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DIRECT RADIOCARBON DATING OF LATE PLEISTOCENE HOMINIDS IN EURASIA: CURRENT STATUS, PROBLEMS, AND PERSPECTIVES

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ABSTRACT. The corpus of radiocarbon dates run directly on Pleistocene-age human remains in Eurasia (~120 values, with ~80 of them found to be reliable) is analyzed and interpreted. The latest Neanderthals are dated to ~34,000–30,500 BP (~38,800–35,400 cal BP). They probably coexisted with the first modern humans at ~36,200–30,200 BP (~42,500–32,800 cal BP) in the western and central parts of Europe. The earliest direct ^{14}C dates on modern humans in Eurasia are ~34,950–33,300 BP (~40,400–37,800 cal BP). A paucity of ^{14}C dates corresponding to the LGM is evident for Europe, but Asia perhaps had larger populations during this timespan. The main criteria for the selection of bone/tooth material for direct ^{14}C dating as now widely accepted are (1) the collagen yield (generally, 1% or more) and (2) the C:N ratio (within the 2.9–3.4 range).

INTRODUCTION

The direct radiocarbon dating of Late Pleistocene humans from Eurasia is an important task. It was initiated in the 1970–1980s, and progress was at first slow (see e.g. review in Bednarik 2009:274–5). More results were published in the early 2000s when the accelerator mass spectrometry (AMS) technique was more widely used (e.g. Gambier et al. 2000; Richards et al. 2001; Svoboda et al. 2002). Since the mid-2000s, direct AMS ^{14}C dating of Pleistocene human fossils greatly accelerated. A more extensive program of direct dating has become all the more important since it was demonstrated that several hominids previously thought to be of Late Pleistocene age are in fact of Holocene origin (e.g. Vogelherd, see Conard et al. 2004; for other cases, see Street et al. 2006; Keates et al. 2007).

In order to estimate how many human fossils have direct dates, the following example can be used. If the total number of Neanderthal individuals in Eurasia is at least 280 (Klein 1999:372; Derevianko 2009), only 15 of them (5.4% of the total) have been directly dated. This calls for more serious efforts to increase the age determinations for Late Pleistocene humans. Recent overviews of the Eurasian records are presented by Higham et al. (2011), Prat et al. (2011), and Keates et al. (2012). This article reports the latest developments and discusses some of the existing problems.

MATERIAL AND METHODS

The database for this study consists of about 120 ^{14}C values obtained directly on human fossils from Eurasia, which were published before early 2014 to the best of our knowledge; about 80 of these are considered to be reliable according to the original researchers (see Table 1). Only pre-Holocene ^{14}C dates (i.e., older than ~10,000 BP, or ~11,500 cal BP) associated with the Paleolithic cultural complexes are included. Mesolithic-associated ^{14}C dates older than ~10,000 BP (e.g. Meiklejohn et al. 2010) are not considered due to space limitations. If there are two (or more) ^{14}C dates generated for the same individual, and they overlap in calendar age, only one ^{14}C value is included in Table 1 (the other values are given in the footnotes) and Figure 2.

The remains of 15 Neanderthals and 60 anatomically modern humans constitute the basis of this study. Their geographic distribution is uneven (Figure 1). The majority of Neanderthals with direct dates are from western (53%) and central (33%) Europe (86% of the total). In eastern Europe and Asia, only two sites (Mezmaiskaya and Okladnikov caves) have direct ^{14}C dates. The same trend can

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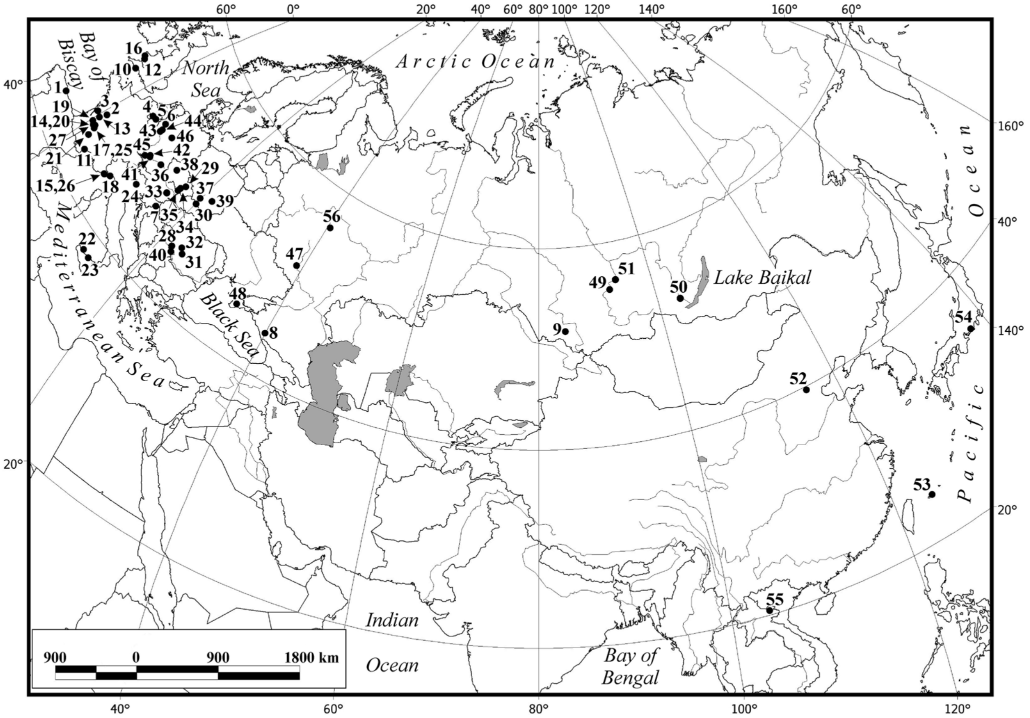

Figure 1 Geographic distribution of directly ^{14}C-dated Late Pleistocene humans in Eurasia (numbers correspond to Table 1).

be observed for modern humans: their number for western/southern Europe is 30%, and for central Europe it is 47% (together, 77%); the rest of Eurasia has only 23% of the dates.

In this overview article, we do not evaluate every direct ^{14}C date on human fossils based on modern criteria (e.g. Brock et al. 2010a, 2012) because of space limitations and insufficient information on collagen yield and C:N ratio in many of the original publications. Also, most of the ^{14}C dates have been evaluated by the authors of the original reports and in several review articles (e.g. Higham et al. 2006a, 2011; Street et al. 2006; Pinhasi et al. 2011; Prat et al. 2011; White and Pettitt 2012; Keates et al. 2012), and we agree with their evaluations. Furthermore, several ^{14}C dates that were not accepted by the original authors are mentioned in the footnotes of Table 1 as "rejected."

In this study, only ^{14}C dates produced on human remains are considered. This is because other dating methods, mainly uranium series (U-series) and electron spin resonance (ESR), require prior assumptions (first of all, annual radiation dose and relative humidity of fossil-bearing sediments; e.g. Malainey 2011:109–40). However, this information cannot always be derived from the sites either because they were entirely excavated or because of a complicated taphonomy; see the recent example of the Tam Pa Ling site in Laos (Demeter et al. 2012a,b; Pierret et al. 2012). Therefore, the results of both U-series and ESR dating of fossil humans should be treated with caution.

As a striking example, the Tabun Cave in the Levant can be used. Before attempts were made to date directly the Neanderthal skeleton C1, analysis of the site's chronology and stratigraphy by Farrand (1994) resulted in his conclusion that the early uptake (EU) model for ESR dating is the most appropriate one (see Farrand 1994:50). The first U-series dating campaign produced an age of ~34,000–33,000 yr using the EU model for the C1 mandible and linear uptake (LU) for the C1 femur

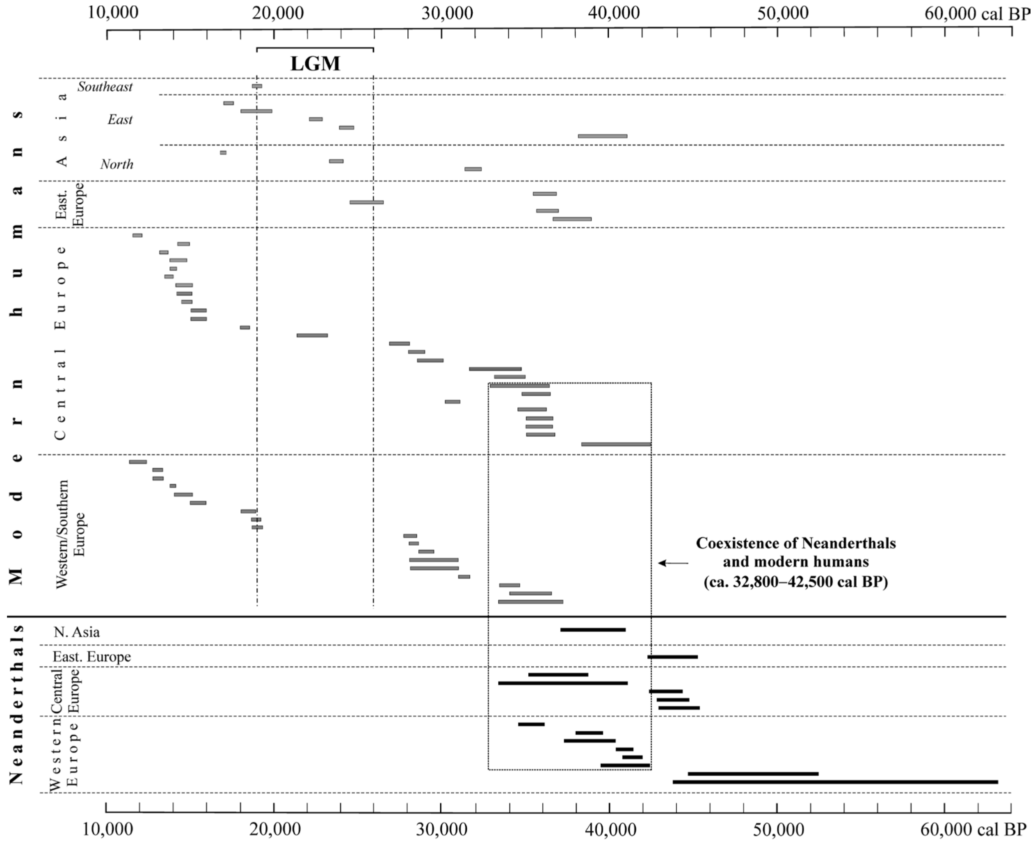

Figure 2 Calendar age ranges for directly ^{14}C-dated Late Pleistocene humans in Eurasia (sequence of values corresponds to Table 1).

(Schwarcz et al. 1998); the EU model gives a date of ~19,000 yr for the femur. These results were considered to be too young, and the second campaign using the ESR method generated a much older age of ~143,000–112,000 yr for the C1 tooth (Grün and Stringer 2000). Assuming that Farrand's (1994) conclusion about the uranium uptake model is the correct one, the ESR age of the C1 tooth is 112,000 ± 29,000 yr (Grün and Stringer 2000:610). The LU–ESR model was considered as the best one to estimate the age of Layer B at Tabun at ~122,000 yr (Grün and Stringer 2000:610).

However, these studies have a major weakness in terms of the uncertain provenance of the C1 skeleton (from either Layer B or Layer C; e.g. Farrand 1994). As a result, assumptions about the dose rate that should be used for age calculation of the U-series and ESR methods (e.g. Grün and Stringer 2000:608–10) are, in our opinion, at the level of mere guessing. This is why it is impossible to establish the "true" age of Tabun layers B and C. The basic assumptions concerning the dose rate (caused by the fact that the human fossil-bearing sediments were removed long before the dating campaigns) are quite uncertain, and this is why all the results of direct dating of the Tabun C1 human fossils are very approximate (e.g. Grün 2006:31). In such cases (and in general), only direct ^{14}C dating, which does not require any prior assumptions about a sample's burial history, can shed light on the exact age of human fossils within the upper limit of the dating method, around 50,000 BP (e.g. Wood et al. 2010), corresponding tentatively to ~53,000 cal BP (see Bronk Ramsey et al. 2012).

Table 1 Direct ^{14}C dates of Paleolithic humans in Eurasia.*

Site** and nr of individual	Lat., N	Long., W/E	^{14}C date, yr BP	Lab code	Calendar age***	Skeleton part	Reference
Neanderthals							
Western Europe							
1. El Sidrón (Sample 00/46)[1]	43°23′	05°20′W	48,400 ± 3200	OxA-21776[†]	43,850–63,310[§]	Bone****	Wood et al. 2013
2. Les Rochers-de-Villeneuve	46°25′	00°44′E	45,200 ± 1100	OxA-15257[†]	44,740–52,390[§]	Femur	Beauval et al. 2006
3. Saint-Césaire SP28	45°45′	00°30′W	36,200 ± 750	OxA-18099[†]	39,480–42,380	Tibia	Hublin et al. 2012
4. Spy II	50°29′	04°42′E	36,350 + 310/−280	GrA-32626	40,940–41,980	Incisor	Semal et al. 2009
Spy I[2]			35,810 + 260/−240	GrA-32623	40,420–41,550	Molar	Semal et al. 2009
Spy VI[3]			33,950 ± 500	OxA-21610[†]	37,320–40,320	Mandible	Crevecoeur et al. 2010
Spy 430a[4]			33,940 + 220/−210	GrA-32630	38,000–39,580	Phalanx	Semal et al. 2009
5. Engis 2[5]	50°36′	05°24′E	30,460 ± 210	GrA-21545	34,590–36,110	Parietal	Toussaint and Pirson 2006
Central Europe							
6. Kleine Feldhofer Grotte, NN 4	51°14′	06°57′E	40,360 ± 760	ETH-19661	43,030–45,350	Tibia	Schmitz et al. 2002
Kleine Feldhofer Grotte, Nean 1			39,900 ± 620	ETH-20981	42,900–44,830	Humerus	Schmitz et al. 2002
Kleine Feldhofer Grotte, NN 1			39,240 ± 670	ETH-19660	42,430–44,460	Humerus	Schmitz et al. 2002
7. Vindija Cave, Vi 207[6]	46°18′	16°04′E	32,400 ± 1800	OxA-X-2089-07[†]	33,380–41,120	Mandible	Higham et al. 2006a
Vindija Cave, Vi 208[6]			32,400 ± 800	OxA-X-2089-06[†]	35,170–38,770	Parietal	Higham et al. 2006a
Eastern Europe							
8. Mezmaiskaya Cave, Mez 2[7]	44°10′	40°00′E	39,700 ± 1100	OxA-21839[†]	42,190–45,310	Cranium	Pinhasi et al. 2011
Northern Asia (Siberia)							
9. Okladnikov Cave[8]	51°40′	84°20′E	37,800 ± 450	OxA-15481[†]	41,740–43,060	Humerus	Krause et al. 2007
Okladnikov Cave[8]			34,860 ± 360	Beta-186881	38,930–40,880	Humerus	Krause et al. 2007
Okladnikov Cave[8]			29,990 ± 500	KIA-27011[†]	33,270–36,170	Humerus	Krause et al. 2007
Modern humans							
Western/Southern Europe							
10. Kent's Cavern 4[9]	50°28′	03°30′W	30,900 ± 900	OxA-1621	33,380–37,340	Maxilla	Hedges et al. 1989
11. La Crouzade VI	43°08′	03°05′E	30,640 ± 640	Erl-9415	33,970–36,580	Maxilla	Henry-Gambier and Sacchi 2008

Table 1 Direct ^{14}C dates of Paleolithic humans in Eurasia.* *(Continued)*

Site** and nr of individual	Lat., N	Long., W/E	^{14}C date, yr BP	Lab code	Calendar age***	Skeleton part	Reference
12. Paviland ("Red Lady")[10]	51°33′	04°15′W	29,490 ± 210	OxA-16413†	33,490–34,680	Scapula	Jacobi and Higham 2008
13. Vilhonneur 1[11]	45°41′	00°25′E	27,110 ± 210	Beta-216141	31,110–31,630	Rib (nr 18)	Henry-Gambier et al. 2007
14. Cussac 1	44°50′	00°51′E	25,120 ± 120	Beta-156643	28,090–31,020	Rib	Pettitt 2011:156
15. Barma Grande 6	43°47′	07°36′E	24,800 ± 800	OxA-10093†	28,090–31,020	Metatarsal	Formicola et al. 2004
16. Eel Point[12]	51°39′	04°42′W	24,470 ± 110	OxA-14164†	28,650–29,590	Humerus	Schulting et al. 2005
17. La Rochette	45°00′	01°05′E	23,630 ± 130	OxA-11053†	27,970–28,710	Ulna	Orschiedt 2002a
18. Arene Candide ("Il Principe")	44°10′	08°20′E	23,440 ± 190	OxA-10700†	27,830–28,630	Femur	Pettitt et al. 2003
19. Saint-Germain-la-Rivière	44°57′	00°20′E	15,780 ± 200	GifA-95456	18,650–19,400	Rib	Gambier et al. 2000
20. Laugerie-Basse[13]	44°57′	01°00′E	15,660 ± 130	GifA-94204	18,600–19,270	Post-cranium	Gambier et al. 2000
21. Lafaye	44°03′	01°40′E	15,290 ± 150	GifA-95047	18,030–18,830	Rib	Gambier et al. 2000
22. Grotta Addaura Caprara 1	38°10′	13°22′E	12,890 ± 60	KIA-36055	15,010–16,060	Fibula	Mannino et al. 2011
23. Grotta di San Teodoro 1	38°03′	14°34′E	12,580 ± 130	ETH-34451	14,130–15,230	Humerus	Mannino et al. 2011
24. Villabruna 1	45°56′	11°44′E	12,140 ± 70	KIA-27004	13,800–14,180	Bone	Vercellotti et al. 2008
25. Roc-de-Cave	44°48′	01°19′E	11,210 ± 140	GifA-95048	12,730–13,340	Rib	Gambier et al. 2000
26. Grotte des Enfantes	43°46′	07°32′E	11,130 ± 100	GifA-94197	12,730–13,240	Cranium	Riel-Salvatore and Gravel-Miguel 2013
27. La Madeleine	44°58′	01°02′E	10,190 ± 100	GifA-95457	11,400–12,380	Cranium	Gambier et al. 2000
Central Europe							
28. Peştera cu Oase 1[14]	45°01′	21°50′E	> 35,200	OxA-11711†	> 40,400	Mandible	Trinkaus et al. 2003
Peştera cu Oase 1[14]			34,290 + 970/−870	GrA-22810	36,980–41,150	Mandible	Trinkaus et al. 2003
29. Mladeč 9a[15]	49°42′	17°01′E	31,500 + 420/−400	VERA-3076A	35,060–36,680	Tooth	Wild et al. 2005
Mladeč 2			31,320 + 410/−390	VERA-3074	35,010–36,570	Tooth	Wild et al. 2005
Mladeč 1			31,190 + 400/−390	VERA-3073	34,950–36,510	Tooth	Wild et al. 2005
Mladeč 8			30,680 + 380/−360	VERA-3075	34,640–36,280	Tooth	Wild et al. 2005
Mladeč 25c			26,330 ± 170	VERA-2736	30,660–31,230	Ulna	Wild et al. 2005
30. Obłazowa Cave	49°27′	20°09′E	31,000 ± 550	OxA-4586	34,690–36,540	Phalanx	Prat et al. 2011
31. Peştera Muierii 1[16]	45°12′	23°45′E	30,150 ± 800	LuA-5228†	32,940–36,490	Scapula, tibia	Soficaru et al. 2006
Peştera Muierii 2			29,110 ± 190	OxA-16252†	33,210–34,510	Temporal	Soficaru et al. 2006

Table 1 Direct ^{14}C dates of Paleolithic humans in Eurasia.* *(Continued)*

Site** and nr of individual	Lat., N	Long., W/E	^{14}C date, yr BP	Lab code	Calendar age***	Skeleton part	Reference
32. Peştera Cioclovina Uscată[17]	45°35′	23°07′E	29,000 ± 700	LuA-5229†	31,720–34,780	Temporal	Soficaru et al. 2007
33. Willendorf I	48°19′	15°23′E	24,250 ± 180	ETH-20690	28,540–29,480	Femur	Teschler-Nicola and Trinkaus 2001
34. Brno 2	49°12′	16°37′E	23,680 ± 200	OxA-8293	27,940–29,080	Rib	Svoboda et al. 2002
35. Dolní Věstonice I, Fossil 35	48°53′	16°39′E	22,840 ± 200	OxA-8292	26,850–28,110	Femur	Svoboda et al. 2002
36. Mittlere Klause[18]	48°56′	11°48′E	18,590 ± 260	OxA-9856	21,440–23,180	Vertebra	Street et al. 2006
37. Maszycka Cave[19]	50°05′	19°58′E	15,015 ± 50	KIA-39227	18,010–18,540	Cranium	Kozłowski et al. 2012
38. Koněprusy	49°55′	14°04′E	12,870 ± 70	GrA-13696	14,970–16,050	Bone	Svoboda et al. 2002
39. Wilczyce	50°45′	21°39′E	12,870 ± 60	OxA-16729†	14,970–16,020	Infant bone	Irish et al. 2008
40. Climente II[20]	44°35′	22°16′E	12,590 ± 50	OxA-24990†	14,480–15,170	Femur	Bonsall et al. 2012
41. Brillenhöhle	48°25′	09°47′E	12,470 ± 65	OxA-11054†	14,160–15,040	Skull	Orschiedt 2002b
42. Burkhardtshöhle	48°31′	09°37′E	12,450 ± 110	ETH-7613	14,100–15,070	Cranium	Street et al. 2006
43. Neuwied-Irlich (adult)[21]	50°27′	07°27′E	11,910 ± 70	OxA-9847	13,490–13,950	Femur	Street et al. 2006
Neuwied-Irlich (neonate)[22]			12,110 ± 90	UtC-9221	13,750–14,200	Bone	Street et al. 2006
44. Bonn-Oberkassel, female	50°43′	07°10′E	12,180 ± 100	OxA-4792	13,770–14,790	Humerus	Street et al. 2006
Bonn-Oberkassel, male			11,570 ± 100	OxA-4790	13,240–13,690	Humerus	Street et al. 2006
45. Burghöhle Dietfurt[23]	48°05′	09°08′E	12,420 ± 60	KIA-3838	14,120–14,980	Cranium	Street et al. 2006
46. Rhünda	51°07′	09°25′E	10,200 ± 60	GrA-15947	11,630–12,110	Cranium	Street et al. 2006
Eastern Europe[24]							
47. Kostenki 14[25]	51°23′	39°03′E	33,250 ± 500	OxA-X-2395-15	36,690–38,980	Tibia	Marom et al. 2012
Kostenki 1[26]			32,070 ± 190	OxA-15055†	35,710–37,000	Femur	Higham et al. 2006b
Kostenki 18	51°23′	39°03′E	21.020 ± 180	OxA-7128	24.500–26.560	Bone	Richards et al. 2001
48. Buran-Kaya III[27]	45°00′	34°24′E	31,900 + 240/−220	GrA-37938	35,510–36,890	Parietal	Prat et al. 2011
Northern Asia (Siberia)[28]							
49. Maly Log 2 [Pokrovka 2]	55°20′	92°27′E	27,740 ± 150	OxA-19850†	31,420–32,440	Frontal	Akimova et al. 2010
50. Malta [Mal'ta] 1[29]	51°00′	103°30′E	19,880 ± 160	OxA-7129	23,330–24,260	Bone	Richards et al. 2001
51. Afontova Gora 2	56°00′	92°45′E	13,810 ± 35	UCIAMS-79661	16,750–17,080	Humerus	Raghavan et al. 2014

Table 1 Direct ^{14}C dates of Paleolithic humans in Eurasia.* *(Continued)*

Site** and nr of individual	Lat., N	Long., W/E	^{14}C date, yr BP	Lab code	Calendar age***	Skeleton part	Reference
East Asia							
52. Tianyuan Cave	39°39′	115°52′E	34,430 ± 510	BA-03222	38,120–40,940	Femur	Shang et al. 2007
53. Shiraho-Saonetabaru Cave[30]	24°24′	124°15′E	20,415 ± 115	MTC-12820	23,930–24,780	Parietal	Nakagawa et al. 2010
Shiraho-Saonetabaru Cave[30]			18,750 ± 100	MTC-13228	22,060–22,900	Metatarsal	Nakagawa et al. 2010
Shiraho-Saonetabaru Cave[30]			15,750 ± 420	MTC-12818	18,000–19,840	Fibula	Nakagawa et al. 2010
54. Negata [Hamakita][31]	34°52′	137°48′E	14,200 ± 50	Beta-160572	16,970–17,580	Occipital	Kondo and Matsu'ura 2005
Southeast Asia							
55. Tam Hang Cave	20°24′	104°02′E	15,740 ± 80[32]	GrA-10952[33]	18,670–19,280	Bone	Demeter et al. 2009

*The bulk collagen fraction of bone was dated unless otherwise indicated. Coordinates are rounded to the next one minute of latitude and longitude.

**The number before a site name indicates its position in Figure 1.

***Ages are in cal BP, according to the calibration using the CALIB 6.1.1 software based on the IntCal09 data set (Reimer et al. 2009) unless otherwise indicated, with ±2σ, and all possible intervals rounded to the next 10 yr and combined.

****All samples labeled as "bone" are from unspecified parts of a skeleton.

[§] The CalPal software (e.g. Weninger and Jöris 2008) was used, with ±2σ, rounded to the next 10 yr.

[†] Ultrafiltered collagen (e.g. Higham et al. 2006b) was dated.

[1] For the rest of direct ^{14}C dates, see Wood et al. (2013).

[2] There are also other ^{14}C dates on Neanderthal human bones from Spy Cave: scapula – 23,880 ± 240 BP (OxA-8912), 24,730 ± 240 BP (OxA-8913), and 31,810 ± 250 BP (GrA-21546) (Semal et al. 2009); and a vertebra (surface find) – 35,250 ± 500 BP (OxA-10560) (Toussaint and Pirson 2006). The ~23,880–31,810 BP values are considered too young for a Neanderthal and have been rejected, and the date of ~35,250 BP may correspond to the end of Neanderthal occupation of southern Belgium (Toussaint and Pirson 2006:379).

[3] Crevecoeur et al. (2010:652) also cite a date of 32,970 +200/–190 BP (GrA-32627) (34,920–36,540 cal BP) for the mandible fragment Spy 646a; it overlaps in calendar age with this value.

[4] This sample also yielded a date of 32,550 ± 400 BP (OxA-17916), but because its C:N ratio of 3.8 is beyond secure values (2.9–3.4), it was rejected (Semal et al. 2009:426).

[5] This bone also has a ^{14}C date of 26,820 ± 340 BP (OxA-8827), which is considered to be too young for a Neanderthal and was rejected (Toussaint and Pirson 2006:376).

[6] Other ^{14}C dates (~29,080–29,100 BP for Vi-207; and ~28,020–31,390 BP for Vi-208), obtained without the ultrafiltration step in collagen extraction, were rejected (see Higham et al. 2006a).

[7] Another date of ~29,200 BP, obtained on the Mez 1 individual, is excluded (see text).

[8] The same individual was dated; an average value of 34,190 ± 760 BP (Krause et al. 2007, Supplement 1, p 1) was suggested as the age estimate; it corresponds to 37,130–40,950 cal BP (see Figure 2).

[9] This age determination was revised by Higham et al. (2011) to ~36,000 BP (~41,500–44,200 cal BP) based on ^{14}C-dated animal bones presumably associated with the human fossil (cf. White and Pettitt 2012).

[10] There are also three other ^{14}C values on this individual (overlapping with the calibrated age of the OxA-16413 date): rib, 28,870 ± 180 BP (OxA-16412) (32,880–34,430 cal BP); scapula, 28,820 ± 340 BP (OxA-16503) (32,280–34,520 cal BP); and rib, 28,400 ± 320 BP (OxA-16502) (31,600–33,590 cal BP). There are also two ^{14}C dates on the same individual, 26,350 ± 550 BP (OxA-1815, femur and tibiae) (29,750–31,610 cal BP) and 25,840 ± 280 BP (OxA-8025, rib) (30,180–31,140 cal BP), which are probably too young (e.g. Jacobi and Higham 2008:903).

[11] There is another ^{14}C date from this site, on rib 19: 26,790 ± 190 BP (Beta-216142) (31,010–31,440 cal BP); it overlaps in calendar age with this value.

[12] There is a second ^{14}C date of this humerus: 24,000 ± 140 BP (OxA-11015) (28,410–29,300 cal BP) (see Schulting et al. 2005), overlapping in calendar age with this value. The third date, 23,370 ± 110 BP (OxA-11543) (27,870–28,530 cal BP), is slightly too young (Schulting et al. 2005:496).

[13] In Table 1 of Gambier et al. (2000:204) this age is given, while in the text (Gambier et al. 2000:203) it is slightly different: 15,700 ± 150 BP.

[14] The same individual was dated; an average age of 34,950 +990/–890 BP (40,440 ± 1030 cal BP, or 38,380–42,500 cal BP with ±2σ) is suggested (Trinkaus et al. 2003:245; Rougier et al. 2007) (see Figure 2).

[15] This is the date on "white-coloured collagen"; the "brown-coloured collagen" is dated to 27,370 ± 230 BP (VERA-3076B) (31,180–32,050 cal BP) (Wild et al. 2005), and this collagen is perhaps contaminated (Wild et al. 2005:334).

[16] The cranium of this individual was dated to 29,930 ± 170 BP (OxA-15529) (34,110–35,010 cal BP), overlapping in calendar age with this value.

[17] The occipital of this individual was dated to 28,150 ± 170 BP (OxA-15527) (31,690–33,000 cal BP), overlapping in calendar age with this value.

[18] The tibia of this individual was dated to 18,200 ± 200 BP (UCLA-1869) (21,310–22,290 cal BP), overlapping in calendar age with this value.

[19] There is another ^{14}C date from this site on a mandible: 15,115 ± 60 BP (KIA-39228) (18,030–18,600 cal BP); it overlaps in calendar age with this value.

[20] There is a second ^{14}C date for the same individual, 12,535 ± 55 BP (OxA-22042), and the combined age is 12,565 ± 37 BP; the reservoir-corrected age is 12,220 ± 58 BP (13,850–14,270 cal BP) (Bonsall et al. 2012:324) (see Figure 2).

[21] Possibly the same individual was dated (Street et al. 2006:568). A rib from this site with a date of 12,310 ± 120 BP (OxA-9736) is identified as "*Homo sapiens* ?" (Baales 2004:65, Table 1; Street et al. 2006:569) and as a "human bone" (Bronk Ramsey et al. 2002:10–1). Because of the apparently uncertain classificatory status of this bone, it is excluded from this table.

[22] A rib of this individual was dated to 11,965 ± 65 BP (OxA-9848) (13,650–14,000 cal BP), overlapping in calendar age with this value.

[23] A second date for this cranium, 12,210 ± 60 BP (KIA-3837) (13,840–14,510 cal BP), overlaps in calendar age with this value.

[24] The series of ^{14}C dates on three individuals at the Sungir site (No. 56 in Figure 1) is not included here due to the problematic situation (e.g. Keates et al. 2012:342–3; see also Kuzmin et al., these proceedings).

[25] The hydroxyproline fraction of bone collagen was dated. For previous ^{14}C dates of this skeleton, see Marom et al. (2012:6879).

[26] There is another ^{14}C date on the same femur of this individual, run on the gelatin fraction of collagen without the ultrafiltration step: 32,600 ± 1100 BP (OxA-7073) (34,930–39,920 cal BP) (Richards et al. 2001), overlapping in calendar age with this value.

[27] There is a second ^{14}C date on this individual, 32,790 ± 280 BP (OxA-13302) (36,680–38,430 cal BP) (Higham et al. 2011), overlapping in calendar age with this value.

[28] The Baigara find (Kuzmin et al. 2009) has not been included; this is because of its recent redating to ~9000 BP (after the sample's misplacement and erroneous date of greater than 40,300 BP).

[29] There is a second date on the humerus of this individual, 20,240 ± 60 BP (UCIAMS-79666) (23,890–24,420 cal BP) (Raghavan et al. 2014), overlapping in calendar age with this value.

[30] Each date was run on a different individual; original dates are rounded to the next 5 yr.

[31] There are also two other ^{14}C dates on human remains from this locality, on a parietal: 14,050 ± 50 BP (Beta-160571) (16,860–17,440 cal BP); and on a humerus: 13,860 ± 50 BP (Beta-160570) (16,770–17,130 cal BP); they overlap in calendar age with this value.

[32] According to the records of the Center for Isotope Research, University of Groningen (J van der Plicht, personal communication, 2014), where the sample was run, the age is 13,740 ± 80 BP.

[33] J van der Plicht (personal communication, 2014).

RESULTS AND DISCUSSION

According to the existing corpus of ^{14}C dates, the age of Eurasian Neanderthals is ~48,400–30,500 BP (~63,300–35,400 cal BP), with the latest specimens from modern Belgium (Engis 2) and Croatia (Vindija Cave) (Figure 2). The oldest ^{14}C value comes from the El Sidrón site (Spain); due to the large standard deviation, its calendar age can provisionally be determined as ~53,600 cal BP (median value, see Table 1). Obviously, Neanderthals existed in Europe before this date (e.g. Harvati 2007), but these remains are beyond the limits of ^{14}C dating.

The rib of the Mezmaiskaya Cave individual Mez 1, found in Layer 3, was directly ^{14}C dated to 29,195 ± 965 BP (Ua-14512) (Ovchinnikov et al. 2000). In light of the Oxford ultrafiltered collagen date, produced on the Mez 2 skeleton from the overlying Layer 2 (~39,700 BP, see Table 1), and the ^{14}C dates from Layer 3 generated on animal bones (greater than 45,200–46,100 BP, see Pinhasi et al. 2011), the ~29,200 BP value for the Mez 1 Neanderthal from Layer 3 is perhaps too young. It was suggested that this is due to collagen contamination, which was later eliminated after more rigorous pretreatment using the ultrafiltration protocol (e.g. Pinhasi et al. 2011:8613).

The earliest directly ^{14}C-dated modern humans come from different parts of Eurasia (Table 1): central Europe (Peştera cu Oase: ~34,950 BP or ~40,400 cal BP), East Asia (Tianyuan Cave: ~34,400 BP or ~39,500 cal BP), and eastern Europe (Kostenki 14: ~33,300 BP or ~37,800 cal BP).

Higham et al.'s (2011) very early age of the KC4 maxilla from Kent's Cavern in Britain (see Table 1) is disputed by White and Pettitt (2012) based on an analysis of archival records, concluding that not all the strata in Kent's Cavern are *in situ* position. This indicates that the use of the animal bone ^{14}C dates by Higham et al. (2011) to establish the age of the KC4 specimen may not be valid. Because the provenance of the KC4 specimen is not well known according to White and Pettitt (2012), the dating of material supposedly associated with the human fossil to establish its age as was done by Higham et al. (2011) cannot guarantee that it is the correct date. Therefore, its previous direct ^{14}C age of ~30,900 BP (~35,400 cal BP) should be kept (see Figure 1 and Table 2) as a tentative value until this controversy is resolved.

The possible coexistence of both the latest Neanderthals and the earliest modern humans in Eurasia is one of the most debated issues in Paleolithic archaeology and anthropology (e.g. Gravina et al. 2005; Finlayson et al. 2006; Higham et al. 2011). Judging from information available in early 2014, it is clear that there is a definite overlap in ^{14}C dates for both species (subspecies) in western/central Europe (Figure 2). It seems that at ~36,200–30,200 BP (~42,500–32,800 cal BP, see Figure 2) both Neanderthals and modern humans lived in several parts of Europe, although due to the small number of directly dated fossils further study is needed. Nevertheless, at some sites of similar age and located in the same greater region (Vindija Cave and Mladeč in central Europe; and Engis 2 and Kent's Cavern in western Europe) Neanderthals and moderns may well have been contemporaneous.

A gap in the ^{14}C dates of modern humans in Europe corresponding to the Last Glacial Maximum (LGM, ~22,000–16,000 BP or ~26,000–19,000 cal BP; see Clark et al. 2009) is evident, with only a few values (e.g. Mittlere Klause site in southern Germany, ~18,600 BP; see Figure 2). In Asia, however, there are several directly ^{14}C-dated human remains belonging to this timespan, from Malta (Siberia) and Shiraho-Saonetabaru Cave (Ryukyu Archipelago, Japan).

The general ^{14}C chronology of the Siberian Upper Paleolithic based on ^{14}C records of nonhuman Paleolithic materials (e.g. charcoal and animal bone; see Kuzmin and Keates 2013) shows that there was no significant depopulation of northern Asia at the LGM. This conclusion, initially put forward in the late 1990s (see details: Kuzmin 2008:203–5), was repeatedly confirmed in the 2000s (e.g. Kuzmin 2008, 2009; Kuzmin and Keates 2005). Opponents of this model, who had for years argued that people were not able to cope with the harsh environment of the LGM in Siberia (e.g. Goebel 2004; Graf 2005, 2009), have recently abandoned their opinion and suggest that "...parts of south-central Siberia were occupied by humans throughout the coldest stages of the last ice age" (Raghavan et al. 2014:89). This is presented as their own achievement, without any mention of studies where exactly the same interpretation was published before (e.g. Kuzmin and Keates 2005), thereby ignoring the primary sources on this subject. Also important is that all previous results by Graf (2005, 2009) concerning the LGM depopulation of Siberia contradict what is now claimed in Raghavan et al. (2014), where K E Graf is one of the leading coauthors.

The quality of human fossils for ^{14}C dating is also very important for the correct interpretation of the results obtained. The collagen fraction is the most reliable compound for bone ^{14}C dating. As an illustration of this, the case of the Wajak site on Java (Southeast Asia) can be used. Here, a direct AMS ^{14}C age of a human bone (femur) was obtained: 6560 ± 140 BP (AA-7718) (Shutler et al. 2004:90; see also Keates et al. 2012:339), corresponding to a calendar age of ~7500 cal BP. However, presumably due to poor preservation of collagen, the apatite fraction of the bone was dated (Shutler et al. 2004:91). More recently, Storm et al. (2013) performed laser ablation U-series dating of other human bones from the Wajak site, and received much older ages: ~37,400–28,500 yr. The apatite fraction of their WF1 sample (post-cranial bone) was ^{14}C dated to 14,870 ± 100 BP (S-ANU-25111), corresponding to an age of ~18,200 cal BP. The U-series age of this specimen is 36,500 ± 5800 yr. According to Storm et al. (2013), the Holocene age of Shutler et al.'s (2004) femur may be explained by the fact that the apatite fraction is almost always younger than the collagen. Also, Storm et al. (2013:362) found significant secondary carbonate contamination of the Wajak crania WF1–WF2 and extremely low collagen yields (0.01–0.19%). Thus, poor collagen preservation may also be responsible for distorted ages (see below).

The gradual developments in ^{14}C dating of bone material (Longin 1971; Brown et al. 1988; Arslanov and Svezhentsev 1993; Higham et al. 2006b; Brock et al. 2010b, 2012; Talamo and Richards 2011) resulted in a widely accepted protocol for collagen extraction by dissolution of bone/tooth material in acid, and gelatinization of the remaining organic fraction. The evaluation of the quality of collagen also advanced (e.g. van Klinken 1999; Brock et al. 2010a). Two main criteria for the selection of bone/tooth material for direct ^{14}C dating are (1) the collagen yield, which should generally be 1% or higher (e.g. Brock et al. 2012); and (2) a C:N ratio of collagen within the 2.9–3.4 range (e.g. DeNiro 1985). Samples with both parameters outside of these limits are usually not suitable for a secure age determination, and are now routinely rejected at the very preliminary stage (e.g. Brock et al. 2012).

CONCLUSIONS

In the Late Pleistocene, the youngest Neanderthals existed in several regions of Eurasia, mainly in Europe, until ~30,500 BP (~35,400 cal BP). Beginning at ~34,950–33,300 BP (~40,400–37,800 cal BP), modern humans occupied different parts of Eurasia over thousands of kilometers. It is therefore possible that both Neanderthals and modern humans coexisted, at least in western/central Europe at ~36,200–30,200 BP (~42,500–32,800 cal BP). Modern humans associated with Upper Paleolithic complexes lived in Eurasia until ~10,000 BP, and continued as Mesolithic-Neolithic populations afterwards. A few of the European directly ^{14}C-dated finds are from the time of the LGM, and more materials are known from Asia. This may reflect the relative density of human populations at the LGM in different parts of Eurasia; however, more data are needed to arrive at a solid conclusion.

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