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Colonization of Northern Eurasia by Modern Humans: Radiocarbon Chronology and Environment

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The distribution of frequencies of radiocarbon-dated Palaeolithic sites in northern Eurasia shows three peaks of 40–30, 24–18 and 17–1 ka BP. We argue that these peaks reflect the waves in the colonization of that area by Anatomically Modern Humans stemming from Central and Eastern Europe and caused by environmental stress.
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Introduction

The present article is aimed at the discussion of the initial dispersal of anatomically modern humans (AMH) in northern Eurasia, as inferred mainly from radiocarbon chronology and palaeoenvironmental evidence. In this respect this article may be viewed as a direct development of the previous publication, focused on East European Plain (Dolukhanov, Shukurov & Sokoloff, 2001). The area considered here extends to Siberia and Russian Far East, which are viewed against the wider background of the Eurasian continent. The period of time considered encompasses the episodes of the Last Ice Age in the range between ca 50,000 and 10,000 years before present (50–10 ka). This includes Oxygen Isotope Stage (OIS) 2 with the "megainterstadial" (or "interpleniglacial"), and OIS 3 consisting of the Late Glacial Maximum (LGM) and the Late Glacial Recession.

Data and Methods

Radiocarbon age

The main resource of the present study consists of the database of radiocarbon measurements of Siberia's Palaeolithic sites compiled at the Radiocarbon Laboratory of the Institute for History of Material Culture, Russian Academy of Sciences, St Petersburg. It exceeds in scope the previously published compendia by Lisitsyn & Svezhentsev (1997) and Kuzmín & Tankersley (1997). The measurements included in the database have been performed, in most cases, with the conventional technique in the institutions of the Russian Academy of Sciences: at Institute of Geology in Moscow (GIN), Institute of Geography in Moscow (IGAN), Institute of Ecology and Evolution in

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Moscow (IM), Institute for History of Material Culture in St Petersburg (LE), Laboratory for Quaternary Geology and Geochronology in Magadan (MAG), the Vernadsky Institute of Geochemistry in Moscow (MO), and Institute of Geology and Mineralogy in Novosibirsk (SOAN). Several important series were measured in Groningen University, Holland (GrA and GrN). The database includes samples from several sites measured with the use of Accelertor Mass Spectrometry (AMS) in several laboratories including the Oxford Radiocarbon Accelerator Unit, U.K. (OxA), University of Arizona, U.S.A. (AA) and others.

The original database has been screened with the use of procedures discussed by Dolukhanov, Shukurov & Sokoloff (2001):

(1) All dates where association with archaeological deposits has not been demonstrated were rejected.
(2) Wherever possible, preference was given to the dates supplied with adequate stratigraphic and/or planigraphic information.
(3) Equally, we preferred the measurements confirmed by inter-laboratory cross-checking.
(4) Controversial dates (e.g., those failing inter-laboratory cross-checking or a single date strongly deviating from a series of close-by dates for the same site) were discarded.

Such a screening is necessary because some sites have vastly different number of radiocarbon date determinations. For example, 14 dates have been published for the Berelyoh site, one of them being 42·0 ka (with insufficient stratigraphic information and published without its error) and the remaining ones in the range 13·4–10·3 ka. Our screened date-list includes just one date of 11·8 ka (No. 105 in Table 2) that is close to the median of the date cluster of the younger age. The geographical areas discussed here (the Altai Mountains, the Yenisei, Angara and Aldan Rivers, the Lake Baikal area and the Maritime Region) have been rather thoroughly surveyed by several generations of Russian archaeologists. The frequencies of the screened dates per chosen time interval can be used as a reliable indicator of the population (or settlement) density at a given time only provided each settlement (or rather a distinct stage of its existence) enters the analysis with equal weight, e.g., as a single date per settlement per chronological stage. A few examples of the screening are given below.

As a result, two new data-lists have been developed, one for Southern-Central Siberia (SCS. 97 dates), and North-Eastern Siberia and Russian Far East (NES. 22 dates), shown in Tables 1 and 2. The data-lists include the following information: entry number; laboratory index as defined above; site name; date (uncalibrated BP); the date uncertainty; cluster size (the number of dates in the original database from which the date shown is chosen using the screening criteria discussed above); location with respect to Russia's administrative division, i.e., *oblast*/*kray* (e.g., Irkutsk, Krasnoyarsk) or *autonomous republic*/*autonomos oblast* (Altai, Khakassia, Yakutia); geographical co-ordinates (northern latitude X and eastern longitude Y in degrees and minutes); dated material (charcoal, antler or bone), and the stratigraphic position. Apparently most of the dated bone and antler do not have any clear signs of human modification.

Using also the previously published data for East European Plain (EEP) (Dolukhanov, Shukurov & Sokoloff, 2001), we have presented the radiocarbon dates in the frequency histograms showing the occurrences of the radiocarbon dated sites per 1000 years. These are shown for EEP in Figure 1, SCS in Figure 2, and NES in Figure 3. The Figures also show a composite record of oxygen isotope variations from the sediment cores in the Atlantic Ocean (Imbrie *et al*., 1990), with larger $\delta^{18}O$ values indicating colder climate throughout the Northern Hemisphere.

As demonstrated by Dolukhanov, Shukurov & Sokoloff (2001), calibration of the radiocarbon dates belonging to the periods discussed (allowing for variations in the ^{14}C production rate in the exchange reservoir) does not affect the general trends, and so our conclusions. Some statistical aspects of our arguments are discussed in Appendix 1.

Palaeoenvironment

Apart from the oxygen isotope data, we discuss evidence pertinent to the Late Quaternary climate and environment of the major areas in Northern Eurasia, as well as to the immediate setting of the sites. The climate reconstructions are based on the existing publications where descriptive qualitative and/or quantitative non-statistical methods were used (e.g. Frenzel, Pecsi & Velichko, 1992). In several cases, quantitative characteristics of the climate were based on the concept of biomization: pollen spectra grouped into plant functional types (PFT) were calibrated against the present-day climatic variables (Prentice *et al*., 1992; Peyron *et al*., 1998; Tarasov *et al*., 1999*a*).

European Russia

Palaeoenvironment

The climate of the Middle Würm/Valdai "megainterstadial" (OIS 3), which lasted in European Russia from 48–25 ka, was cool and unstable with at least five milder oscillations (Arslanov, 1992). According to Frenzel, Pecsi & Velichko (1992), summer and winter temperatures in Eastern Europe were lower than today by 4–6°C and 4–10°C, respectively. Annual precipitation of that period is estimated as 150–250 mm, also lower than now.

The Last Glacial Maximum (LGM), 20–18 ka, featured the maximum extension of ice sheets on East European Plain. The biomization-based quantitative assessment (Tarasov *et al*., 1999*a*) indicates a considerable depression of temperatures, by 20–29°C in winters and 5–10°C in summers. The annual precipitation resulting from this approach is 200–450 mm less than today, with the drought index showing particularly dry conditions in northern and mid-latitude Russia. The vegetation was dominated by the "periglacial" tundra and cold-resistant steppe in combination with open woodland of larch and birch (Grichuk, 1992).

The Late Glacial Recession at 18–10 ka was marked by the degradation of ice sheets, punctuated by short-lived glacial advances (Chebotareva & Makarycheva, 1982). Several areas were affected by a permafrost with the ground temperature of −(3–5)°C (Morozova & Nechaev, 1997: 57).

Human settlements

The early stage. Judging from radiocarbon dates, the initial appearance of Upper Palaeolithic sites on East European Plain occurred in the time-span of 39–36 ka (Sinitsyn *et al*., 1997). These sites were evenly scattered across the entire area; they are known in Western Ukraine, Moldavia, Crimea, Pontic Lowland, on the River Don, in the Ural Mountains and even north of the Polar Circle.

Pollen analysis (Spiridonova, 1991) shows predominantly pine forests in the River Don valley at the time of early UP settlements. As the climate grew colder, spruce forests and the cold-resistant "periglacial" grassland took up increased areas. The wild horse was the principle hunting prey, followed by the mammoth and reindeer (Praslov & Rogachev, 1982).

In the cultural sense, the early UP sites belonged to at least three distinctive traditions: Streletsian, Aurignacian, and "protogravettian" (Sinitsyn *et al*., 1997: 42). The Streletsian inventories initially identified in the Kostenki area on the Don, were later found on the Severski Donets River in the Ukraine, in Central Russia (Sungir'), and on the Kama River in the Urals (Bradley, Anikovich & Giria, 1995). These inventories included archaic Mousterian elements combined with the UP "laminar" technology. Both the Aurignacian and "protogravettian" featured the fully developed Upper Palaeolithic "core-and-blade" technique (Sinitsyn *et al*., 1997).

The middle stage. Frequencies of radiocarbon dated sites show a clear increase in the range of 29–26 ka apparently forming a maximum at 24–18 ka. The sites of that age were found mainly in the "periglacial" zone of East European Plain, usually on elevated river terraces facing the widened flood plains (Gribchenko & Kurenkova, 1997). Their natural habitat consisted of treeless "periglacial" grassland with rare cold-resistant shrubs (Spiridonova, 1991). The mammoth dominated the animal remains, with rare occurrences of reindeer and polar fox (Praslov & Rogahev, 1982).

Traditionally, the sites belonging to this time-span in Eastern Europe were summarily labelled as the "eastern Gravettian". Grigor'ev (1993) has identified, among them, the "Kostenki-Avdeevo" Culture exposing stylistic similarities with the sites in Central Europe, notably, Willendorf, Predmosti and Dolni Vestonice.

The later stage. The latest recognizable increase in the density of UP sites occurred at 18–15 ka. At that stage cultural fragmentation became apparent, the cultural entities being restricted to major river basins: the Prut-Dniestrian, Upper Dnieprian, Donian, etc. (Sinitsyn *et al*., 1997). The UP sites completely disappeared in the central area of East European Plain at ages less than 11–12 ka.

South-Central Siberia

Palaeoenvironment

The time-span of OIS3–OIS2 in that part of Siberia included the Karginian Interglacial (50–22 ka) and the Sartan Glacial (22–10 ka) (Velichko, 1993). Frenzel, Pecsi & Velichko (1992) estimate that Karginian climate as colder than now, by 4°C in summers and 6°C in winters, with the annual precipitation lower than today by 80–50 mm. During the milder episode of 30–35 ka, forests spread far to the north along the Yenisei River Valley. Forests and forest-steppe occurred both in the Altai and Trans-Baikal mountains (Drozdov *et al*., 1990). The animal world consisted of large herd mammals and included the mammoth, woolly rhinoceros, wild horse, reindeer and elk. The bison, mountain goat and sheep, red deer, bear and leopard were common in the Altai Mountains.

The Sartan Glacial featured limited-scale ice-sheets confined to the Yamal and Taymyr peninsula (Velichko *et al*., 1998). Small-size glaciers occurred in the Altai and Trans-Baikal mountains. Frenzel, Pecsi & Velichko (1992) reconstruct a strong thermal depression for that period, with winter temperatures by about 12°C, summer temperatures, about 6°C lower than at present, and mean annual precipitation varying between 50 and 250 mm below the present-day values. A biomization-based quantitative climate reconstruction for the southern part of western Siberia and northern Mongolia (Tarasov *et al*., 1999*b*) yields similar estimates, with the winters colder than today by 7–15°C, and summers, by 1–7°C. According to these calculations, the precipitation remained basically similar to the present-day values.

Pollen data show the treeless tundra alternating with the "cool" steppe covering the entire area with a few refuges of broadlead forests hidden in the South Siberian mountains (Maloletko, 1998).

Human settlements

The early stage. A series of radiometric dates (both conventional radiocarbon and the AMS) has recently

Table 1. Radiocarbon dates for Southern-Central Siberia (uncalibrated, BP)

Nos.	Laboratory index	Site Name	Date (year BP)	Error (year)	Cluster size	Location	X	Y	Material	Position
1	IM-887	Haergas	16,000	200	1	Yakutia	60°00′	117°22′	Bone	Level 6
2	Le-1434	Yanova	30,700	400	1	Krasnoyarsk	54°51′	90°55′	Tusk	Arch. Level
3	Le-1549	Telezhnyi Log	15,480	500	1	Krasnoyarsk	55°05′	92°11′	Bone	Arch. Level
4	Le-1984	Nizhni Idzhir 1	17,200	140	1	Khakassia	52°05′	92°22′	Charcoal	Arch. Level
5	Le-3611	Sabanikha	22,930	350	5	Khakassia	54°22′	51°06′	Charcoal	Level 3·7 m
6	Le-1409	Biryusa-3	34,000	1500	1	Krasnoyarsk	55°55′	89°04′	Bone	Level A
7	SOAN1519	Proskuryakov Cave	40,770	1075	3	Khakassia	54°15′	89°21′	Bone	Arch. Level
8	GIN-5929	Ust-Kova	34,300	900	9	Krasnoyarsk	58°17′	100°19′	Charcoal	Lower Level
9	SOAN1875	Ust-Kova1	28,050	670	2	Krasnoyarsk	58°17′	100°19′	Charcoal	Lower Level
10	GIN-4440	Military Hospital	29,700	500	1	Irkutsk	52°34′	100°25′	Bone	Arch. Level
11	SOAN-1680	Buret	21,190	100	1	Irkutsk	52°57′	103°30′	Bone	Arch. Level
12	GIN-5329	Ust-Belaya	11,930	230	1	Irkutsk	52°5′	103°31′	Charcoal	Level 14
13	GIN-5328	Sosnovyi Bor	12,060	120	1	Irkutsk	52°36′	103°49′	Charcoal	Level 3B
14	Le-1592	Igutinskii Log	23,508	250	4	Irkutsk	53°25′	103°56′	Charcoal	Lower Level
15	Mo-441	Verholenskaya Gora	12,570	180	1	Irkutsk	52°34′	104°25′	Charcoal	Arch. Level
16	Le-3931	Alekseevka 1	22,410	480	1	Irkutsk	54°04′	105°29′	Charcoal	Arch. Level
17	AA-8882	Shishkino 8	21,190	175	1	Irkutsk	54°01′	105°40′	Bone	Arch. Level
18	SOAN3092	Ust-Kyahta 17	11,500	100	3	Buryatia	50°31′	106°16′	Bone	Level 5
19	GIN-6214	Kunalei	21,100	300	1	Irkutsk	50°36′	107°48′	Bone	Level 3
20	SOAN3133	Kamenka1	31,060	530	2	Buryatia	51°43′	108°15′	Bone	Complex A
21	IM-236	Avdeikha	15,200	300	2	Irkutsk	59°24′	112°45′	Charcoal	Level C
22	Le-4172	Boishoi Yakor	12,400	150	6	Irkutsk	56°13′	115°44′	Charcoal	Level C
23	Le-3821	Tarachikha	19,850	180	2	Krasnoyarsk	73°04′	86°50′	Bone	Level 3A
24	SOAN1124	Malaya Saya	20,300	350	5	Khakassia	54°23′	89°25′	Charcoal	Arch. Level
25	SOAN1125	Bolshoi Kemchug	10,980	55	2	Krasnoyarsk	54°27′	89°30′	Charcoal	Level 1·0 m
26	Le-5233	Dvuglazka	44,400	1600	8	Krasnoyarsk	54°35′	90°51′	Bone	Level 5
27	Le-4801	Tashtyk 2	13,550	320	1	Krasnoyarsk	54°37′	90°55′	Bone	Level 2
28	Le-3739	Novoselovo 13	21,580	480	3	Krasnoyarsk	54°58′	90°57′	Charcoal	Arch. Level
29	Le-4189	Ui-1	22,830	500	4	Khakassia	52°56′	91°05′	Bone	Level 2
30	Le-3609	Ui-2	11,970	230	3	Khakassia	52°26′	91°05′	Charcoal	Level 4
31	GIN-90	Kokorevo 2	13,330	100	5	Krasnoyarsk	55°05′	91°10′	Charcoal	Arch. Level
32	IGAN-105	Kokorevo 1	15,200	200	7	Krasnoyarsk	55°05′	91°10′	Charcoal	Level 2
33	Le-629	Kokorevo 3	12,690	140	1	Krasnoyarsk	55°05′	91°10′	Charcoal	Arch. Level
34	Le-540	Kokorevo 4	15,460	320	2	Krasnoyarsk	55°00′	91°10′	Charcoal	Level 2, 2·6 m
35	Le-4895	Berezovyi Ruchei	15,210	800	2	Krasnoyarsk	55°10′	91°12′	Bone	Arch. Level
36	Le-4806	Divnyi 1	13,220	150	1	Krasnoyarsk	55°05′	91°15′	Bone	Arch. Level
37	GrN21368	Kamennyi Log	33,740	500	8	Krasnoyarsk	55°05′	91°23′	Charcoal	Level 4B
38	GrN20869	Kurtak-Berezhkovo	31,880	350	9	Krasnoyarsk	55°09′	91°28′	Wood	Level 3B
39	GIN-2102	Kurtak 3	16,900	700	4	Krasnoyarsk	55°09′	21°28′	Charcoal	Hearth, 2·8 m
40	Le-3351	Kurtak 4	24,170	230	9	Krasnoyarsk	55°09′	21°28′	Charcoal	Level 14
41	Le-2300	Maina	12,120	120	19	Khakassia	52°57′	91°28′	Charcoal	E. S. 3, Level 2
42	Le-2383	Maina	15,200	150	19	Khakassia	57°57′	91°28′	Charcoal	E. S. 6, Level 3
43	GIN-6969	Kashtanka	29,400	400	5	Krasnoyarsk	55°07′	91°30′	Charcoal	Level 2
44	Le-1101	Golubaya-1	13,050	90	6	Krasnoyarsk	52°57′	91°32′	Charcoal	Level 3, Hearth
45	SOAN2854	Pritubinsk	15,600	495	1	Krasnoyarsk	53°53′	92°00′	Charcoal	Level 3
46	SOAN1465	Tonnelnaya	13,840	345	2	Krasnoyarsk	55°50′	92°10′	Bone	Level 6
47	GIN-6965	Listvenka	13,100	410	6	Krasnoyarsk	55°56′	92°22′	Charcoal	E. S. 3, Level 7
48	SOAN3309	Yeleneva Cave	12,085	105	10	Krasnoyarsk	55°56′	92°29′	Charcoal	Hearth 5·5 m
49	Le-3777	Biryusa	14,480	400	7	Krasnoyarsk	56°04′	92°32′	Bone	Level 3A
50	SOAN3315	Bol. Slizneva Cave	13,540	500	2	Krasnoyarsk	56°09′	92°55′	Charcoal	Level 8
51	GrN22274	Afontova Gora	13,990	110	11	Krasnoyarsk	55°58′	92°57′	Charcoal	Level 3b
52	Mo-343	Afontova Gora	11,330	270	11	Krasnoyarsk	55°58′	92°57′	Charcoal	Upper Level
53	Le-4894	Druzhiniha	43,580	8800	7	Krasnoyarsk	56°54′	93°22′	Bone	Arch. Level
54	GIN-5821	Strizhova Gora	12,000	150	9	Krasnoyarsk	55°48′	96°46′	Bone	Level 14
55	SOAN810	Tolbaga	15,100	520	4	Irkutsk	51°15′	109°20′	Bone	Level 0·75 m
56	GIN-5330	Krasnyi Yar	19,100	100	1	Irkutsk	53°44′	103°22′	Bone	Arch. Level
57	GIN-7709	Mal'ta	20,700	150	20	Irkutsk	52°49′	103°33′	Bone	Arch. Level
58	GIN-480	Makarovo 2	11,860	200	3	Irkutsk	53°55′	105°51′	Charcoal	Level 3. Hearth
59	GIN-7067	Makarovo 3	31,200	500	1	Irkutsk	53°55′	105°51′	Bone	Lower Level
60	GIN-6121	Ust-Kyahta	11,630	140	6	Buryatia	50°31′	106°16′	Charcoal	Hearth, 2·9 m
61	SOAN3404	Podzvonkaya	26,000	920	2	Buryatia	50°35′	107°35′	Bone	Arch. Level
62	Le-3950	Balysheva	25,100	940	2	Irkutsk	57°30′	107°48′	Bone	Level 2
63	SOAN1524	Varvarina Gora	34,900	780	6	Buryatia	51°47′	108°15′	Bone	Arch. Level
64	SOAN2903	Kamenka-1	28,060	475	10	Buryatia	51°43′	108°15′	Bone	Complex A
65	GIN-5465	Ust-Menza	16,980	150	7	Chita	50°15′	108°37′	Charcoal	Level 20

Table 1. (Continued)

Nos.	Laboratory index	Site Name	Date (year BP)	Error (year)	Cluster size	Location	X	Y	Material	Position
66	SOAN1652	Studence	12,510	80	18	Chita	50°15′	108°37′	Charcoal	Level 13, Hearth
67	SOAN3078	Tolbaga	26,900	225	4	Chita	51°15′	109°20′	Charcoal	Level 4
68	SOAN1396	Kurla 1	15,200	1250	2	Buryatia	55°43′	109°28′	Charcoal	Hearth
69	SOAN1397	Kurla 3	24,060	570	2	Buryatia	55°43′	109°28′	Charcoal	Level 3, Hearth
70	AA-8888	Masterov Klyuch	24,360	270	1	Irkutsk	51°19′	110°31′	Bone	Level 3
71	SOAN32467	Kuhor-Tala	11,240	360	2	Buryatia	51°43′	110°39′	Charcoal	Trench 3
72	GIN-5791	Muhino	13,270	140	1	Buryatia	52°51′	111°01′	Bone	Level 3
73	Le-2402	Altan	18,760	200	1	Chita	52°29′	111°32′	Charcoal	Level 13
74	Le-2967	Artin-2	37,360	2000	1	Chita	51°15′	112°24′	Charcoal	Arch. Level
75	Le-3652	Sohatino-4	15,820	300	6	Chita	52°01′	113°31′	Charcoal	Level 3
76	GIN-6468	Bolshoi Yakor’	12,330	250	1	Irkutsk	56°13′	115°44′	Bone	Level 8
77	GIN-6469	Ust-Karenga	12,880	130	5	Irkutsk	54°26′	116°31′	Charcoal	Arch. Level
78	Le-1952	Nizhn. Dzhilinda	11,280	80	1	Buryatia	52°26′	116°52′	Charcoal	Lower Level
79	SOAN110	Logovo Gyeny	32,700	2800	1	Altai			Bone	Level 2
80	Le-1812	Sumpanya	11,970	120	1	Tyumen	60°03′	64°36′	Charcoal	Arch. Level
81	GIN-622	Chernoozer’e-2	14,500	500	1	Omsk	55°44′	73°58′	Charcoal	Hearth
82	SOAN111	Volch’ya Griva	14,450	110	2	Novosibirsk	54°42′	80°07′	Bone	Arch. Level
83	GIN-1701	mogochinskaya	27,300	400	3	Tomsk	57°42′	83°35′	Charcoal	Arch. Level
84	SOAN3219	Strashnaya	31,510	2615	3	Altai	51°45′	83°51′	Bone	Level 3
85	RIDDL718	Okladnikov Cave	33,500	700	7	Altai	51°38′	84°29′	Bone	Level 1
86	RIDDL720	Okladnikov Cave	40,700	1100	7	Altai	51°38′	84°19′	Bone	Level 3
87	SOAN2504	Denisova Cave	37,235	1000	9	Altai	51°23′	84°40′	Bone	Level 11
88	SOAN3005	Anui-2	26,810	290	8	Altai	51°23′	84°40′	Charcoal	Level 12, Hearth
89	SOAN2869	Ust-Karakol 1	31,345	275	12	Altai	51°23′	84°41′	Charcoal	Level 5, Hearth
90	SOAN3702	Kaminnaya Cave	10,870	150	5	Altai	52°16′	84°49′	Charcoal	Level 11A
91	GIN-2100	Tomskaya	18,300	1000	1	Altai	56°28′	84°56′	Charcoal	Hearth, 3·5 m
92	SOAN2485	KaraTenesh	42,165	4170	5	Altai	51°02′	86°17′	Charcoal	Level 2·0 m
93	SOAN2861	Mohovo-2	30,330	445	2	Kemerovo	54°33′	86°21′	Bone	Level 2·5 m
94	GX-17596	Kara Bom	43,300	1600	11	Altai	50°11′	86°41′	Charcoal	Level 6
95	GX-17593	Kara Bom	30,990	460	11	Altai	50°11′	86°41′	Charcoal	Level 5A
96	SOAN300	Kara Bom	21,280	440	11	Altai	50°11′	86°41′	Charcoal	Level 3
97	SOAN20800	Shestakovo	20,800	450	9	Kemerovo	55°53′	87°58′	Charcoal	Level 6

Table 2. Radiocarbon dates for North-Eastern Siberia and Russian Far East (uncalibrated, BP)

Nos.	Laboratory Index	Site name	Date (year BP)	Error (year)	Cluster size	Location	X	Y	Material	Position
98	Le-898	Ust-Timpton	10,650	80	4	Yakutia	58°45′	127°11′	Charcoal	Level 6
99	Le-920	Ust-Timpton2	10,300	50	1	Yakutia	58°45′	127°11′	Charcoal	Dwelling
100	Le-1000	Ust-Mil	33,000	500	7	Yakutia	59°38′	133°08′	Wood	Level 1·9 m
101	GIN-404	Dyuktai Cave	14,000	100	7	Yakutia	59°35′	133°11′	Charcoal	Level 7b
102	GIN-1020	Ihnie-2	31,200	500	10	Yakutia	62°53′	134°13′	Wood	Level 1·2 m
103	SOAN-3185	Ihnie-3	20,080	150	3	Yakutia	62°53′	134°13′	Bone	Arch. Level
104	Le-906	Verhne-Troickoe	17,680	250	3	Yakutia	60°25′	134°41′	Wood	Arch. Level
105	LU-147	Berelyoh	11,830	110	14	Yakutia	70°26′	144°25′	Wood	Level 1·6 m
106	MAG-916	Siberdik	13,225	230	1	Yakutia	61°35′	149°49′	Charcoal	Level 3
107	Le-3697	Ushki 1	11,120	500	2	Kamchatka	56°12′	159°58′	Charcoal	Level 7
108	SOAN-784	Ust-Igrima	11,350	180	1	Maritime			Bone	Level 1·5 m
109	SOAN-825	Filimoshki	20,350	850	1	Amur			Detritus	Arch. Level
110	SOAN-3827	Malye Kurutachi	14,200	130	8	Maritime	50°17′	130°19′	Charcoal	Arch. Level
111	IGAN-341	Geograph Society Cave	32,570	1510	1	Maritime	42°52′	13°01′	Bone	Arch. Level
112	Le-1566	Pereval	10,100	100	2	Maritime	42°55′	133°06′	Charcoal	Arch. Level
113	GEO-1412	Ustinovka 6	11,550	240	2	Maritime	44°16′	135°18′	Charcoal	Level 3
114	AA-9463	Suvorovo 4	15,105	110	2	Maritime	44°14′	135°22′	Charcoal	Arch. Level
115	Le-1781	Gasya	12,960	120	2	Khabarovsk	50°35′	137°11′	Charcoal	Arch. Level
116	AA-13392	Hummi	13,260	100	3	Khabarovsk	48°44′	135°37′	Charcoal	Lower Level
117	AA-20864	Ogonki 5	19,320	145	3	Sakhalin	46°46′	142°31′	Wood	Level 2b
118	GIN-167	Ushki 2	13,600	250	7	Kamchatka	56°12′	159°58′	Charcoal	Level 6

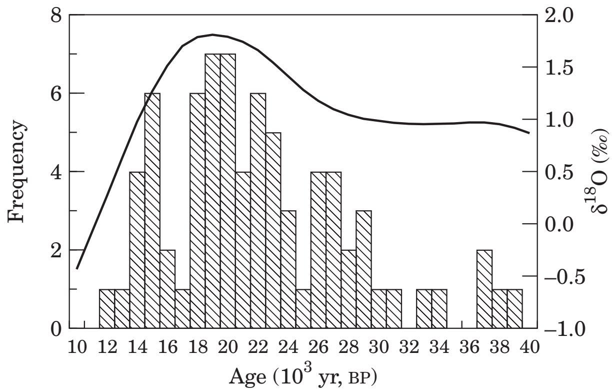

Figure 1. Frequency per millennium of uncalibrated radiocarbon dates for East European Plain (Dolukhanov, Shukurov & Sokoloff, 2001) (histogram) and the ^{18}O isotope variations with higher values indicating colder climate (Imbrie *et al*., 1990) (solid).

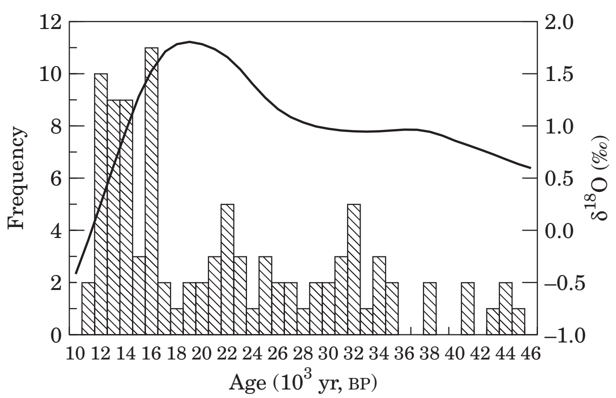

Figure 2. As in Figure 1, but for Southern-Central Siberia.

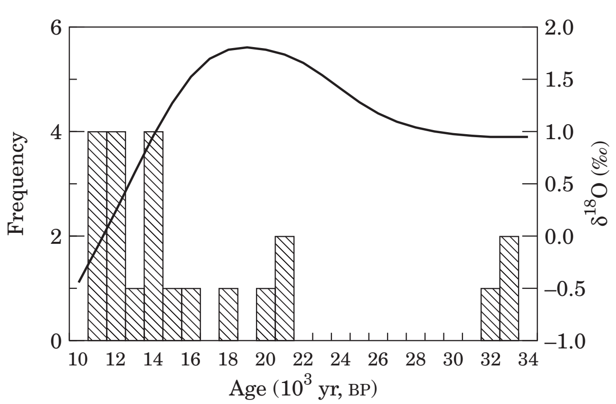

Figure 3. As in Figure 1, but for North-Eastern Siberia and Russian Far East.

been obtained for Palaeolithic sites in the Altai Mountains (the cave sites of Kara-Bom, Okladnikov, Strashnaya, Denisova, Kara-Tenesh and Anui 2, as well as at an open-air site of Ust-Karakol) (Derevyanko & Markin, 1998*a*). Their age is in the range of ca 40–30 ka; reaching ca 42 ka for Kara-Tenesh and ca 43 ka for Kara-Bom. The latter site includes two lower strata, both identified as Mousterian, and six upper levels considered as UP (Derevyanko, Petrin & Rybin, 2000). Both the upper Mousterian and the lower UP strata have similar dates, >44 and 43·20 ± 1·5 ka, respectively. These levels included identical animal remains (woolly rhinoceros, brown bear, wolf, bear, wild horse, kulan wild ass, gazelle). Furthermore, they contained the same categories of tools; the only distinction consists in an increased rate of "elongated blades" in the UP level (Derevyanko, Petrin & Rybin, 2000: 47). The Okladnikov Cave included human remains, five teeth and three postcranial skeletal fragments. Alexeev (1998) found no deviations from the morphology of modern humans in these remains, with only one molar showing an "archaic trait".

Conventioal radiocarbon dates of that time span have been obtained for the sites in the Yenisei Valley (Nos 37 and 40) and the nearby Angara River (Nos 8, 9, 10 & 53) (Figure 4).

Two sites in the Southern Siberia (Figure 5) have yielded the AMS dates in the range of 33–39 ka (No. 59 in the upper stretches of the River Lena, and No. 63 in Buryatia) (Goebel & Aksenov, 1995). The animal remains consisted of the woolly rhinoceros (in both cases), red deer and roe deer (No. 59), Mongolian gazelle and argali sheep (No. 63). In the Trans-Baikal area, similar dates have been obtained for sites on the Khilka and Artin Rivers (No. 74) (Medvedev, 1998).

The middle stage. Several sites with the radiocarbon dates in the range of 25–17 ka lie on the terraces of the Yenisey River (Nos 39, 40, 28 & 23). The animal remains at all these sites consisted of the mammoth, woolly rhinoceros, wild horse, reindeer, bison and wild goat. This stage also includes the site No. 29 on the southern stretch of the river (Derevyanko & Markin, 1998*b*).

A large concentration of sites of that stage occurred in the terraced valleys of the Angara and its tributaries. This included the "twin" sites of Mal'ta (No. 57) and Buret' (No. 11) (Sitlivy, Medvedev & Lipinina, 1997). The former site included a burial with two (or three) children of a modern human type (Alexeev & Gokhman, 1987). The reindeer was the main hunting prey at these sites (Ermolova, 1978). Other sites in that area included Nos 70, 14, 16 & 17. The site No. 69 on the northwestern shore of the Lake Baikal also belongs to that stage.

The later stage. The sites with the radiocarbon age in the range of 17–10 ka show the highest frequencies in that part of Siberia. Several large open-air settlements were located in the Minusinsk depression on the middle stretches of the Yenisei River (Nos 31–34 & 51–52). Fragmented human bones have been found in the deposits of the Afontova Gora 2 site (No. 51), including a frontal bone, a radius, humerus and child's

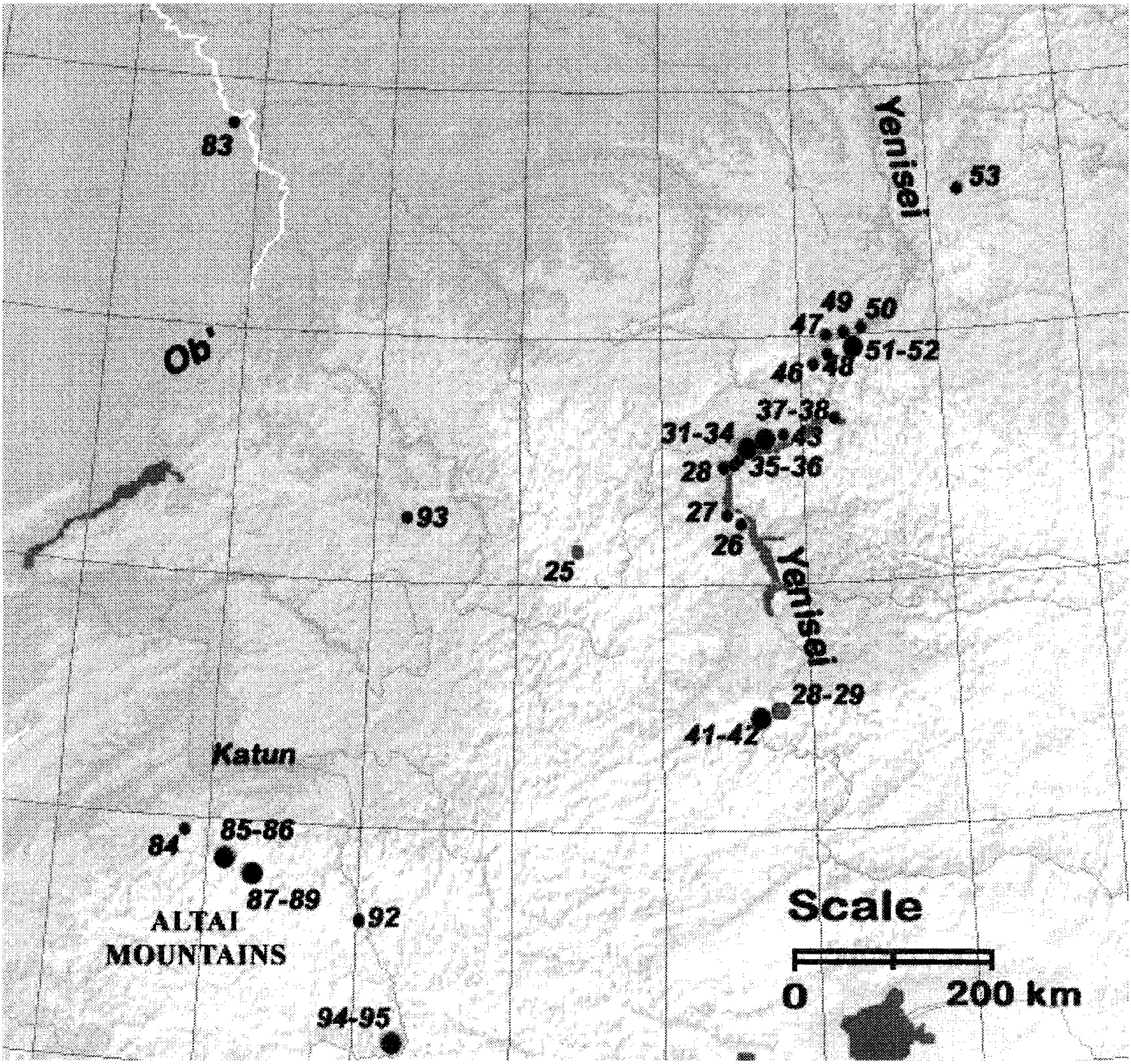

Figure 4. Radiocarbon-dated sites in the Altai Mountains and on the Yenisei Basin in Southern-Central Siberia. The sites are labelled with entry number from Column 1 of Table 1. Larger circles indicate date clusters.

teeth—all belonging to modern humans. Animal remains consisted of the wild horse, aurochs, red deer, wild goats and Arctic fox. The group of sites 13·0 ka old located on the right tributary of the Yenissei (No. 44) is distinctive by the presence of microblades.

The Maina group of sites (Nos 30, 41 & 42) lies in the southern stretches of the Yenisei River where it crosses the Sayan foothills. The animal remains included the bison, kulan, red deer and Siberian goat (Vasil'ev, 1983, 2000). The radiocarbon measurement of 12·0 ka (No. 54) has been obtained for the site No. 54 on the River Kan, farther east.

This stage includes a group of sites in the Trans-Baikal region of Southern Siberia. A series of AMS dates around 12·5 ka has been obtained for the site of Studenoe 2 (No. 66) located on the Chikoi River (Goebel *et al*., 2000). Other sites in that area having a similar component, Nos 65 & 75, have revealed a younger age (17·0 & 15·8 ka).

North-East Siberia and Russian Far East

Palaeoenvironment

According to Anderson & Lozhkin (2001), the climate of North-Eastern Siberia during the Karginian Interval (43–25 ka) was either similar to or slightly colder than now. Nevertheless, pollen and plant macrofossil

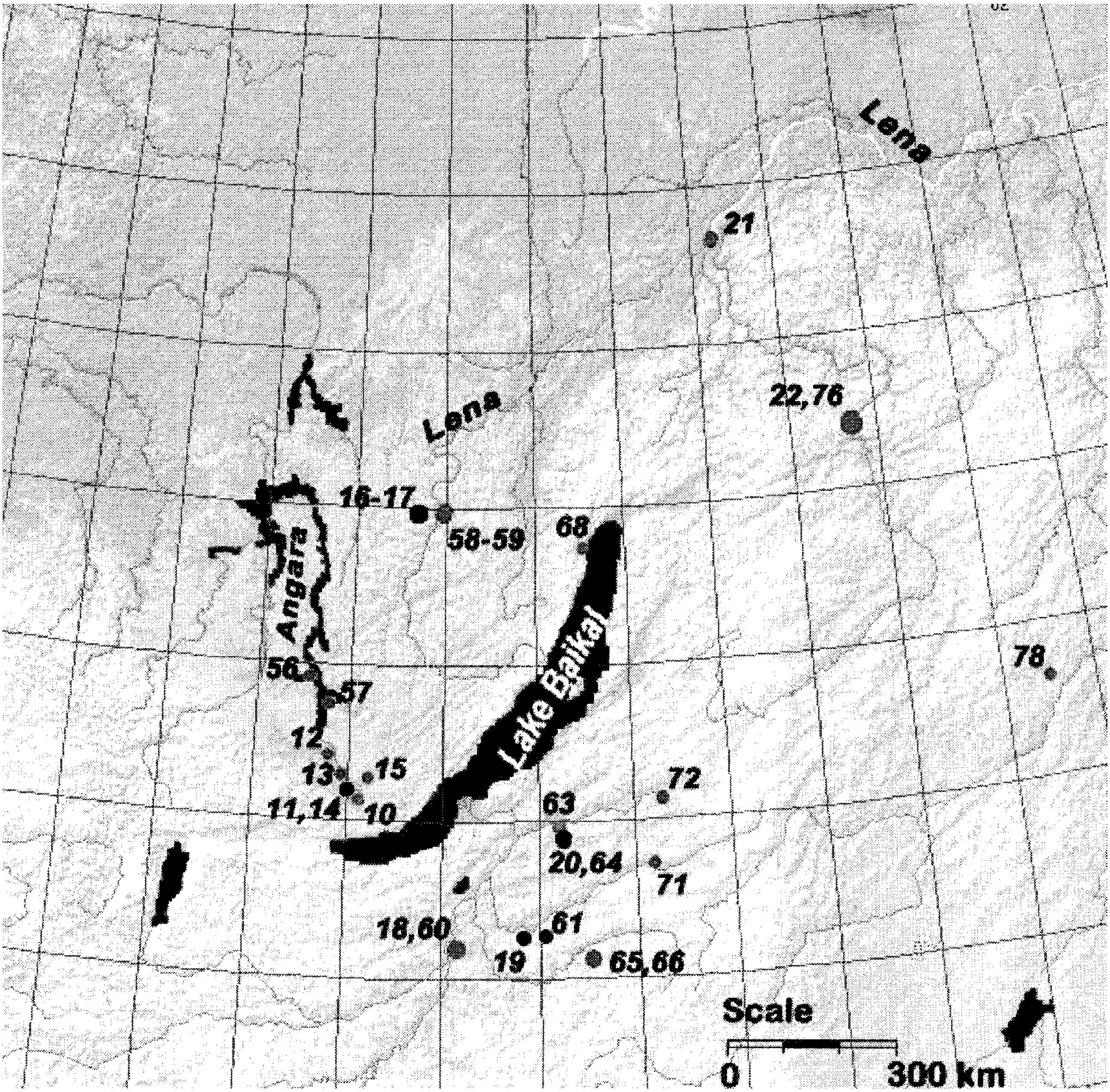

Figure 5. As in Figure 4, but for the Angara and Baikal areas in Southern-Central Siberia.

records for the New Siberian Archipelago in the Arctic Ocean (Andreev *et al*., 2001) show the summer temperature to be warmer than today by at least 2°C. Considerable areas in that part of Siberia were taken up *Larix* forests, whereas the "tundra-steppe" prevailed on the exposed Arctic shelf. The biomass of these landscapes was sufficiently high to support a large population of herbivores. Accumulations of the bones of mammoth, reindeer and wild horse found at various sites have been radiocarbon dated to 36·7–12·5 ka.

During the Sartan Glacial, the permafrost and an intensive aeolean deflation affected the lower areas, with small-scale glaciers restricted to the mountains. Pollen records show a rapid reduction of forests and massive spread of the "tundra-steppe". The present-day Arctic tundra became established in the lowlands already at 15–14 ka, and remained basically unchanged, with sparse coniferous forests spreading during the milder intervals (Velichko, Andreev & Klimanov, 1997; Mochanov & Savvinova, 1980). The biomass of these landscapes remained sufficiently high to sustain numerous herds of large herbivores.

The Sartan Glacial climate in the Maritime Region (Primorskiy Kray) of the Russian Far East remained very dry and cold, with temperatures lower than today, by 15°C in winters and 10°C in summers, and the annual precipitation 400 mm less than now. Spruce, birch and larch forests occurred in the lowland, with the forest-tundra and mountain tundra at higher levels (Korotkii, 1994).

During the Karginian Interglacial, the sea level was at least 40 m below its present position (Pavlidis, Dunayev & Shcherbaskov, 1997). The maximum drop in the sea level, 130 m below the present stand, occurred during the Sartan Glacial maximum. The shoreline at that time moved off by 400–700 km, exposing vast areas of the continental shelf. This led to the emergence of the Beringia landmass linking the Siberian mainland with Alaska. During that period the Asian continent became connected both with the Sakhalin Island and the Japanese Archipelago. The land bridge remained in place until 10 ka, when the level of the Japan Sea was ca 50 m below the present position (Korotkii, 1994).

Human settlements

The early stage. At least two Palaeolithic sites located on the lower and middle stretches of the Aldan River in Yakutia yielded the radiocarbon dates proving that this vast area had a substantial human population at that stage (Nos 100 & 102, see Figure 6). According to Mochanov (1977) these sites correspond to the "Proto-Dyuktai", the cultural tradition which was essentially different from those in the southern and central Siberia.

In the Russian Far East, a date of 32·6 ka has been reported for the cave site (No. 111). The animal remains at that site included the mammoth, woolly rhinoceros, wild horse, roe and red deer (Derevyanko, 1998).

The middle stage. The radiocarbon-dated sites of this stage are located on the Aldan River (Nos 103 & 104). The site No. 109 on the River Zeya was dated 20·3 ka, although its archaeological context is not quite clear. A similar data had been obtained for a site on the Sakhalin Island (No. 117).

The later stage. Similarly to the southern and central parts of Siberia, the sites of this stage show the highest frequencies. Among them is a cluster of sites on the Aldan River (Nos 98, 99, 101), attributed by Mochanov (1977) to the Dyuktai Culture. Culturally related sites were found near the Arctic coast (No. 105) and in the Kolyma River basin (No. 106). We have selected three representative dates out of numerous radiocarbon date measurements for this site.

Further to the east, a series of radiocarbon dates are available for the stratified site of Ushki 1 on the Kamchatka Peninsula (Dikov, 1977). This includes one date of 21 ka (GIN), three dates in the range 13·6–14·3 ka (GIN and LE) and three dates of 10·4–10·9 ka (MAG and MO). We have discarded the single older date and the dates of 13·6 and 10·4 have been included into our date-list (Nos 118 & 119).

Another cluster of sites was located in the Maritime Region of the Russian Far East represented by Nos 113 & 114. Several sites located on the lower stretches of the Amur River included fragments of ceramic ware (Nos 115, 116) (Derevyanko & Medvedev, 1995; Kuzmin & Orlova, 1999).

Discussion

The frequency distributions of radiocarbon-dated Palaeolithic sites in distinct areas of northern Eurasia, shown in Figures 1, 2 & 3, exhibit statistically reliable differences (see Appendix 1). Specifically, the positions (and plausibly numbers) of maxima and minima differ in different areas. For example, the strongest differences between the East European Plain (EEP) and Southern-Central Siberia (SCS) data occur at 46–42, 32–30 ka, 28–26, 24–22, 20–16, 14–10 ka.

The period 46–32 ka

Sites in the range 46–32 ka are absent in the EEP sample. In the SCS sample, the sites of this age are all located in the Altai Mountains and are considered as pertaining to the Mousterian–Upper Palaeolithic transition (Derevyanko, Petrin & Rybin, 2000). Sites of comparable age reflecting the initial spread of Upper Palaeolithic are known for cave sites to the west of the EEP in Bulgaria (Bacho Kiro, Level 11, >43 ka for the conventional dates and 38–37 ka for the AMS dates—Hedges *et al.*, 1994), Southern Germany (40·2 ka—Bolus & Conrad, 2001) and Spain (El Castillo and La Arbelna, 40 ka—Rink *et al.*, 1997). This implies that sites of that age could have existed on the EEP as well but so far have not been found or have been destroyed by erosion at open-air sites dominant on the EEP.

The sites 40–32 ka old are spread across East European Plain, including the Pechora River north of the Polar Circle. They form a dense concentration in the Altai Mountains, several sites have been found on the Yenisei River, in the Baikal and Trans-Baikal areas of southern Siberia, and also in Yakutia and the Far East. Therefore, we consider the difference between the date frequencies of that age to be due to incomplete sampling. The entire time span of 46–32 ka can thus be viewed as the stage of incipient spread of the AMH in northern Eurasia.

An influential school of thought identifies the AMH only with the manifestations of the UP "core-and-blade" technology. The so-called "transitional" industries of that age are known in various parts of Europe, such as Châtelperronian in France, Uluzzo in Italy, Szeletian and Bohunician in Central Europe and Streletsian in Russia. They all include archaic elements apparently inherited from the Mousterian tradition and are viewed either as a product of the

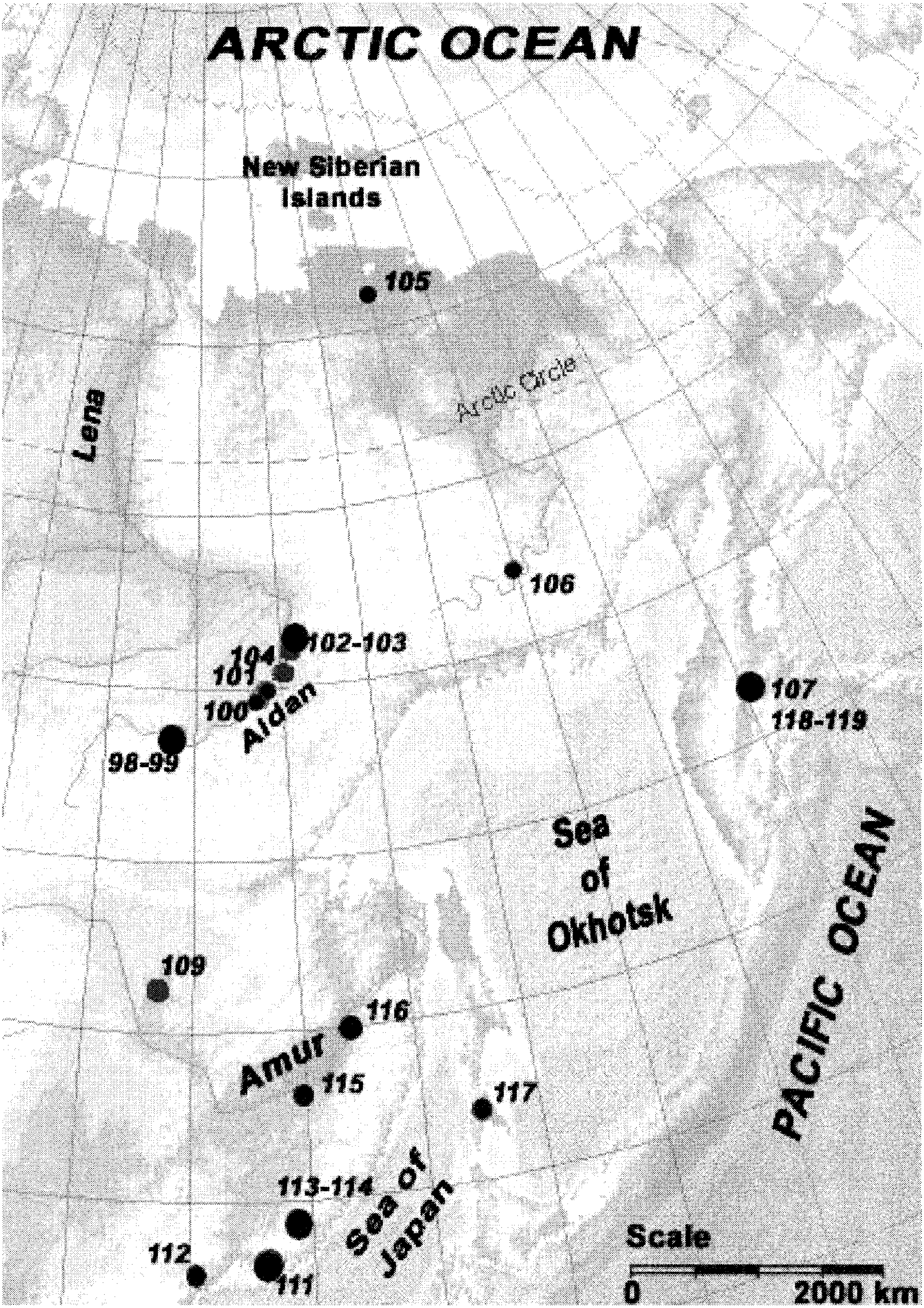

Figure 6. As in Figure 4, but for North-Eastern Siberia and Russian Far East with labels from Table 2.

"acculturation" of the Neandertals under the impact of AMH (Mellars, 1999) or as an independent Neandertal invention (Errico *et al*., 1998). Yet, fossil remains of the Neandertals have never been found at any Streletsian sites. Human remains found in this context of the Mousterian–Upper Palaeolithic transition at the Okladnikov Cave show "no major deviations" from the AMH morphology (Alexeev, 1998).

One should note that the archaic implements combined with an advanced "laminar" technology constitute a characteristic feature of the Siberian "Upper Palaeolithic" as a whole (Grigor'ev, 1977; Okladnikov, 1981; Sitlivy, Medvedev & Lipinina, 1997; Vasil'ev, 2000). The archaic elements often found together with remains of modern humans. We recall that remains of both Neandertals and AMH, who apparently coexisted, were found in the Levant in an essentially similar context of the "Levantine Mousterian" (Lieberman, 1998). Further east, archaic elements are abundant in the inventory of the Salawusu site on the Ordos Plateau in Inner Mongolia dated to 50–37 ka, that yielded the remains of *Homo sapiens* (Jia Lanpo & Huang Weiwen, 1985; Wu Xinzhi & Wang Linghong, 1985).

Thus, we can argue that the Palaeolithic sites in northern Eurasia radiocarbon dated to 46–32 ka reflect the initial colonization of that area by the AMH, regardless of the character of lithic industries. The advancement of the AMH proceeded from the core area in the Levant where the presence of "primitive" modern humans is acknowledgeable already at 100–80 ka (Stringer *et al*., 1989). According to our results, this movement could have encompassed the entire East European Plain, further leading into Southern Siberia, Mongolia and Russian Far East, and presumably to Northern and Central China. As the land bridges linked the Siberian mainland with the Sakhalin Island and Hokkaido, occasional penetration of early AMH to the Japanese Archipelago could have occurred at that stage. This is confirmed by the skeletal remains of an AMH child at Yamashita-cho on the Okinawa, with the radiometric age of >32 ka (Trinkaus & Ruff, 1996).

The period 30–19 ka

There are several features in the date frequencies for the EEP and SCS in this period. The most important difference between the histograms of Figures 1 & 2 is that the EEP dates exhibit a broad and strong absolute maximum, whereas the SCS data show two lower peaks. Both data samples have deep frequency minima at 18–19 ka. The period of 32–18 ka was the next stage in the settlement of northern Eurasia by early modern humans. Remarkably, the greater part of Western and Central Europe became depopulated during that time, where only sporadically sustaining scarce human groups remained (Housley *et al*., 1997; Street & Terberger, 2000). It is plausible that significant eastbound migration occurred at this stage caused by environmental stress encompassing Siberia and reaching Yakutia and Russian Far East.

According to quantitative estimates (Tarasov *et al*., 1999*a*), during the LGM, in an environment of considerable temperature depressions, the annual precipitation in the western Eurasia remained sufficiently high to produce a thick snow cover. The precipitation in Siberia, being basically similar to the present-day values, would have only formed a thin snow cover (similarly to what occurs now in Central Mongolia where the winter precipitation is between 5 and 30 mm). Hence, the conditions for winter pastures in the east were more favourable: large herds of herbivores were well provided with the fodder easily available beneath the thin snow cover.

With the fall in the sea-level by at least 130 m, the Japanese Archipelago became accessible to the advancing groups of AMH via land bridges both in the north (Hokkaido-Sakhalin) and in the south (Kyusyu-Tsushima-Korea). This may account for the appearance of sites with the blade technique component in Japan (Oda & Keally, 1979).

The period 18–10 ka

At that stage one notices an increase in the number of Palaeolithic sites in European Russia, and an all-time maximum in Siberia (Figures 1–3). The difference between the data sets is the strongest during this period (Appendix 1). The enhancement in the frequency is also well pronounced in the extreme north-east including Yakutia and Kamchatka, the Lower Amur and the Maritime Region in the Far East.

Settlements with the evidence of potery-making first appeared in the lower Amur catchment at 13–11 ka. The subsistence of these sites was based on the exploitation of riverine and estuarine resources with the prominence of the procurement of spawning salmon (Kononenko, 1998). By their stylistic and technological characteristics, the ceramic ware of the Lower Amur sites is similar to certain varieties of the early Jomon pottery in Japan (Kajiwara, 1998). Hence one may suggest the occurrence of a network of settlements based on riverine-maritime adaptation in the circum-Japanese (and, possibly, Okhotsk) Sea area. With the gradual rise of the sea level, the "northern route" became the only way connecting Japan to the Asian landmass. A marked increase in the frequencies of sites belonging to the "Micro-Blade" and "Incipient Jomon" traditions may have been largely due to the population influx from the continent.

During the same period, human groups apparently stemming from North-Eastern Siberia have spread to America. The existing evidence suggests that this was a predominantly coastal migration along the southern margin of the Bering Land Bridge and further south along the Pacific Coast of the Americas (Dixon, 2001).

Conclusions

(1) The colonization of Northern Eurasia took the form of several (plausibly, three) consecutive waves, spreading from the west towards the east in the time-span between ca 46 and 10 ka BP.
(2) All the waves included exclusively groups of Anatomically Modern Humans.
(3) Groups of AMH spreading during 46–30 ka BP used various types of stone industries including those with strong Mousterian element.
(4) The intense east-bound migration of AMH groups was largely caused by environmental stress.

Appendix 1

In this appendix we discuss statistical evidence supporting our conclusions. First, we demonstrate that the dates in all three samples shown in Figures 1, 2 & 3 for EEP, SCS and NES, respectively, deviate significantly from uniform distributions, and therefore contain statistically significant peaks and/or minima. Secondly, we infer that the date samples originating from EEP and SCS are statistically distinct. This implies that the trends in the population dynamics were different in the two areas. We further isolate periods of the strongest differences and identify them with major migration events discussed in the text.

We used the Kolmogorov–Smirnov one-sample test in order to check whether the distributions shown in Figures 1, 2 & 3 (see also Tables 1 & 2) differ from the corresponding uniform distributions over the time span of each sample (see e.g., Sect. 4.3 in Siegel & Castellan, 1988). The maximum (by modulus) deviation of the cumulative probability distribution from the uniform one was 0·24, 0·26 and 0·42 for the EEP, SCS and NES samples containing 75, 97 and 22 dates, respectively. This implies that the probability, for the samples to originate from a uniform distribution is less than 0·2% in all the cases. Therefore, the distributions shown in Figures 1–3 do contain statistically significant time variations of the Palaeolithic site frequency in all three geographical areas.

In order to determine the significance of pairwise differences between the samples we applied the χ^2 test for two independent samples (e.g., Sect. 6.2 in Siegel & Castellan, 1988) to the EEP and SCS date lists. (The NES sample is too small to warrant analysis of this type.) The alue of χ^2 obtained when comparing the EEP and SCS samples (binned to 13 time intervals to have appropriately large expected frequencies) is as large as 34·2; the samples are different with a probability of 99·9%. It is notable that the contribution of the dates in the range 46–36 ka to χ^2 is rather small (0·5); therefore the lack of dates older than 40 ka in the EEP sample does not affect our conclusions.

The maximum contributions to χ^2 comes from the time intervals 20–18 ka and 14–10 ka (8·5 and 11·3, respectively, each exceeding $2\chi^2_1$ (0·05)=7·7). The underlying difference between the EEP and SCS samples is in the positions and heights of the maxima at 20–10 ka: the maximum in the EEP sample is relatively weak and occurs earlier whereas that in the SCS sample is very strong and shifted towards the younger ages. We interpret this as an indication that the migration of AMH proceeded from the west (EEP) to the east (SCS) at least in this time interval, and this has resulted in the relative time shift of the maxima in the EEP and SCS data sets.

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