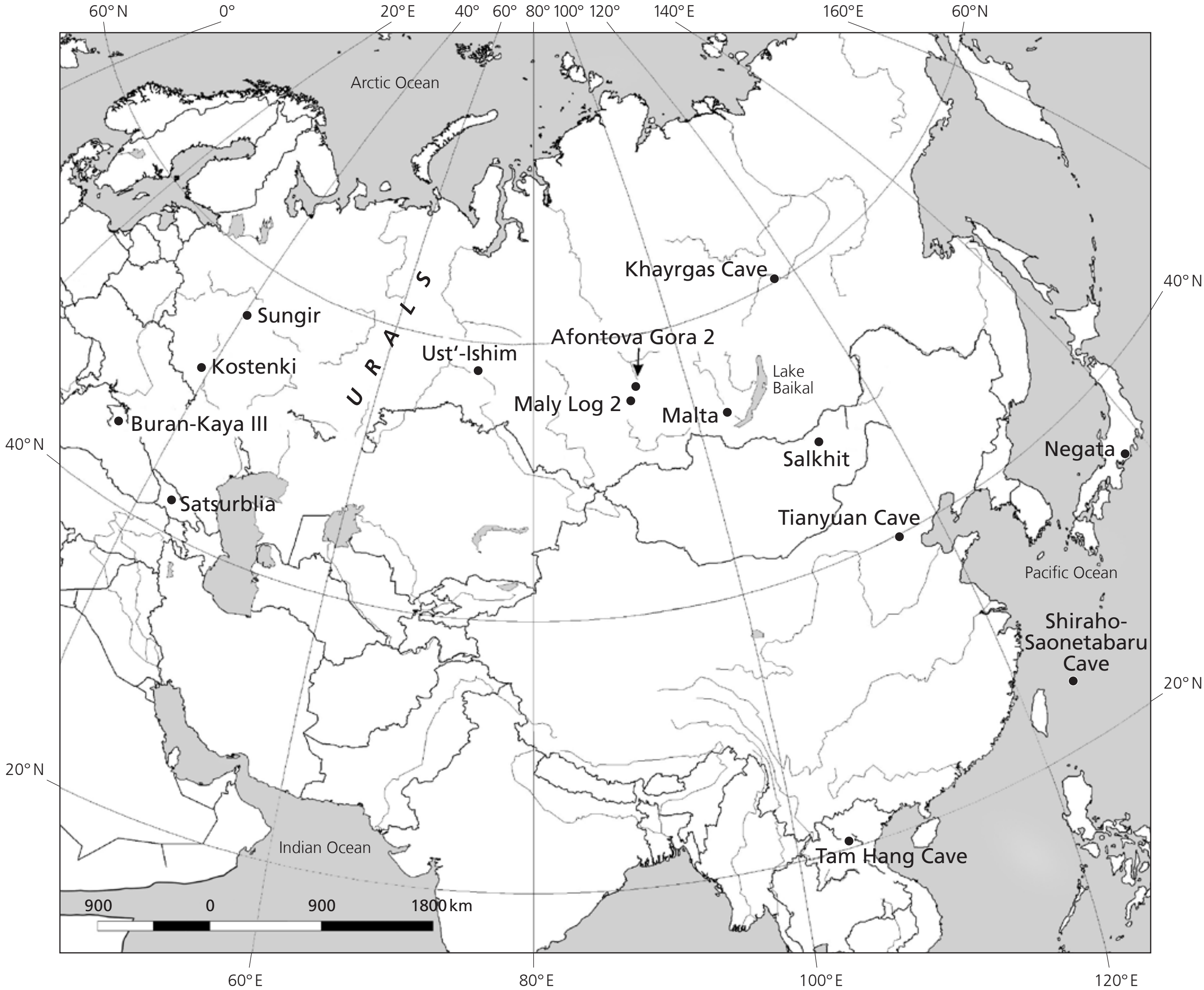


Fig. 4 Geographic distribution of early modern *H. sapiens* (EMHS) with direct ^{14}C dates in Eastern Europe and Asia (according to the data as of January 2021).

Pleistocene *H. sapiens* in Eurasia comes from the Misliya Cave in the Levant; the combined age by the U-series and ESR methods is 174,000 ± 20,000 (calendar) years ago (Hershkovitz et al., 2018). For South-east Asia, the earliest date is from the Niah Cave dating to 35,200 ± 2,600 years ago; for Tabon Cave dates in the range of ca. 16,500-47,000 years ago are less reliable (cf. Keates et al., 2012: 343-346).

Reviews of other direct dates using the U-series method for EMHS in Eurasia are presented in our works (Keates et al., 2012; Kuzmin and Keates, 2014). It should be emphasized that the early dates for the Skhul II and Skhul IX in the Levant, in the range of ca. 121,000-131,000 years ago, are quite problematic (cf. Grün, 2006: 31-34). The issue of the age for modern human remains in Tam Pa Ling Cave in Laos, ca. 46,000 years ago or older (Demeter et al., 2012), needs further confirmation (cf. Pierret et al., 2012).

Radiocarbon chronology of early modern humans in Eastern Europe, Siberia and East Asia

For Eastern Europe, Siberia, and East Asia, relatively few ^{14}C dates have been obtained on EMHS fossils (**Figs. 4-5**; **Tab. 1**). As it was already noted, the earliest finds are Ust'-Ishim and Kostenki 14 (**Fig. 5**). It is of some interest that the Ust'-Ishim specimen in West Siberia, along with Bacho Kiro in south-eastern Europe (**Fig. 3**), have provided some of the oldest direct ^{14}C dates for EMHS in entire territory of Eurasia.

An important aspect of determining the ^{14}C age is the ability to control the results obtained using independent information – for example, stratigraphic markers such as layers of volcanic ash (tephra) with a known age. Unfortunately, in most cases such verification is impossible. However, for two sites of the Kostenki site cluster in Eastern Europe stratigraphic age confirmation is given.

For the Kostenki 1 skeleton (Layer 3), two ^{14}C dates were generated resulting in ca. 35,520 y.a. (collagen without ultrafiltration) and ca. 36,360 y.a. (ultrafiltered collagen, **Tab. 1**). These calendar ages correspond well to the chronology of Layer 3, for which a series of ^{14}C dates was obtained on charcoal with the earliest one of ca. 35,500 cal BP. It also fits well the general stratigraphy of the site where Layer 3 is very likely to be located above the tephra layer known as the Campanian Ignimbrite (CI) dated to ca. 39,000-40,000 cal BP (Holliday et al., 2007; cf. Muscheler et al., 2020). The CI tephra is also present at the Kostenki 14 site, where the age of a human burial dated using HYP is ca. 37,400 y.a. (Marom et al., 2012; **Tab. 1**). The well-preserved modern human skeleton here is associated with Layer 3, and it was found in a shallow pit which cuts through the CI tephra. Other ^{14}C dates from Layer 3 of Kostenki 14 are in the range of ca. 32,300-35,700 cal BP (Holliday et al., 2007); according to the latest information, the age of Layer 3 is younger than ca. 37,300-38,900 cal BP (Dinnis et al., 2019).

Difficulties with ^{14}C dating of some EMHS fossils (Kostenki 18, Sungir, and Salkhit), as well as with the ^{14}C age of finds with unclear species determination (Tuyana and Okladnikov Cave) should be considered separately.

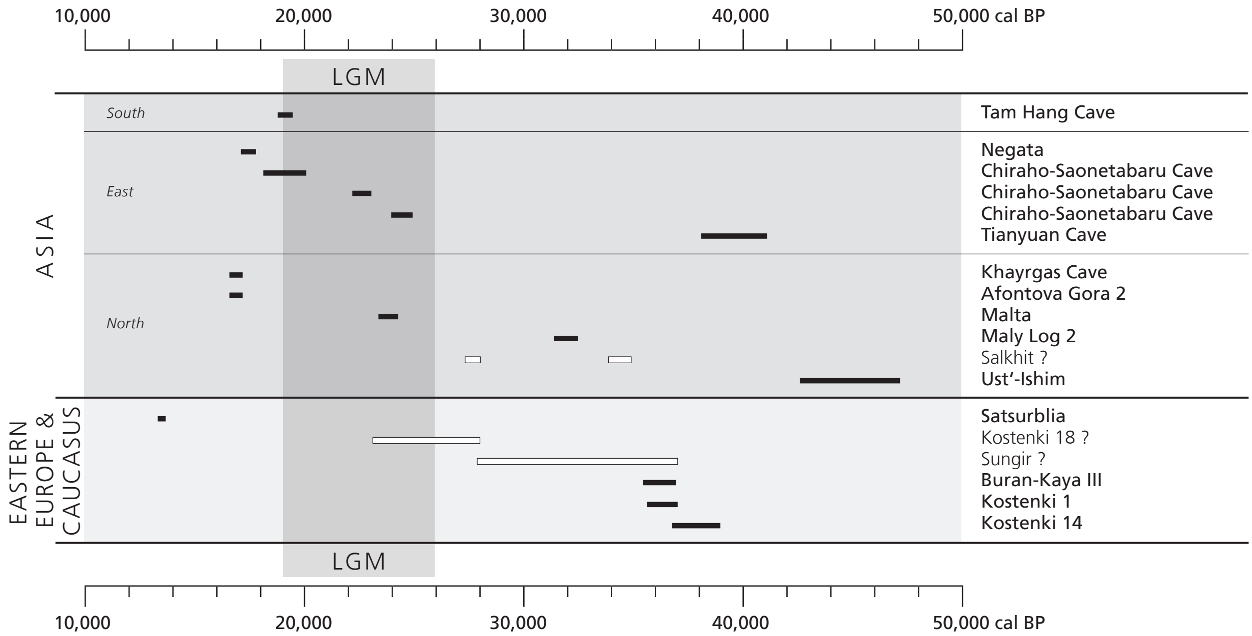


Fig. 5 Chronology of early modern *H. sapiens* (EMHS) in Eastern Europe and Asia (cf. **Tab. 1**; ages of problematic finds are shown by non-filled rectangles); LGM Last Glacial Maximum.

For Kostenki 18, several ^{14}C dates (**Fig. 6**) were obtained on mammoth and human bones (Reynolds et al., 2017). The discrepancy between the age of the burial based on ^{14}C-dated HYP fraction and the overlying mammoth bones which are clearly younger than the human bones is noteworthy, although it is assumed that the skeleton and overlaying mammoth bones were simultaneously placed in the ground (Reynolds et al., 2017: 1439). Also, the ^{14}C dates for human bones run on bulk collagen and HYP differ significantly from each other (**Fig. 6**). The reasons for these discrepancies remain unclear. Therefore, it is not possible to accept the conclusion by Reynolds et al. (2017) about the age of the Kostenki 18 modern human as ca. 27,600 y.a. Further work is required, including new ^{14}C dates on animal bones from this site.

The situation with the ^{14}C age of the Sungir burials looks even more complicated; this issue was discussed several times (cf. Kuzmin et al., 2014; Reynolds et al., 2017; Kuzmin, 2019; Higham, 2019; Pettitt, 2019). By February 2020, a total of 21 ^{14}C values had been generated for five EMHS fossils from this site (**Fig. 7**). Their ages range from ca. 23,000-31,800 y.a. (Kuzmin et al., 2014; Sikora et al., 2017) to ca. 34,000-34,100 y.a. (Marom et al., 2012; Nalawade-Chavan et al., 2014). Because there is no independent stratigraphic marker for the Sungir site that could help to establish the upper or lower limit for the antiquity of human bones, the only indirect way to assess the reliability of their ^{14}C dates is to compare them with the age of animal bones from the same site.

The age of the reindeer bones is ca. 30,700-31,500 y.a.; and the ^{14}C date of horse bones collected from a relatively large area is ca. 29,900 y.a. In addition, the ^{14}C values of the woolly mammoth (*Mammuthus primigenius*) bone from a clear stratigraphic context (horizons 3 and 4, i.e., the lower part of the cultural layer) are ca. 30,400-32,000 y.a. (non-ultrafiltered bulk collagen). It should be noted that the ^{14}C dates of ca. 33,600-34,200 y.a., generated for the mammoth bone using ultrafiltered collagen and HYP (Marom et al., 2012; cf. Kuzmin, 2019), are clearly older than the bulk collagen ^{14}C age of ca. 31,400 y.a. for the same specimen. The reason for this is still not clear. Most of the other mammoth bones from Sungir have a ^{14}C age similar to the value generated on non-ultrafiltered collagen from horizons 3-4: ca. 30,700-

Locality	Laboratory code	^{14}C date [BP]	Calendar age [cal BP]	Reference
Ust'-Ishim	OxA-25516	41,400 ± 1,300	43,210-46,880	Fu et al., 2014
Tianyuan Cave	BA-03222	34,430 ± 510	38,120-40,940	Shang et al., 2007
Kostenki 14	OxA-X-2395-15	33,250 ± 500	36,690-38,980	Marom et al., 2012
Kostenki 1	OxA-15055	32,070 ± 190	35,710-37,000	Higham et al., 2006a
Buran-Kaya III	GrA-37938	31,900 +240/-200	35,510-36,890	Prat et al., 2011
Maly Log 2 (Pokrovka 2)	OxA-19850	27,740 ± 150	31,420-32,440	Akimova et al., 2010
Shiraho-Saonetabaru Cave	MTC-12820	20,415 ± 115	23,930-24,780	Nakagawa et al., 2010
	MTC-13228	18,750 ± 100	22,060-22,900	Nakagawa et al., 2010
	MTC-12818	15,750 ± 420	18,000-19,840	Nakagawa et al., 2010
Malta (Mal'ta)	UCIAMS-79666	20,240 ± 60	23,890-24,420	Raghavan et al., 2013
	OxA-7129	19,880 ± 160	23,330-24,260	Richards et al., 2001
Tam Hang Cave	GrA-10952	15,740 ± 80	18,670-19,280	Demeter et al., 2009
Negata	Beta-160572	14,200 ± 50	16,970-17,580	Kondo and Matsu'ura, 2005
Afontova Gora 2	UCIAMS-79661	13,810 ± 35	16,750-17,080	Raghavan et al., 2013
Khayrgas Cave	Beta-453115	13,790 ± 40	16,550-16,940	Kılınç et al., 2021
Satsurblia	OxA-34632	11,415 ± 50	13,130-13,380	Fu et al., 2016

Tab. 1 Direct ^{14}C dates of early modern *H. sapiens* (EMHS) in Eastern Europe, Siberia and Asia (as of January 2021). Calibration performed using Calib Rev 7.0.4 software (available at http://calib.org/calib/), with ± 2 sigma.

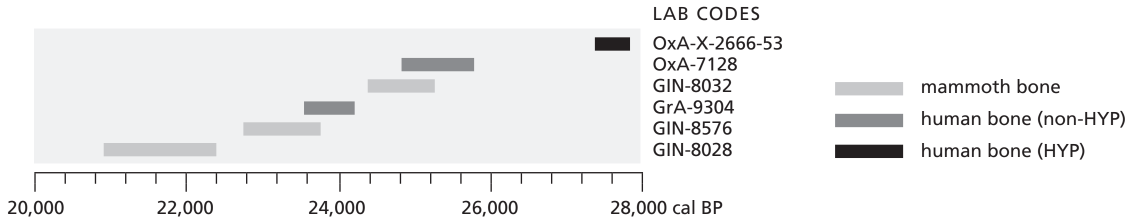


Fig. 6 The calibrated ^{14}C dates of early modern *H. sapiens* (EMHS) and mammoth bones at the Kostenki 18 site (Reynolds et al., 2017; Kuzmin, 2019); lab codes for ^{14}C dates are shown to the right.

32,000 y. a. (Trinkaus et al., 2015). It can be concluded that the ^{14}C dates of human bones obtained using HYP, when compared to the ^{14}C age of the reindeer and horse bones, as well as the majority of mammoth ^{14}C values, seem to be clearly older. Given this, the "true" age of the Sungir EMHS, however, remains unknown (Kuzmin, 2019; Kuzmin et al., 2014).

As for the EMHS skull cap found in northern Mongolia, in the area of Salkhit within a gold placer field, two ^{14}C dates were obtained: ca. 27,700 y. a. on ultrafiltered collagen; and ca. 34,000 y. a. on HYP (Devièse et al., 2019) (**Fig. 5**). Since there is no additional information about the age of what is essentially a surface find, such a significant difference between the ^{14}C dates of the two collagen fractions generates the question which age should be accepted as the valid one? Devièse et al. (2019) believe that the HYP ^{14}C value looks more reliable because the skull cap from which the sample was taken had been treated with conservants. This conclusion is part of a more general approach *sensu* Higham (2011, 2019) who considers the oldest ^{14}C values as the most reliable ones because younger ^{14}C dates reflect contamination which was not removed prior to dating (see also Discussion). In my opinion, the question of Salkhit's age remains entirely unresolved.

For one of the hominin bones found at Okladnikov Cave in the Altai Mountains of southern Siberia (a fragment of an adult humerus; Krause et al., 2007), a ^{14}C date of ca. 28,300 y. a. was obtained. Because DNA was not retrieved from this sample (Krause et al., 2007: SI, p. 4), it is impossible to establish its taxonomic affiliation, whether it is a Neanderthal or a modern human. The age of the latest Neanderthals in Eurasia is ca. 35,400-38,800 y. a. (Kuzmin and Keates, 2014). Thus, the adult humerus from Okladnikov Cave most likely belongs to a EMHS. In this case, again, the question arises about the degree of disturbance of the site's stratigraphy as suggested by Turner et al. (2013: 220; cf. Kuzmin and Keates, 2020).

More recently, data on hominin fossils from the Tuyana site in the Cis-Baikal region of southern Siberia were published (Vasiliev et al., 2017; Shchetnikov et al., 2019). For two human bones, ^{14}C dates of ca. 31,100 y. a. and ca. 52,800 y. a. were generated. Because it is impossible to determine unequivocally the hominin species to which the Tuyana finds belong, the question remains open until the results of ancient DNA analysis will be available (Vasiliev et al., 2017: 159). Based on the general chronology of EMHS in Eurasia (**Fig. 3**), it can be assumed that a bone with a date of ca. 31,100 y. a. belongs to a modern human.

Errors in radiocarbon dating of early modern humans in Eurasia

In rare cases, errors in the ^{14}C dating of EMHS have occurred, and were subsequently corrected. The human talus bone found at the Baigara locality in central West Siberia was originally ^{14}C dated to $>$ 44,300 BP (Kuzmin et al., 2009). When the DNA was extracted from this bone at the Institute for Evolutionary Anthropology of the Max Planck Society (Leipzig, Germany), it turned out that the DNA structure is atypical for the

Palaeolithic (B. Viola, personal communication 2011). Repeated ^{14}C dating in three laboratories (University of Arizona, Tucson, AZ, USA; University of Groningen, Groningen, the Netherlands; and Klaus-Tschira Laboratory, Mannheim, Germany) showed that the age of the bone is much younger, ca. 10,300-10,440 y.a. (Kuzmin, 2016). Upon additional investigation, it was found that this happened as a result of the unintentional misplacement of two samples at the AMS Laboratory of the University of Arizona in 2008: at some stage, the bone of a fossil elk (*Alces latifrons* or *A. alces*) was mislabelled as a human bone. Initially, the elk bone was ^{14}C-dated to ca. 10,100 cal BP (Kuzmin et al., 2009). The subsequent re-dating of the elk gave the age of > 44,000 BP (G.W.L. Hodgins, personal communication 2013). However, this was a single error in this laboratory in the dating of about 1000 samples submitted by me in 1997-2014. Thus, Baigara should be excluded from the list of EMHS localities in Siberia (Kuzmin and Keates, 2014: 760).

DISCUSSION

Nowadays, it seems obvious that ^{14}C dating of materials (presumably) associated with human remains (for example, animal bones or charcoal from the layer in which human bones are found) does not always give a reliable result. A clear case is the Vogelherd Cave in southern Germany, where *H. sapiens* remains were dug into an early Upper Palaeolithic (Aurignacian) cultural layer. The directly ^{14}C-dated human bones transpired to be much younger, ca. 5500-5750 y.a. (Conard et al., 2004), than the animal bones from the Aurignacian, dating to ca. 35,700-40,300 y.a. (Conard and Bolus, 2003), indicating a Neolithic burial context for the human remains (Conard et al., 2004). Ironically, for many years the presumed "undisturbed" stratigraphy of the Vogelherd Cave did not raise any doubts among Palaeolithic experts on the context of these finds. Another example is the estimated age of an EMHS child burial at the Hungsugul Cave of the Turubong (Durubong) cave complex in South Korea (Nelson, 1993: 43; Norton, 2000). This burial, excavated in 1982, had always been associated with the Palaeolithic (e.g., Lee, 1997). Direct ^{14}C dating of this skeleton, finally conducted in the mid-2000s (de Lumley et al., 2011: 286), generated a very late age that falls into the seventeenth to nineteenth centuries AD.

To these cases one can add the unexpectedly late, Holocene ^{14}C dates for a number of presumed Pleistocene EMHS finds in Germany, including even skeletal remains that were previously directly ^{14}C-dated to ca. 40,800 y.a. (Hahnöfersand), 29,800-31,700 y.a. (Paderborn-Sande), ca. 25,500 y.a. (Binshof-Speyer), and ca. 35,200 y.a. (Kelsterbach) (Street et al., 2006). Also, some human fossils from Germany initially associated with the Palaeolithic, like Urdhöhle Cave, Weißenthurm, and Niedermendig, turned out to be of the Holocene age after direct ^{14}C dating (Street and Terberger, 2004: 288-289).

The studies by Street et al. (2006), and Street and Terberger (2004) serve as excellent examples of how additional research fundamentally changed the view of the archaeological record. It can be added that by direct ^{14}C dating of some surface finds of modern humans, which were considered to be of Late Pleistocene age, it was possible to establish their antiquity towards a much younger date, like in the case of a femur from the Ordos region in northern China (Keates et al., 2007).

There are considerable more examples of conflicting dating results of EMHS based on *indirect* dates, and here I discuss one of them in order to illustrate the danger of uncritical acceptance of such ages. Liu et al. (2015) dated the geological contexts of modern human teeth in Fuyan Cave in southern China by the U-series method to ca. 80,000-120,000 years ago. From Layer 1, overlying the human fossils, a U-series date of ca. 80,000 years ago was obtained on carbonates (speleothems, in this case flowstone and stalagmites). From Layer 2, containing the teeth of EMHS, U-series dates on carbonates have resulted in a large scatter of

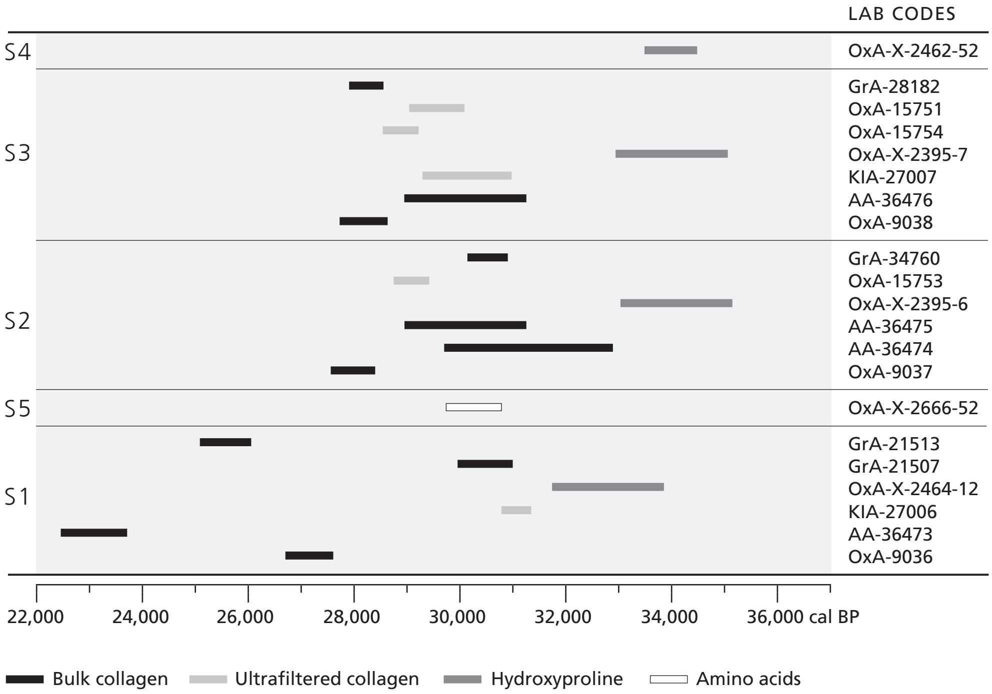


Fig. 7 The calibrated ^{14}C dates of early modern *H. sapiens* (EMHS) at the Sungir site (Kuzmin, 2019; Kuzmin et al., 2014; Sikora et al., 2017). S 1-S 5 are skeleton and bone numbers (cf. Trinkaus et al., 2014); lab codes for ^{14}C dates are shown to the right.

dates, ranging from ca. 121,000 years ago to ca. 556,000 years ago. This allows me to suggest that the material in Layer 2 is mixed, and explains why it has such a wide age range. For Layer 2, the ^{14}C date on animal bones of ca. 43,000 y.a. (uncalibrated ^{14}C value: 39,150 ± 270 BP, lab code: BA-14021; produced at the AMS Center, School of Physics, Peking University) was also generated. This information is presented only in the electronic Supplement to Liu et al. (2015: SI, p. 4). Liu et al. (2015: SI, p. 4) consider this value as beyond the range of the ^{14}C dating method and therefore omit it: "This is close to the organic material background of AMS radiocarbon dating in Peking University (PKU) lab. Thus, 39150 ± 270 BP is beyond the limits of the radiocarbon technique at the lab." This, in my opinion, is an attempt to justify the incorrect standpoint. Realising the importance of the Fuyan Cave human fossils, it should not be difficult to measure the ^{14}C age of animal bones in AMS laboratories where the background of bone material is about 50,000 BP. Somehow, this was not done, and one can wonder what the reason for that may have been.

It is obvious that all the bones in Layer 2 of Fuyan Cave are not *in situ*; Liu et al. (2015) reluctantly admitted that the position of the bones was distorted after deposition in the cave, but, again, only in the electronic Supplement (see Liu et al., 2015: SI, pp. 2-3). Therefore, the lack of a direct determination of the age of the human teeth – for example, using the Uranium-Thorium method of dating tooth enamel (e.g., Walker, 2005) – makes the conclusions by Liu et al. (2015) highly questionable (cf. Michel et al., 2016).

Nevertheless, there are also examples of careful (albeit indirect) determinations of the age of EMHS. Westaway et al. (2017) dated modern human fossils from the Lida Ajer Cave on Sumatra Island (Indonesia). Several methods applied regularly in Quaternary geochronology were used to produce a reliable age estimate: 1) coupled U-series and ESR dating of orangutan and gibbon teeth located next to the human remains because the curators of the museum in Leiden (the Netherlands), where the human fossils are stored, did not give permission for direct dating of the latter (K. Westaway, personal communication 2018); 2) determina-

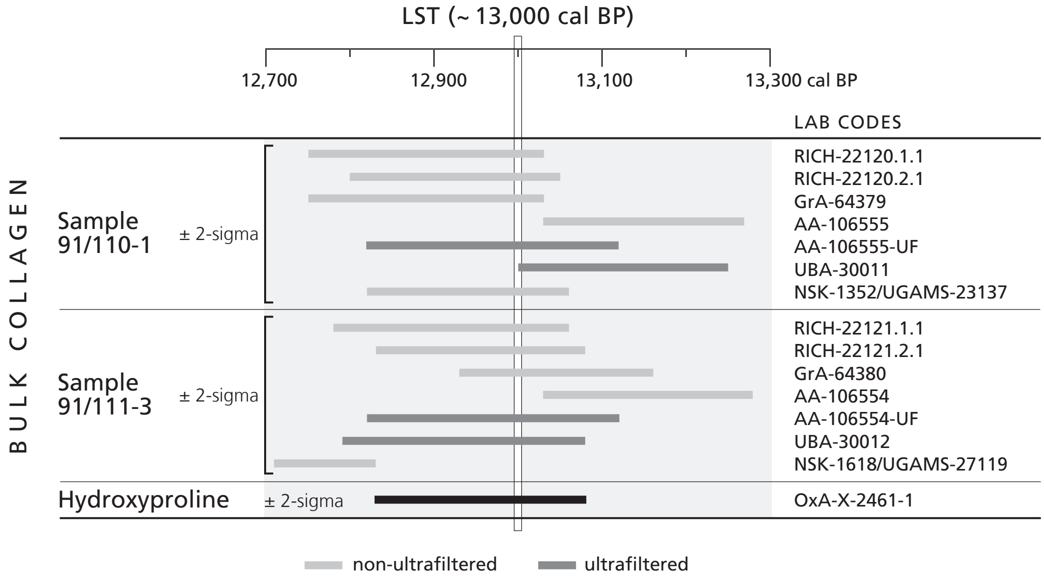


Fig. 8 The calibrated ^{14}C dates of the elk bone from the Miesenheim IV locality and the time of eruption of the Laacher See Tephra (Kuzmin et al., 2018); lab codes for ^{14}C dates are shown to the right.

tion of the age of carbonate flowstone by the U-series method; and 3) luminescent dating of quartz grains in the bone-bearing breccia. It should be noted that the work was carried out at an updated methodological level, with the selection of samples of fauna and cave deposits from *in situ* conditions. Combining all dating results and Bayesian age modelling for the layer in which the human teeth were found made it possible to establish the time of this EMHS's presence in central Sumatra at 68,000 ± 5,000 years ago.

In the recent debate about direct ^{14}C dating of human fossils (Kuzmin, 2019; Higham, 2019; Pettitt, 2019), some authors accept *a priori* that the oldest dates are the most reliable ones (Higham, 2011; Reynolds et al., 2017). However, one should bear in mind that at many Upper Palaeolithic sites the bones of two species of the extinct Pleistocene megafauna are often dated – the woolly mammoth and the woolly rhinoceros (*Coelodonta antiquitatis*). The dates of these bones do not necessarily correspond to the time of human habitation, since it is well known that Upper Palaeolithic people collected large subfossil bones and tusks of animals, which died naturally, for various purposes (e.g., Soffer, 2003). In this case, the ^{14}C dates obtained from megafaunal bones may well be older than the time of human presence. More reliable ages can be determined by ^{14}C dating of materials such as charcoal and bones of other animals that were probably hunted, such as Pleistocene bison (*Bison priscus*) and horse (*Equus caballus*), or other ungulates. Therefore, it is methodologically incorrect to simply accept the oldest ^{14}C dates as the reliable ones *sensu* Higham (2011). That such a view may be too simplistic, was proven for Upper Palaeolithic sites in the central Russian Plain (Praslov and Sulerzhitski, 1999).

Concerning the issue which organic fraction of the bone – bulk collagen, ultrafiltered collagen, or HYP – is the most reliable material for ^{14}C dating, there is still no consensus (see discussion in: Kuzmin, 2019; Higham, 2019). Since the "true" age (i.e., supported by independent data, as in the case of the skeletons of Kostenki 1 and Kostenki 14) of the human fossils in most of cases is unknown, this kind of discussion without the possibility to evaluate the ^{14}C dates by independent means is essentially fruitless. As an example, there were three ^{14}C dating campaigns for bones of Neanderthals from the Vindija Cave in Croatia. The first ^{14}C values on bulk collagen were in the range of ca. 32,000-33,000 y.a. (Smith et al., 1999). Later, they were replaced by older ^{14}C dates run on ultrafiltered collagen of ca. 36,600-36,800 y.a. (Higham et al., 2006b). Finally, all these dates were declared as too young, and the HYP ^{14}C values of ca. 46,300-47,000 y.a. were accepted (Devièse et al., 2017). It is still not clear: which series of dates is the most reliable one? Probably, none of them, because at Vindija Cave there are no age markers which can be used as independent criteria to test the validity of the produced ^{14}C dates.

Some researchers (e.g., Higham, 2019) believe that HYP is the most reliable material for ^{14}C dating of bones. This, however, has not been supported by the measurement of the ^{14}C age for a sample with a known upper age limit. The skeleton of an elk (*A. alces*), found at the locality of Miesenheim IV in the German Rhineland, was selected for cross-dating in several laboratories, applying different collagen extraction methods. At Miesenheim IV, elk bones were buried below the Laacher See Tephra (LST), the eruption of which is reliably dated to ca.13,000 cal BP (Fiedel et al., 2013; Kuzmin et al., 2018). Parallel ^{14}C dating in five laboratories of bulk collagen and ultrafiltered collagen, followed by comparison with the HYP ^{14}C value, showed that all dates are almost contemporaneous (**Fig. 8**) and do not contradict the age of the tephra (Kuzmin et al., 2018). Thus, the "superiority" of HYP compared to other collagen fractions *sensu* Higham (2019) has not been proven in this particular case.

When bones were treated with conservants (mainly synthetic substances made of fossil carbon compounds, e.g., natural oil, such as the most commonly used polyvinyl acetate glue: PVA), the question of which collagen fraction is the most reliable for ^{14}C dating is a complicated issue. Our limited experience in cleaning the elk bones from the Miesenheim IV locality shows that solvent treatment (by hexane, acetone, and ethanol) can be successful in removing the PVA glue (Kuzmin et al., 2018: 11-13).

CONCLUSIONS

An overview of the state-of-the-art for direct ^{14}C dating of EMHS from Eastern Europe, Siberia and Asia indicates that there is still little information available for these regions compared to Western, Southern, Central and south-eastern Europe. Nevertheless, it is possible to draw some conclusions. The oldest directly ^{14}C-dated EMHS in Eastern Europe and Asia is Ust'-Ishim from West Siberia, with an age of ca. 45,000 y.a. In East Asia, the oldest EMHS from Tianyuan Cave is dated to ca. 39,500 y.a. In Eastern Europe, the oldest EMHS fossils come from the Kostenki 14 and Kostenki 1 localities, and dated to ca. 35,500-37,400 y.a. The presence of humans in Siberia (Malta site) and East Asia (Shiraho-Saonetabaru Cave on Ryukyu Islands, Japan) at the height of the last glaciation (LGM) is noteworthy.

In most cases, it is impossible to assess the reliability of the ^{14}C dates due to the lack of independent age markers, although for Kostenki 1 and Kostenki 14 there is a good correspondence between the ^{14}C dates and the tephrochronology. In some cases (e.g., Kostenki 18 and Sungir), there are obvious contradictions that can be resolved only after generating new data, preferably using non-conserved samples. The degree of collagen preservation can be controlled by generally accepted parameters (collagen content in bone; carbon and nitrogen contents in collagen; atomic ratio of carbon to nitrogen; and carbon and nitrogen stable isotopes' ratios). When a sample satisfies these requirements, the ^{14}C date of bulk collagen seems to be reliable. The conclusion that HYP is the most reliable collagen fraction for ^{14}C dating of bones has not been strictly proven.

Acknowledgements

I am indebted to Prof. Dr. Sabine Gaudzinski-Windheuser and Dr. Olaf Jöris for inviting me to prepare a paper for this *Festschrift*. Discussions of the results obtained were carried out with a number of colleagues, including L.D. Sulerzhitsky (deceased), A.A. Sinitsyn, K.N. Gavrilov, S.V. Vasiliev, A.A. Bessudnov, P.A. Kosintsev, D.I. Razhev, M. Boudin, S.G. Keates, J. van der Plicht, K. Westaway, G.S. Burr, A.J.T. Jull, S. Talamo, and G.W.L. Hodgins. I express my gratitude to all of them for the opportunity to communicate and exchange opinions.

REFERENCES

Akimova, E., Higham, T., Stasyuk, I., Buzhilova, A., Dobrovolskaya, M., Mednikova, M., 2010. A new direct radiocarbon AMS date for an Upper Palaeolithic human bone from Siberia. *Archaeometry* 52, 1122-1130.

Anikovich, M.V., Sinitsyn, A.A., Hoffecker, J.F., Holliday, V.T., Popov, V.V., Lisitsyn, S.N., Forman, S.L., Levskovskaya, G.M., Pospelova, G.A., Kuz'mina, I.E., Burova, N.D., Goldberg, P., Macphail, R.I., Giaccio, B., Praslov, N.D., 2007. Early Upper Paleolithic in Eastern Europe and implications for the dispersal of modern humans. *Science* 315, 223-226.

Arslanov, K.A., Svezhentsev, Y.S., 1993. An improved method for radiocarbon dating fossil bones. *Radiocarbon* 35, 387-391.

Brock, F., Higham, T.F.G., Bronk Ramsey, C., 2010. Pre-screening techniques for identification of samples suitable for radiocarbon dating of poorly preserved bones. *Journal of Archaeological Science* 37, 855-865.

Brock, F., Wood, R., Higham, T.F.G., Ditchfield, P., Bayliss, A., Bronk Ramsey, C., 2012. Reliability of nitrogen content (%N) and carbon:nitrogen atomic ratios (C:N) as indicators of collagen preservation suitable for radiocarbon dating. *Radiocarbon* 54, 879-886.

Conard, N.J., Bolus, M., 2003. Radiocarbon dating the appearance of modern humans and timing of cultural innovations in Europe: New results and new challenges. *Journal of Human Evolution* 44, 331-371.

Conard, N.J., Grootes, P.M., Smith, F.H., 2004. Unexpectedly recent dates for human remains from Vogelherd. *Nature* 430, 198-201.

Craig, O.E., Biazzo, M., Colonese, A.C., Di Giuseppe, Z., Martinez-Labarga, C., Lo Vetro, D., Lelli, R., Martini, F., Rickards, O., 2010. Stable isotope analysis of Late Upper Palaeolithic humans remains from Grotta del Romito (Cosenza), Italy. *Journal of Archaeological Science* 37, 2504-2512.

de Lumley, H., Lee, Y.-J., Park, Y.-C., Bae, K. (Eds.), 2011. *Les Industries du Paléolithique Ancien de Coreé du Sud dans leur Contexte Stratigraphique et Paléoécologique*. CNRS Éditions, Paris.

Demeter, F., Sayavongkhamdy, T., Patole-Edoumba, E., Coupey, A.-S., 2009. Tam Hang rockshelter: Preliminary study of a prehistoric site in northern Laos. *Asian Perspectives* 48, 291-308.

Demeter, F., Shackelford, L.L., Bacon, A.-M., Duringer, P., Westaway, K., Sayavongkhamdy, T., Braga, J., Sichanthongtip, P., Khamdalavong, P., Ponche, J.-L., Wang, H., Lundstrom, C., Patole-Edoumba, E., Karpoff, A.-M., 2012. Anatomically modern human in Southeast Asia (Laos) by 46 ka. *Proceedings of the National Academy of Sciences of the USA* 109, 14375-14380.

Devièse, T., Karavanić, I., Comeskey, D., Kubiak, C., Korlević, P., Hajdinjak, M., Radović, S., Procopio, N., Buckley, M., Pääbo, S., Higham, T., 2017. Direct dating of Neanderthal remains from the site of Vindija Cave and implications for the Middle to Upper Paleolithic transition. *Proceedings of the National Academy of Sciences of the USA* 114, 10606-10611.

Devièse, T., Massilani, D., Yi, S., Comeskey, D., Nagel, S., Nickel, B., Ribechini, E., Lee, J., Tseveendorj, D., Gunchinsuren, B., Meyer, M., Pääbo, S., Higham, T., 2019. Compound-specific radiocarbon dating and mitochondrial DNA analysis of the Pleistocene hominin from Salkhit Mongolia. *Nature Communications* 10, no. 274; https://doi.org/10.1038/s41467-018-08018-8.

Devièse, T., Abrams, G., Hajdinjak, M., Pirson, S., De Grootef, E., Di Modica, K., Toussaint, M., Fischer, V., Co, D., Spindler, L., Meyer, M., Semal, P., Higham, T., 2021. Reevaluating the timing of Neanderthal disappearance in Northwest Europe. *Proceedings of the National Academy of Sciences of the USA* 118, e2022466118; https://doi.org/10.1073/pnas.2022466118.

Dinnis, R., Bessudnov, A., Reynolds, N., Devièse, T., Pate, A., Sablin, M., Sinitsyn, A., Higham, T., 2019. New data for the Early Upper Palaeolithic of Kostenki (Russia). *Journal of Human Evolution* 127, 21-40.

Fiedel, S.J., Southon, J.R., Taylor, R.E., Kuzmin, Y.V., Street, M., Higham, T.F.G., van der Plicht, J., Nadeau, M.-J., Nawalade-Chavan, S., 2013. Assessment of interlaboratory pretreatment protocols by radiocarbon dating an elk bone found below Laacher See tephra at Miesenheim IV (Rhineland, Germany). *Radiocarbon* 55, 1443-1453.

Formicola, V., Pettitt, P.B., Maggi, R., Hedges, R., 2005. Tempo and mode of formation of the Late Epigravettian necropolis of Arene Candide cave (Italy): Direct radiocarbon evidence. *Journal of Archaeological Science* 32, 1598-1602.

Fu, Q., Li, H., Moorjani, P., Jay, F., Slepchenko, S.M., Bondarev, A.A., Johnson, P.L.F., Aximu-Petri, A., Prüfer, K., de Filippo, C., Meyer, M., Zwyns, N., Salazar-García, D.C., Kuzmin, Y.V., Keates, S.G., Kosintsev, P.A., Razhev, D.I., Richards, M.P., Peristov, N.V., Lachmann, M., Douka, K., Higham, T.F.G., Slatkin, M., Hublin, J.-J., Reich, D., Kelso, J., Viola, T.B., Pääbo, S., 2014. The genome sequence of a 45,000-year-old modern human from Western Siberia. *Nature* 514, 445-450.

Fu, Q., Posth, C., Hajdinjak, M., Petr, M., Mallick, S., Fernandes, D., Furtwängler, A., Haak, W., Meyer, M., Mittnik, A., Nickel, B., Peltzer, A., Rohland, N., Slon, V., Talamo, S., Lazaridis, I., Lipson, M., Mathieson, I. Schiffels, S., Skoglund, P., Derevianko, A.P., Drozdov, N., Slavinsky, V., Tsybankov, A., Grifoni Cremonesi, R., Mallegni, F., Gély, B., Vacca, E., González Morales, M.R., Straus, L.G., Neugebauer-Maresch, C., Teschler-Nicola, M., Constantin, S., Moldovan, O.T., Benazzi, S., Peresani, M., Coppola, D., Lari, M., Ricci, S., Ronchitelli, A., Valentin, F., Thevenet, C., Wehrberger, K., Grigorescu, D., Rougier, H., Crevecoeur, I., Flas, D., Semal, P., Mannino, M.A., Cupillard, C., Bocherens, H., Conard, N.J., Harvati, K., Moiseyev, V., Drucker, D.G., Svoboda, J., Richards, M.P., Caramelli, D., Pinhasi, R., Kelso, J., Patterson, N., Krause, J., Pääbo, S., Reich, D., 2016. The genetic history of Ice Age Europe. *Nature* 534, 200-205.

Garralda, M.-D., Maíllo-Fernández, J.-M., Higham, T., Neira, A., de Quirós, F.B., 2019. The Gravettian child mandible from El Castillo Cave (Puente Viesgo, Cantabria, Spain). *American Journal of Physical Anthropology* 170, 331-350.

Gazzoni, V., Goude, G., Herrscher, E., Guerreschi, A., Antonioli, F., Fontana, F., 2013. Late Upper Palaeolithic human diet: First stable isotope evidence from Riparo Tagliente (Verona, Italy). *Bulletins et Mémoires de la Société d'Anthropologie de Paris* 25, 103-117.

Gilligan, I., 2019. *Climate, Clothing and Agriculture in Prehistory: Linking Evidence, Causes, and Effects*. Cambridge University Press, New York.

Grün, R., 2006. Direct dating of human fossils. *Yearbook of Physical Anthropology* 49, 2-48.

Hershkovitz, I., Weber, G.W., Quam, R., Duval, M., Grün, R., Kinsley, L., Ayalon, A., Bar-Matthews, M., Valladas, H., Mercier, N., Arsuaga, J.L., Martinón-Torres, M., Bermúdez de Castro, J.M., Fornai, C., Martín-Francés, L., Sarig, R., May, H., Krenn, V.A., Slon, V., Rodríguez, L., García, R., Lorenzo, C., Carretero, J.M., Frumkin, A., Shahack-Gross, R., Bar-Yosef Mayer, D.E., Cui, Y., Wu, X., Peled, N., Groman-Yaroslavski, I., Weissbrod, L., Yeshurun, R., Tsatskin, A., Zaidner, Y., Weinstein-Evron, M., 2018. The earliest modern humans outside Africa. *Science* 359, 456-459.

Higham, T., 2011. European Middle and Upper Palaeolithic radiocarbon dates are often older than they look: Problems with previous dates and some remedies. *Antiquity* 85, 235-249.

Higham, T.F.G., 2019. Removing contaminants: A restatement of the value of isolating single compounds for AMS dating. *Antiquity* 93, 1072-1075.

Higham, T.F.G., Jacobi, R.M., Bronk Ramsey, C., 2006a. AMS radiocarbon dating of ancient bone using ultrafiltration. *Radiocarbon* 48, 179-195.

Higham, T., Bronk Ramsey, C., Karavanić, I., Smith, F.H., Trinkaus, E., 2006b. Revised direct radiocarbon dating of the Vindija G1 Upper Paleolithic Neandertals. *Proceedings of the National Academy of Sciences of the USA* 103, 553-557.

Holliday, V.T., Hoffecker, J.F., Goldberg, P., Macphail, R.I., Forman, S.L., Anikovich, M., Sinitsyn, A., 2007. Geoarchaeology of the Kostenki–Borshchevo sites, Don River valley, Russia. *Geoarchaeology* 22, 181-228.

Hublin, J.-J., Sirakov, N., Aldeias, V., Bailey, S., Bard, E., Delvigne, V., Endarova, E., Fagault, Y., Fewlass, H., Hajdinjak, M., Kromer, B., Krumov, I., Marreiros, J., Martisius, N.L., Paskulin, L., Sinet-Mathiot, V., Meyer, M., Pääbo, S., Popov, V., Rezek, Z., Sirakova, S., Skinner, M.M., Smith, G.M., Spasov, R., Talamo, S., Tuna, T., Wacker, L., Welker, F., Wilcke, S., Zahariev, N., McPherron, S.P., Tsanova, T., 2020. Initial Upper Palaeolithic *Homo sapiens* from Bacho Kiro Cave, Bulgaria. *Nature* 581, 299-302.

Keates, S.G., Hodgins, G.W.L., Kuzmin, Y.V., Orlova, L.A., 2007. First direct dating of a presumed Pleistocene hominid from China: AMS radiocarbon age of a femur from the Ordos Plateau. *Journal of Human Evolution* 53, 1-5.

Keates, S.G., Kuzmin, Y.V., Burr, G.S., 2012. Chronology of Late Pleistocene humans in Eurasia: Results and perspectives. *Radiocarbon* 54, 339-350.

Keates, S.G., Postnov, A.V., Kuzmin, Y.V., 2019. Towards the origin of microblade technology in Northeastern Asia. *Vestnik of Saint Petersburg University, Series History* 64, 390-414.

Kılınç, G.M., Kashuba, N., Koptekin, D., Bergfeldt, N., Dönertaş, H.M., Rodriguez-Varela, R., Shergin, D., Ivanov, G., Kichigin, D., Pestereva, K., Volkov, D., Mandryka, P., Kharinskii, A., Tishkin, A., Ineshin, E., Kovychev, E., Stepanov, A., Dalén, L., Günther, T., Kırdök, E., Jakobsson, M., Somel, M., Krzewińska, M., Storå, J., Götherström, A., 2021. Human population dynamics and *Yersinia pestis* in ancient northeast Asia. *Science Advances* 7, eabc4587.

Kondo, M., Matsu'ura, S., 2005. Dating of the Hamakita human remains from Japan. *Anthropological Science* 113, 155-161.

Krause, J., Orlando, L., Serre, D., Viola, B., Prüfer, K., Richards, M.P., Hublin, J.-J., Hänni, C., Derevianki, A.P., Pääbo, S., 2007. Neanderthals in Central Asia and Siberia. *Nature* 449, 902-904.

Kuzmin, Y.V., 2007. Chronological framework of the Siberian Paleolithic: Recent achievements and future directions. *Radiocarbon* 49, 757-766.

Kuzmin, Y.V., 2008. Siberia at the Last Glacial Maximum: Environment and archaeology. *Journal of Archaeological Research* 16, 163-221.

Kuzmin, Y.V., 2016. The dispersal of early modern humans (*Homo sapiens sapiens*) in Eurasia: Current state of the issue. In: Matveeva, N.P. (Ed.), *Ekologiya Drevnikh i Traditsionnykh Obshchestv, Vypusk 5, Chast 1*. Izdatelvtvo TuymGU, Tuymen, pp. 119-122. (in Russian with English abstract).

Kuzmin, Y.V., 2019. The older, the better? On the radiocarbon dating of Upper Palaeolithic burials in northern Eurasia and beyond. *Antiquity* 93, 1061-1071.

Kuzmin, Y.V., Fiedel, S.J., Street, M., Reimer, P.J., Boudin, M., van der Plicht, J., Panov, V.S., Hodgins, G.W.L., 2018. A laboratory inter-comparison of AMS ^{14}C dating of bones of the Miesenheim IV elk (Rhineland, Germany) and its implications for the date of the Laacher See eruption. *Quaternary Geochronology* 48, 7-16.

Kuzmin, Y.V., Keates, S.G., 2005. Dates are not just data: Paleolithic settlement patterns in Siberia derived from radiocarbon records. *American Antiquity* 70, 773-789.

Kuzmin, Y.V., Keates, S.G., 2013. Dynamics of Siberian Paleolithic complexes (based on analysis of radiocarbon records): The 2012 state-of-the-art. *Radiocarbon* 55, 1314-1321.

Kuzmin, Y.V., Keates, S.G., 2014. Direct radiocarbon dating of Late Pleistocene hominids in Eurasia: Current status, problems, and perspectives. *Radiocarbon* 56, 753-766.

Kuzmin, Y.V., Keates, S.G., 2018. Siberia and neighboring regions in the Last Glacial Maximum: Did people occupy northern Eurasia at that time? *Archaeological and Anthropological Sciences* 10, 111-124.

Kuzmin, Y.V., Keates, S.G., 2020. The chronology of hominin fossils from the Altai Mountains, Siberia: An alternative view. *Journal of Human Evolution* 146, 102834.

Kuzmin, Y.V., Kosintsev, P.A., Razhev, D.I., Hodgins, G.W.L., 2009. The oldest directly-dated human remains in Siberia: AMS ^{14}C age of talus bone from the Baigara locality, West Siberian Plain. *Journal of Human Evolution* 57, 91-95.

Kuzmin, Y.V., Orlova, L.A., Zenin, V.N., Lbova, L.V., Dementiev, V.N., 2011. Radiocarbon dating of the Palaeolithic of Siberia and the Russian Far East: Materials for ^{14}C data catalogue (as of the end of 2010). *Stratum plus* 1, 171-200 (in Russian with English abstract).

Kuzmin, Y.V., van der Plicht, J., Sulerzhitsky, L.D., 2014. Puzzling radiocarbon dates for the Upper Paleolithic site of Sungir (central Russian Plain). *Radiocarbon* 56, 451-459.

Larichev, V., Khol'ushkin, U., Laricheva, I., 1990. The Upper Paleolithic of Northern Asia: Achievements, problems, and perspectives. II. Central and Eastern Siberia. *Journal of World Prehistory* 4, 347-385.

Lee, Y.-J. (Ed.), 1997. *Handbook on Prehistoric Sites in Korea*. Museum of Chungbuk National University, Cheongju.

Liu, W., Martinón-Torres, M., Cai, Y.-J., Xing, S., Tong, H.-W., Pei, S.-W., Sier, M.J., Wu, X.-H., Edwards, R.L., Cheng, H., Li, Y.-Y., Yang, X.-X., Bermúdez de Castro, J.M., Wu, X.-J., 2015. The earliest unequivocally modern humans in southern China. *Nature* 526, 696-699.

Longin, R., 1971. New method of collagen extraction for radiocarbon dating. *Nature* 230, 241-242.

Marom, A., McCullagh, J., Higham, T., Sinitsyn, A., Hedges, R., 2012. Single amino acid radiocarbon dating of Upper Palaeolithic modern humans. *Proceedings of the National Academy of Sciences of the USA* 109, 6878-6881.

McCullagh, J.S.O., Marom, A., Hedges, R.E.M., 2010. Radiocarbon dating of individual amino acids from archaeological bone collagen. *Radiocarbon* 52, 620-634.

Michel, V., Valladas, H., Shen, G., Wang, W., Zhao, J.-X., Shen, C.-C., Valensi, P., Bae, C.J., 2016. The earliest modern *Homo sapiens* in China? *Journal of Human Evolution* 101, 101-104.

Muscheler, R., Adolphi, F., Heaton, T.J., Bronk Ramsey, C., Svensson, A., van der Plicht, J., Reimer, P.J., 2020. Testing and improving the IntCal20 calibration curve with independent records. *Radiocarbon* 62, 1079-1094.

Nakagawa, R., Doi, N., Nishioka, Y., Nunami, S., Yamauchi, H., Fujita, M., Yamazaki, S., Yamamoto, M., Katagiri, C., Mukai, H., Matsuzaki, H., Gakuhari, T., Takigami, M., Yoneda, M., 2010. Pleistocene human remains from Shiraho-Saonetabaru Cave on Ishigaki Island, Okinawa, Japan, and their radiocarbon dating. *Anthropological Science* 118, 173-183.

Nalawade-Chavan, S., McCullagh, J., Hedges, R., 2014. New hydroxyproline radiocarbon dates from Sungir, Russia, confirm early mid Upper Palaeolithic burials in Eurasia. *PLOS ONE* 9, e76896; https://doi.org/10.1371/journal.pone.0076896.

Nelson, S.M., 1993. *The Archaeology of Korea*. Cambridge University Press, Cambridge.

Nielsen, R., Akey, J.M., Jakobsson, M., Pritchard, J.K., Tishkoff, S., Willerslev, E., 2017. Tracing the peopling of the world through genomics. *Nature* 341, 302-310.

Norton, C.J., 2000. The current state of Korean paleoanthropology. *Journal of Human Evolution* 38, 803-825.

Pavlova, E.Y., Pitulko, V.V., 2020. Late Pleistocene and Early Holocene climate changes and human habitation in the arctic Western Beringia based on revision of palaeobotanical data. *Quaternary International* 549, 5-25.

Pettitt, P., 2019. Fast and slow science and the Palaeolithic dating game. *Antiquity* 93, 1076-1078.

Pierret, A., Zeitoun, V., Forestier, H., 2012. Irreconcilable differences between stratigraphy and direct dating cast doubts upon the status of Tam Pa Ling fossil. *Proceedings of the National Academy of Sciences of the USA* 109, E3523; https://doi.org/10.1073/pnas.1216774109.

Pitulko, V.V., Pavlova, E.Y., 2016. *Geoarchaeology and Radiocarbon Chronology of Stone Age Northeast Asia*. Texas A&M University Press, College Station.

Pitulko, V.V., Pavlova, E.Y., 2020. Colonization of the Eurasian Arctic. In: Goldstein, M., DellaSala, D. (Eds.), *Encyclopedia of the World's Biomes 2*. Elsevier, Amsterdam, pp. 374-391.

Praslov, N.D., Sulerzhitskii, L.D., 1999. New data on chronology of the Paleolithic Sites in Kostenki-on-Don. *Doklady Earth Sciences* 365, 196-200.

Prat, S., Péan, S.C., Crépin, L., Drucker, D.G., Puaud, S.J., Valladas, H., Lázničková-Galetová, M., van der Plicht, J., Yanevich, A., 2011. The oldest anatomically modern humans from far southeast Europe: Direct dating, culture and behavior, *PLOS ONE* 6, e20834; https://doi.org/10.1371/journal.pone.0020834.

Qu, T., Bar-Yosef, O., Wang, Y., Wu, X., 2013. The Chinese Upper Paleolithic: Geography, chronology, and techno-typology. *Journal of Archaeological Research* 21, 1-73.

Raghavan, M., Skoglund, P., Graf, K.E., Metspalu, M., Albrechtsen, A., Moltke, I., Rasmussen, S., Stafford, T.W. Jr., Orlando, L., Metspalu, E., Karmin, M., Tambets, K., Rootsi, S., Mägi, R., Campos, P.F., Balanovska, E., Balanovsky, O., Khusnutdinova, E., Litvinov, S., Osipova, L.P., Fedorova, S.A., Voevoda, M.I., DeGiorgio, M., Sicheritz-Ponten, T., Brunak, S., Demeshchenko, S., Kivisild, T., Villems, R., Nielsen, R., Jakobsson, M., Willerslev, E., 2013. Upper Palaeolithic Siberian genome reveals dual ancestry of native Americans. *Nature* 405, 87-91.

Rasmussen, S.O., Bigler, M., Blockley, S.P., Blunier, T., Burchardt, S.L., Clausen, H.B., Cvijanovic, I., Dahl-Jensen, D., Johnsen, S.J., Fischer, H., Gkinis, V., Guillevic, M., Hoek, W.Z., Lowe, J.J., Pedro, J.B., Popp, T., Seierstad, I.K., Steffensen, J.P., Svensson, A.M., Vallelonga, P., Vinther, B.M., Walker, M.J.C., Wheatley, J.J., Winstrup, M., 2014. A stratigraphic framework for abrupt climatic changes during the last glacial period based on three synchronized Greenland ice-core records: Refining and extending the INTIMATE event stratigraphy. *Quaternary Science Reviews* 106, 14-28.

Reimer, P.J., 2020. Composition and consequences of the IntCal20 radiocarbon calibration curve. *Quaternary Research* 96, 22-27.

Reimer, P.J., Bard, E., Bayliss, A., Beck, W.J., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Cheng, H., Edwards, L.R., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., van der Plicht, J., 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0-50,000 years cal BP. *Radiocarbon* 55, 1869-1887.

Reynolds, N., Dinnis, R., Bessudnov, A.A., Devièse, T., Higham, T., 2017. The Kostënki 18 child burial and the cultural and funerary landscape of mid Upper Palaeolithic European Russia. *Antiquity* 91, 1435-1450.

Richards, M.P., Pettitt, P.B., Stiner, M.C., Trinkaus, E., 2001. Stable isotope evidence for increasing dietary breadth in the European

Mid-Upper Paleolithic. *Proceedings of the National Academy of Sciences of the USA* 98, 6528-6532.

Seierstad, I.K., Abbott, P.M., Bigler, M., Blunier, T., Bourne, A.J., Brook, E., Clausen, H.B., Cook, E., Buchardt, S.L., Dahl-Jensen, D., Buizert, C., Davies, S.M., Guillevic, M., Johnsen, S.J., Pedersen, D.S., Popp, T.J., Rasmussen, S.O., Severinghaus, J.P., Svensson, A., Vinther, B.M., 2014. Consistently dated records from the Greenland GRIP, GISP2 and NGRIP ice cores for the past 104 ka reveal regional millennial-scale $\delta^{18}O$ gradients with possible Heinrich event imprint. *Quaternary Science Reviews* 106, 29-46.

Shang, H., Tong, H., Zhang, S., Chen, F., Trinkaus, E., 2007. An early modern human from Tianyuan Cave, Zhoukoudian, China. *Proceedings of the National Academy of Sciences of the USA* 104, 6573-6578.

Shchetnikov, A.A., Bezrukova, E.V., Matasova, G.G., Kazansky, A.Y., Ivanova, V.V., Danukalova, G.A., Filinov, I.A., Khenzykhenova, F.I., Osipova, E.M., Berdnikova, N.E., Berdnikov, I.M., Rogovskoi, E.O., Lipnina, E.A., Vorobyeva, G.A., 2019. Upper Paleolithic site Tuyana – a multi-proxy record of sedimentation and environmental history during the Late Pleistocene and Holocene in the Tunka rift valley, Baikal region. *Quaternary International* 534, 138-157.

Sikora, M., Seguin-Orlando, A., Sousa, V.C., Albrechtsen, A., Korneliussen, T., Ko, A., Rasmussen, S., Dupanloup, I., Nigst, P.R., Bosch, M.D., Renaud, G., Allentoft, M.E., Margaryan, A., Vasilyev, S.V., Veselovskaya, E.V., Borutskaya, S.B., Deviese, T., Comeskey, D., Higham, T., Manica, A., Foley, R., Meltzer, D.J., Nielsen, R., Excoffier, L., Lahr, M.M., Orlando, L., Willerslev, E., 2017. Ancient genomes show social and reproductive behavior of early Upper Paleolithic foragers. *Science* 358, 659-662.

Skoglund, P., Mathieson, I., 2018. Ancient genomics of modern humans: The first decade. *Annual Review of Genomics and Human Genetics* 19, 381-404.

Smith, F.H., Trinkaus, E., Pettitt, P.B., Karavanić, I., Paunović, M., 1999. Direct radiocarbon dates for Vindija G1 and Velika Pećina Late Pleistocene hominid remains. *Proceedings of the National Academy of Sciences of the USA* 96, 12281-12286.

Soffer, O., 2003. Mammoth bone accumulations: Death sites? Kill sites? Dwellings? In: Vasil'ev, S.A., Soffer, O., Kozlowski, J. (Eds.), *Perceived Landscapes and Built Environments: The Cultural Geography of Late Pleistocene Eurasia*. Archaeopress, Oxford, pp. 39-46.

Stafford, T.W. Jr., Brendel, K., Duhamel, R.C., 1988. Radiocarbon, ^{13}C and ^{15}N analysis of fossil bone: Removal of humates with XAD-2 resin. *Geochimica et Cosmochimica Acta* 52, 2257-2267.

Street, M., Terberger, T., 2004. The radiocarbon chronology of the German Upper Palaeolithic: Fifteen years of cooperation with ORAU. In: Higham, T.F.G., Bronk-Ramsey, C., Owen, D.C. (Eds.), *Radiocarbon and Archaeology*. Proceedings of the 4th Symposium, Oxford 2002. Oxford University School of Archaeology Monograph 62. Oxford University School of Archaeology, Oxford, pp. 281-302.

Street, M., Terberger, T., Orschiedt, J., 2006. A critical review of the German Paleolithic hominin record. *Journal of Human Evolution* 51, 551-579.

Trinkaus, E., Buzhilova, A.P., Mednikova, M.B., Dobrovolskaya M.V. (Eds.), 2014. *The People of Sunghir: Burials, Bodies, and Behavior in the Earlier Upper Paleolithic*. Oxford University Press, New York.

Trinkaus, E., Buzhilova, A.P., Mednikova, M.B., Dobrovolskaya, M.V., 2015. The age of the Sunghir Upper Paleolithic human burials. *Anthropologie* 53, 221-231.

Turner, C.G. II, Ovodov, N.D., Pavlova, O.V., 2013. *Animal Teeth and Human Tools: A Taphonomic Odyssey in Ice Age Siberia*. Cambridge University Press, Cambridge.

van Klinken, G.J., 1999. Bone collagen quality indicators for palaeodietary and radiocarbon measurements. *Journal of Archaeological Science* 26, 687-695.

Vasilyev, S.V., Borutskaia, S.B., Rogovskoi, E.O., Berdnikova, N.E., Lipnina, E.A., Berdnikov, I.M., 2017. Report on anthropological finds on the Palaeolithic locality of Tuyana in Tunka Rift Valley (southwest Cis-Baikal). *Izvestiia Irkutskogo Gosudarstvennogo Universiteta, Seriya: Geoarkheologiia. Etnologiia. Antropologiia* 22, 150-165. (in Russian with English abstract).

Walker, M., 2005. *Quaternary Dating Methods*. John Wiley & Sons, Chichester.

Westaway, K.E., Louys, J., Due Awe, R., Morwood, M.J., Price, G.J., Zhao, J.-X., Aubert, M., Joannes-Boyau, R., Smith, T.M., Skinner, M.M., Compton, T., Bailey, R.M., van den Bergh, G.D., de Vos, J., Pike, A.W.G., Stringer, C., Saptomo, E.W., Rizal, Y., Zaim, J., Santoso, W.D., Trihascaryo, A., Kinsley, L., Sulistyanto, B., 2017. An early modern human presence in Sumatra 73,000-63,000 years ago. *Nature* 548, 322-325.

Yang, M.A., Fu, Q., 2018. Insights into modern human prehistory using ancient genomes. *Trends in Genetics* 34, 184-196.

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