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Collection of radiocarbon dates on the mammoths (*Mammuthus primigenius*) and other genera of Wrangel Island, northeast Siberia, Russia

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Abstract

We present and discuss a full list of radiocarbon dates for woolly mammoth and other species of the Mammoth fauna available from Wrangel Island, northeast Siberia, Russia. Most of the radiocarbon dates are published here for the first time. Of the124 radiocarbon dates on mammoth bone, 106 fall between 3700 and 9000 yr ago. We believe these dates bracket the period of mammoth isolation on Wrangel Island and their ultimate extinction, which we attribute to natural causes. The absence of dates between 9–12 ka probably indicates a period when mammoths were absent from Wrangel Island. Long bone dimensions of Holocene mammoths from Wrangel Island indicate that these animals were comparable in size to those on the mainland; although they were not large animals, neither can they be classified as dwarfs. Occurrence of mammoth Holocene refugia on the mainland is suggested. Based on other species of the Mammoth fauna that have also been radiocarbon on Wrangel Island, including horse, bison, musk ox and woolly rhinoceros, it appears that the mammoth was the only species of that fauna that inhabited Wrangel Island in the mid-Holocene.

Keywords: Beringia; Wrangel Island; Mammoth; Mammoth fauna; Radiocarbon

Introduction

The first radiocarbon dates on mammoth remains from Wrangel Island were obtained during preliminary studies in 1989 and 1990 (Vartanyan et al., 1992). Unexpectedly young (late) radiocarbon dates on mammoth tusks and bones from several sites stimulated further geochronological studies of similar finds from the island. Thus far, Wrangel Island has proven to be the last place on earth where mammoths survived, many until the mid-Holocene. The 'Mammoth fauna', including the woolly mammoth itself, once flourished in the Siberian Arctic, as well as in more southerly areas, because of the availability of the so-called "tundra–steppe" landscapes. This was a special kind of palaeo-vegetation biome, without exact modern analogue, that was found during cool periods of the Pleistocene throughout northern Eurasia (Sher, 1997a,b).

The disappearance of this tundra–steppe during the transition from the late Pleistocene to the early Holocene, followed by the emergence of modern Arctic tundra vegetation, is considered to be the main reason for the extinction of many large late Pleistocene herbivores (Sher, 1997a,b). The fact that mammoths survived well into the Holocene on Wrangel Island contradicts these arguments, because the Wrangel Island mammoths appear to have survived under conditions not very different from those in the Siberian Arctic of today.

A large series of radiocarbon dates from a limited area can provide unique possibilities for the analyses of both palaeoenvironments and the ecology of extinct animals (Lavrov and Sulerzhitsky, 1992; Sulerzhitsky, 1995; MacPhee et al., 2002;

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Nikolskiy and Basilyan, 2003; Sher et al., 2005). These data demonstrate that mammoths were more abundant in the High Arctic during warm periods, not in cold periods, and that the presence of mammoths in the High Arctic was controlled by the expansion of subarctic vegetation into the region.

This paper presents the most comprehensive and recent collection radiocarbon dates from mammoth and other genera remains on Wrangel Island, and discusses the importance of these dates for the timing of the presence of mammoths on Wrangel, and of their subsequent extinction.

Study area and methods

Wrangel Island is bordered by the East Siberian Sea and the Chukchi Sea, between 70° and 72° N and 178° E and 177° W (Fig. 1). Its surface area is ca. 8000 km^2. It is separated from the continent by the Long Strait, a water barrier ca. 140 km wide and up to 45 m deep. The central part of the island is covered by low mountains that form three ridges stretching from the west to the east, and with the highest point at 1096 m asl. The west and eastern portions of the island consist of plateaus; plains dominate the north and southern extremes. The unconsolidated sediments of Wrangel Island are not very thick, reaching no more than 20 m in depth south of the foothills of the north maritime lowland, and rarely more than several meters throughout the rest of the island. Recent studies of the Quaternary geology of Wrangel (Gualtieri et al., 2003; Vartanyan, 2004; Gualtieri et al., 2005) suggest that:

1) As of yet, there are no known Quaternary sediments on the island that are older than mid-Pleistocene in age;
2) In the last 100,000 yr, the island was never totally overridden by glaciation. Late Pleistocene marine and alluvial sediments are most characteristic of the island lowlands, while alluvial and fluvioglacial sediments are found in the upland regions;
3) A substantial part of the island was subject to thermokarst activity during the Pleistocene–Holocene transition, which was concurrent with the maximal northward expansion of subarctic vegetation across northeast Siberia. Bog and thermo-lacustrine sediments, with wood remains, are widespread on the plains and intermountain valleys of the island, and have been dated to 12,500–7500 ^{14}C yr BP (Lozhkin et al., 2001; Vartanyan, 2004);
4) Mid-Holocene deposits are mostly represented by slope sediments and by thin (<1 m) sediments of polygenetic origin on the plains. No alluvial or lacustrine sediments dating from 7500–4000 ^{14}C yr BP have been found on the island.

Because of the general shallowness and thinness of Quaternary age deposits on Wrangel Island, and the absence of any known bone-bearing horizons, it has not been possible to obtain a significant faunal collection directly from geological sections. In spite of this, mammoth bones have been found throughout the island, except at higher elevations. Most of these bones have been collected from river beds and coastal beaches, places where the permafrost is most actively being eroded and destroyed. Fewer specimens have been collected from slope and alluvial fan deposits in the upland regions of the island. Based on the excellent state of preservation of most of these finds, it is apparent that most must have been released from the permafrost only a few years prior to their discovery and collection. In order to make the collected sample as representative as possible, we have gathered faunal elements from throughout the island (Fig. 1). Because of where and how these bones were collected, we are unable to identify their *in situ* place of origin or preclude their having been reworked from undiscovered sediments upslope from the point of collection. At the same time, the excellent state of preservation of most of these surface finds has provided quality samples for radiocarbon dating. The following

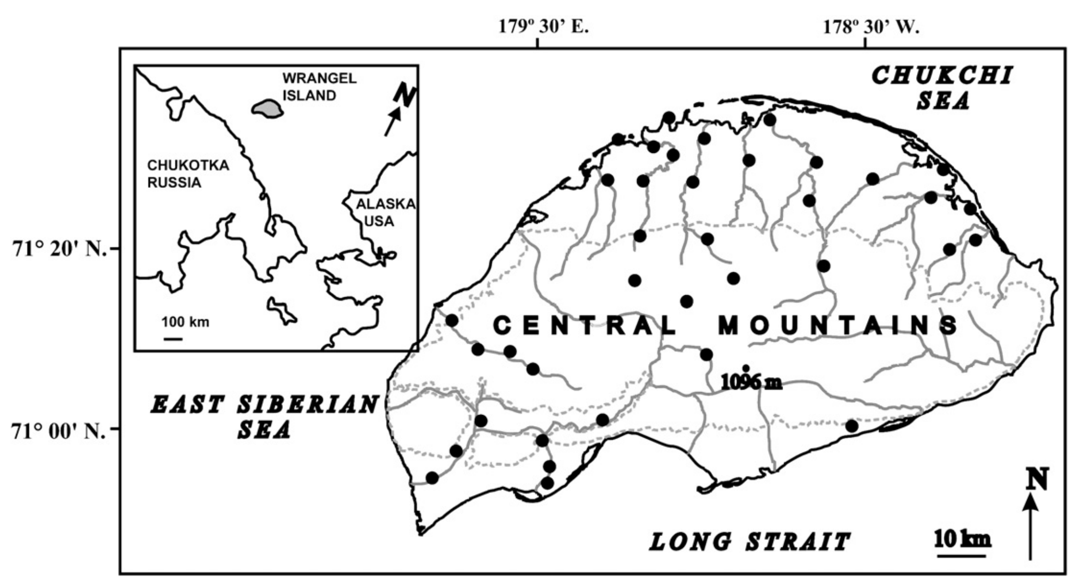

Figure 1. Map of the study area with the locations of sampling (black circles).

guidelines structured our sampling and analysis of this collection:

- Although mammoth remains dominated the collection, samples from all representatives of the Mammoth fauna complex were collected and dated during this study.
- Although perhaps less interesting biologically, both mammoth tusks and fragments of post-cranial bones were collected solely for the purpose of radiocarbon dating.
- Molars in this collection were analysed by morphological criteria and assigned to recognizable morphotypes (e.g., small and large); a random sample of differing morphotypes was dated.
- Mature mammoth long bones (those with fully knit epiphyses) were sampled and dated in an effort to obtain reliable data on mammoth size fluctuations during the late Pleistocene and Holocene.
- We paid special attention to collection of specimens from different individuals. Thus we are sure all dated samples belong to different animals, except for special mentioned cases (Table 1).

Most of the osteological material was collected by S. Vartanyan from 1989 to 2000. Radiocarbon dating was carried out in the following laboratories: the Geographical Institute of St. Petersburg State University (lab designation LU), by Kh. Arslanov, S. Chernov, T. Tertychnaya and S. Vartanyan; the lab of the Geological Institute of the Russian Academy of Sciences/Moscow (GIN), under the supervision of L. Sulerzhitsky; the Institute for the History and Material Cuture of the Russian Academy of Sciences/St. Petersburg (LE), by V. Sementsov and S. Vartanyan; Tandem Laboratory, Uppsala University (Ua); and in the NSF Arizona AMS Facility, University of Arizona, Tucson, USA (AA), by Y. Kuzmin and G. S. Burr. Three of these laboratories (LU, GIN, and LE) used the scintillation technique for dating. To extract collagen from these samples the acid method was used by GIN, while the acid-alkaline method was utilized at LU. Two laboratories (Ua and AA) used AMS technology to date the specimens. A detailed description of these methods and procedures, as well as a discussion of their reliability, has previously been published (Lavrov and Sulerzhitsky, 1992; Arslanov et al., 1993; Long et al., 1994; Vartanyan et al., 1995; Arslanov et al., 1998).

Results and discussion

The dating series according to the mammoth remains

There are 124 radiocarbon dates of mammoth remains from Wrangel Island (Table 1). A histogram of the distribution of these ages at 1000 ^{14}C yr intervals, regardless of their standard deviation, is provided in Figure 2. As can be seen there, the great majority of the ages—106 out of 124 radiocarbon dates—fall within the time interval of 3685 to 8980 ^{14}C yr BP. The existence of a mammoth refuge on Wrangel Island in the Holocene need not be argued further. We believe that the predominance of dated mammoth remains from within this time range, based on of a randomly collected sample, means that their concentration in mid-Holocene sediments was higher than in the previous late Pleistocene and early Holocene horizons.

This mid-Holocene concentration cannot be explained away as an artefact of optimal preservation or favourable taphonomic conditions during this period either. As mentioned above, mid-Holocene sediments are not readily exposed on the island. These sediments mostly occur as slope deposits in which fossils are poorly preserved. Late Pleistocene and early Holocene deposits, as determined by radiocarbon analysis of their plant remains, are quite widespread throughout the island (Vartanyan, 2004). All of the above suggests that these finds accurately reflect the mid-Holocene adaptation of mammoth populations to new habitat conditions not previously encountered by this species in the late Pleistocene and early Holocene.

Until the end of the late Pleistocene, Wrangel Island and the adjacent Arctic shelf was part of the Eurasian continental landmass (Ivanov, 1986). During this time mammoths inhabited this large region of scarce food resources, periodically visiting the high Arctic during their seasonal and latitudinal migrations. The fact that recent herbivores, formerly members of the Mammoth faunal complex, remain seasonal migrants supports this idea. Moreover, during the late Pleistocene, the central part of Wrangel Island was covered by inactive glaciers and perennial snowfields. It is doubtful that mammoths occupied Wrangel Island year round during the cold periods of the late Pleistocene. They, as well as other animals, used the island for summer visits only, as indicated by strotium (Sr) isotope composition of mammoth bones (Arppe et al., 2006).

In the Holocene, however, the situation changed drastically. After the island was separated from the continent by inundation of the continental shelf, resident mammoths were unable to readily leave the island. This means that the number of mammoths on the island during the Holocene had to be large enough to sustain a viable resident population. This means that mammoth population densities on the island had to be higher in the Holocene than in the late Pleistocene. Although radiocarbon dating is not accurate enough to allow for documenting fluctuations in the size of the local mammoth population, in a relative sense having larger mid-Holocene population numbers would explain the predominance of mid-Holocene radiocarbon dates in our sample. The time span of these fluctuations is probably comparable with the measurable standard deviations of our radiocarbon dates. The time interval from 9000–3700 ^{14}C yr BP, within which most of the Holocene dates from Wrangel Island occur, suggests both the temporal beginning of the mammoth isolation on the island and the time of their eventual extinction.

But could the island have separated from the continent as late as ca. 9000 ^{14}C yr BP? If we compare the modelled post-glacial eustatic sea level curve (Ivanov, 1986) to the hydrographic depths reported for Long Strait (Fig. 3) then it is only possible to suggest that the marine inundation that isolated Wrangel Island from the mainland of Eurasia took place no later than 12,000 ^{14}C yr BP. If the Barbados sea level curve of Fairbanks (1989) is applied, the isolation may have occurred as late as 9500 ^{14}C yr BP. However, it should also be noted that the Holocene sea floor relief corresponds only generally to the original late Pleistocene surface topography. Frozen Arctic sediments may contain so much ice of various origins that, when melted, they may lose as

Table 1
Radiocarbon dates for the Wrangel Island mammoths

Number	Field number	Laboratory number	^{14}C yr BP	Material
1	OX-16	Ua-13366	3685±60	Tooth
2	21-M	LU-2741	3730±40	Tusk
3	N-20*	AA-40665	3905±47	Tooth
4	22-M	GIN-6983	3920±30	Tusk
5	8-M	GIN-6985	3920±40	Tusk
6	MAM-6	LU-2798	4010±50	Tooth
7	MAM-2	LU-2808	4040±30	Tooth
8	OX-19	Ua-13369	4085±65	Tooth
9	32-M	LU-4448	4120±110	Tusk
10	OX-6	Ua-13375	4210±70	Tooth
11	12-M	GIN-6993	4230±30	Tusk
12	OX-12	Ua-13362	4260±75	Tooth
13	OX-14	Ua-13364	4335±60	Tooth
14	89	LU-3513	4350±60	Bone
15	14-M	GIN-6984	4370±30	Tusk
16	6-M	GIN-6989	4370±40	Tusk
17	SR-1**	GIN-8249	4370±70	Tusk
18	T-2*	AA-40667	4389±46	Bone
19	9-M	LU-2756	4400±40	Tusk
20	2-M	LU-2768	4410±50	Tusk
21	PIK-7	Ua-13378	4475±60	Tooth
22	27-M	LU-3742	4490±80	Tusk
23	83	GIN-7694	4500±50	Tusk
24	114***	AA-60621	4530±60	Bone
26	J-08	Ua-17616	4585±70	Tooth
27	J-15	Ua-17623	4615±75	Tooth
28	OX-4	Ua-13373	4675±75	Tooth
29	OX-18	Ua-13368	4730±65	Tooth
30	41	LU-2556	4740±40	Bone
31	23-M	GIN-6992	4750±50	Tusk
32	J-12	Ua-17620	4800±75	Tooth
33	P-18	Ua-13358	4860±70	Tooth
34	OX-7	Ua-13376	4860±75	Tooth
35	S-3***	AA-60047	4860±60	Bone
36	4-M	LU-2740	4900±40	Tusk
37	J-05	Ua-17613	4955±80	Tooth
38	86	GIN-7693	4960±120	Bone
39	P-17	Ua-13357	4985±65	Tooth
40	J-09	Ua-17617	5010±75	Tooth
41	MAM-5	LU-2794	5110±40	Tooth
42	J-20	Ua-17628	5185±80	Tooth
43	16-M	LU-2745	5200±30	Tusk
44	15-M	LU-2744	5250±40	Tusk
45	OX-9	Ua-13359	5285±65	Tooth
46	10-M	LU-2742	5310±90	Tusk
47	J-23	Ua-17631	5375±85	Tooth
48	J-19	Ua-17627	5470±85	Tooth
49	J-21	Ua-17629	5475±75	Tooth
50	29	LU-2535	5480±50	Tusk
51	J-18	Ua-17626	5570±85	Tooth
52	17-M	GIN-6988	5610±40	Tusk
53	P-16	Ua-13356	5875±70	Tooth
54	31-M	LU-4474	5910±50	Tusk
55	24-M	LU-3739	6070±70	Tusk
56	OX-2	Ua-13371	6090±75	Tooth
57	33-M	LU-4468	6190±70	Tusk
58	34-M	LU-4471	6220±50	Tusk
59	J-17	Ua-17625	6245±80	Tooth

Table 1 (*continued*)

Number	Field number	Laboratory number	^{14}C yr BP	Material
60	GUS-9	LU-2799	6260±50	Tooth
61	OX-17	Ua-13367	6405±65	Tooth
62	OX-5	Ua-13374	6410±90	Tooth
63	26-M	LU-3741	6390±70	Tusk
64	T-1*	AA-40666	6499±66	Bone
65	OX-10	Ua-13360	6530±70	Tooth
66	29-M	LU-4449	6560±60	Tusk
67	OX-11	Ua-13361	6560±75	Tooth
68	40	LU-2558	6610±50	Tusk
69	25-M	LU-3740	6590±70	Tusk
70	39V	GIN-7692	6650±40	Bone
71	5-M	GIN-6997	6690±60	Tusk
72	69V****	GIN-8654	6720±50	Bone
73	20-M****	GIN-6990	6750±30	Tusk
74	20-M****	LU-2736	6760±50	Tusk
75	69A****	LU-3515	6830±40	Bone
76	GUS-7	LU-2810	6890±50	Tooth
77	13-M	GIN-6994	6900±60	Tusk
78	J-26	Ua-17634	6910±75	Tooth
79	7-M	LU-2746	7040±60	Tusk
80	J-14	Ua-17622	7060±80	Tooth
81	J-13	Ua-17621	7130±85	Tooth
82	39A	LU-3514	7190±70	Bone
83	PIK-1	LU-2809	7250±60	Tooth
84	3-M	GIN-6986	7270±60	Tusk
85	18-M	GIN-6991	7280±40	Tusk
86	28-M	LU-3743	7300±120	Tusk
87	39	LU-2559	7360±50	Tusk
88	6	LU-2444	7390±30	Tusk
89	J-22	Ua-17630	7420±90	Tooth
90	OX-3	Ua-13372	7510±80	Tooth
91	11-M	GIN-6996	7620±30	Tusk
92	1-M	GIN-6995	7710±40	Tusk
93	35-M	LU-4450	7820±220	Tusk
94	J-04	Ua-17612	7835±85	Tooth
95	30-M	LU-4473	7850±80	Tusk
96	OX-1	Ua-13370	7910±80	Tooth
97	OX-8	Ua-13377	8030±75	Tooth
98	J-11	Ua-17619	8085±85	Tooth
99	J-16	Ua-17624	8135±80	Tooth
100	99	GIN-8655	8150±60	Bone
101	J-07	Ua-17615	8445±100	Tooth
102	OX-13	Ua-13363	8640±80	Tooth
103	J-06	Ua-17614	8710±95	Tooth
104	J-01	Ua-17609	8850±95	Tooth
105	113***	AA-60049	8870±100	Bone
106	S-2***	AA-60048	8980±90	Bone
107	GUS-8	LU-2823	12010±110	Tooth
108	J-03	Ua-17611	12415±120	Tooth
109	J-25	Ua-17633	12505±135	Tooth
110	19-M	GIN-6987	12750±50	Tusk
111	KRF-2	LU-2792	12980±80	Tooth
112	J-02	Ua-17610	14570±140	Tooth
113	SR-3**	GIN-8258	15400±100	Tusk
114	64	LU-3510	18030±130	Bone
115	NZV-1	LU-2807	20000±110	Tooth
116	88	LU-3512	20660±190	Bone
117	SR-2**	GIN-8257	22400±200	Bone
118	SR-4**	GIN-8259	22400±300	Tusk
119	T-3*	AA-40668	32400±1500	Bone
120	36-M	LU-4470	33000±760	Tusk
121	87	LU-3511	37080±1650	Bone
122	J-10	Ua-17618	38375±2115	Tooth
123	OX-15	Ua-13365	>38000	Tooth
124	J-24	Ua-17632	>40000	Tooth

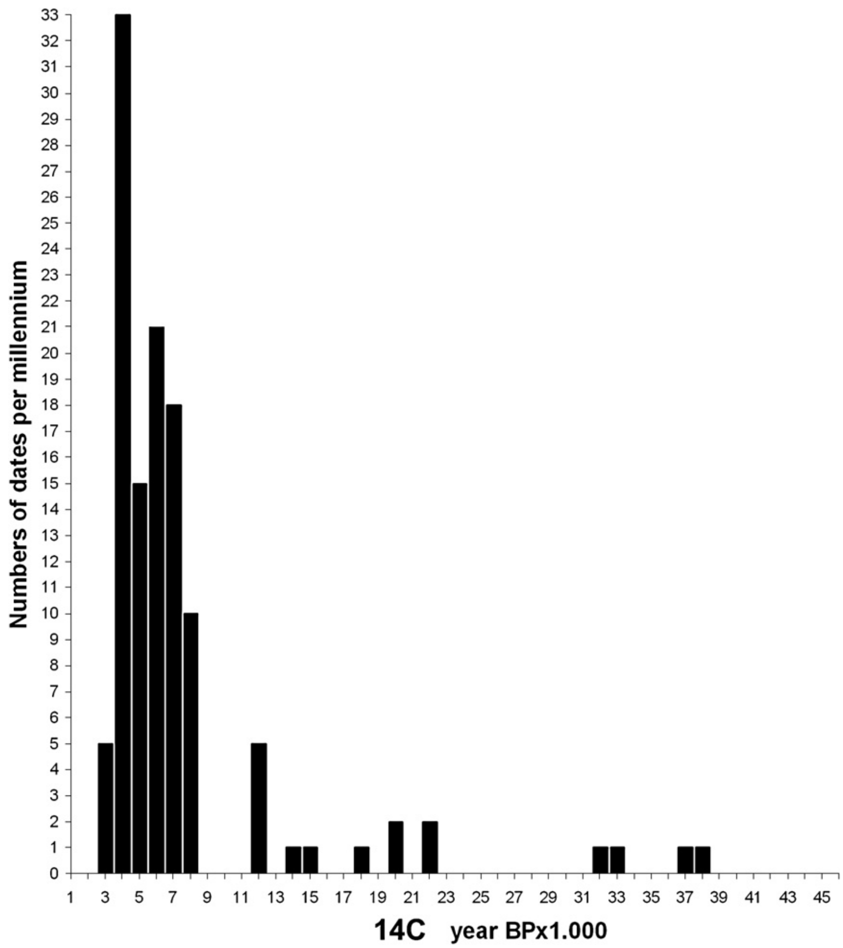

Figure 2. Distribution of ^{14}C dates for mammoths from Wrangel Island.

much as 70% of their frozen volume. Ice wedges up to 5 m wide have been found on the southern coast of Wrangel Island. It is reasonable then to argue that further away from the mountains, where the loose sediments were thicker, the ice content in those sediments may have been much greater.

It is beyond doubt that at the end of the late Pleistocene the original surface of the exposed shelf was higher then we currently find on the modern seabed, and that the process of flooding and inundation was not uniform through time. In short, we cannot accurately estimate the height of the late Pleistocene continental shelf beneath what is now Long Strait. In areas where active thermal abrasion is currently taking place, such as on the New Siberian Islands and the Yakutian coast, some cases of emergent shallow banks 20–40 m high have been reported. In such cases the seabed was deflating for an extended period of time after the initial flooding as long as the roots of the ice veins remain below the sea level (Tomirdiaro, 1976).

Accordingly, the separation of Wrangel Island from the continent may have happened much later than is commonly accepted. In any event, Wrangel Island would have continued to be accessible to large animals from the mainland while the strait remained sufficiently narrow that it could have been easily crossed on winter ice. Judging from the modern relief of the Long Strait seabed, the island would have remained connected longer to western Chukotka and the intervening coastal shelf. It is quite possible that this link was not broken prior to 9000 ^{14}C yr BP.

There are 18 radiocarbon dates on mammoth from Wrangel Island that fall between 12,000 ^{14}C yr BP and infinite (i.e., >40,000 ^{14}C yr BP). The number of these dated specimens is too small for us to accurately quantify changes in mammoth density and distribution during the early Holocene and late Pleistocene. We can only state that mammoth density on the island was not apparently higher than in the period after 9000 ^{14}C yr BP.

Mammoth molar and long bone dimensions

Most of the mammoth molars from Wrangel Island belong to a smaller morphotype characterized by narrow crowns and thin

Notes to Table 1:
*Dating organized with the assistance of Dr. Lyn Gualtieri (Washington State University, Seattle, WA, USA).
**Samples collected by Dr. F. A. Romanenko (Faculty of Geography, Moscow State University, Moscow, Russia).
***Dating performed with the assistance of Dr. Ya.V. Kuzmin (Pacific Institute of Geography FEB RAS, Vladivostok, Russia).
****Four radiocarbon dates (GIN-8654, GIN-6990, LU-2736, LU-3515) belong to one individual.

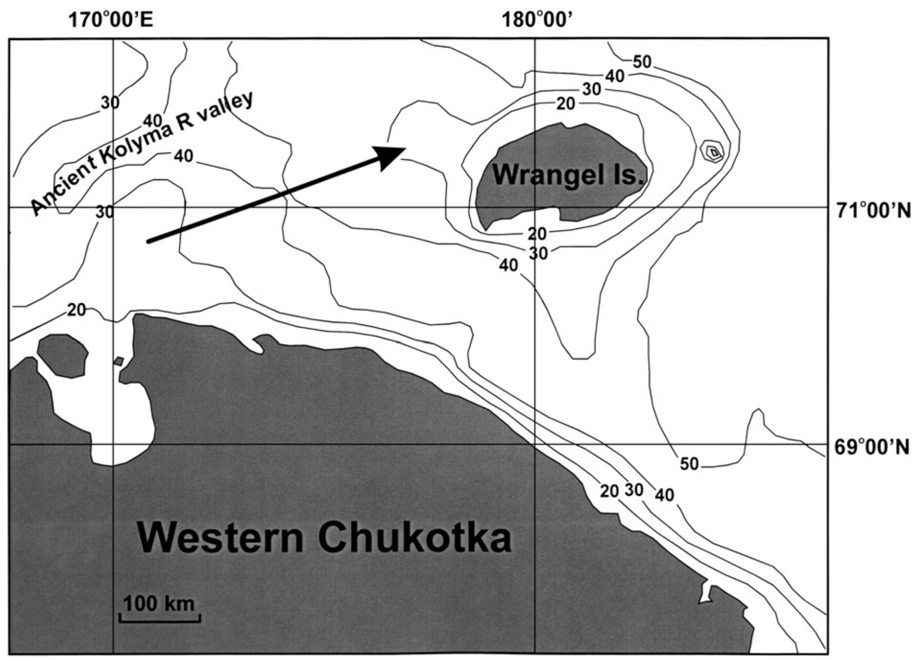

Figure 3. Bathymetry of the shelf adjusted to Wrangel Island (depth in meters). The arrow shows the probable way of mammoth migration to Wrangel Island.

enamel. Such molars found on Wrangel Island have been classified as belonging to a particular subspecies of small Holocene mammoth: *Mammuthus primigenius vrangeliensis* Garutt, Averianov *et* Vartanyan 1993 (Vartanyan et al., 1993; Garutt et al., 1993; Averianov et al., 1995). Originally, seven molars of this form were radiocarbon dated and found to be from the Holocene. Following this, we obtained an eighth radiocarbon date on a similar molar (GUS-8). Based solely on its morphotype this molar should be related to the other molars from the Holocene, but it also has thicker enamel and a more archaic plate form. Its radiocarbon age is 12,010±110 ^{14}C yr BP (LU-2823). Four molars belong to a larger morphotype, which is rare on Wrangel Island. Three of these date to the late Pleistocene, while one (NZV-3, 6830±40 ^{14}C yr BP, LU-3515) is from the Holocene. The dated molars from the Holocene do not show a trend towards size reduction over time. Based on these dated molars, the mammoth population of Wrangel Island seems to have originated as a smaller subspecies on the mainland prior to reaching the island and becoming isolated in the mid-Holocene.

Table 2
Dimensions and age of the mammoth long bones from Wrangel Island

Bone	Field number	Length, mm	^{14}C yr BP	Laboratory number
Femur	86	1010	4960±120	GIN-7693
Femur	39	970	6650±40	GIN-7692
Tibia	T-2	430	4389±46	AA-40667
Tibia	114	456	4530±60	AA-60621
Tibia	S-3	430	4860±60	AA-60047
Tibia	T-1	490	6499±66	AA-40666
Tibia	S-2	490	8980±90	AA-60048

Seven mature mammoth long bones from Wrangel Island have also been dated (Table 2). These can be compared to the long bones of adult mammoths from the Sevsk location of Central Russia, where the femur and tibia bones measured within the range of 830–1010 mm and 460–555 mm length, respectively, and with the femurs and tibias from Berelekh, Siberia which measured in the range of 850–1130 mm and 470–570 mm, accordingly (Mashchenko, 1992). The height of the biggest mammoth from Sevsk, with a femur length of 1010 mm, can be estimated as roughly 215–220 cm. As the mammoth long bones from Wrangel Island are comparable in length to those from the mainland (Sevsk and Berelekh), it is clear that the Wrangel Island bones are not from large individuals, but neither can they be classified as dwarfs. Earlier estimates for the height of Holocene mammoths from Wrangel Island were given as 1.5–2.0 m, based on molar dimensions (Lister, 1993; Garutt et al., 1993), and these preliminary estimates would now seem to require some revision.

Other species

Apart from the mammoth, specimens of bison (*Bison priscus*), horse (*Equus lenensis*), musk ox (*Ovibos moschatus*), and woolly rhinoceros (*Coelodonta antiquitatis*) have also been found on Wrangel Island (Table 3). It is also known that reindeer (*Rangifer tarandus*) existed on the island as late as 9000–10,000 ^{14}C yr BP, based on finds of reindeer excrement in a datable peat sample. It is unclear if reindeer inhabited the island at a later date. First settlers on the island apparently reported finding modern-looking reindeer antlers, but this cannot now be checked or verified because a herd of domestic reindeer has been kept there for several decades. Their bones and antlers are found throughout the island and in many cases

Table 3
Radiocarbon age of mammoth fauna from Wrangel Island

Number	^{14}C yr BP	Laboratory number
Equus lenensis		
1	12500±160	GIN-8988
2	13640±180	LU-2797
3	14480±270	LE-5350
4	28670±1400	GIN-8987
5	28730±1400	LU-2796
6	31560±1200	GIN-8986
Coelodonta antiquitatis		
1	29800±340	GIN-8259A
2	30200±1100	AA-60620
3	35200±1200	LE-5276
4	36600±1600	LE-5275
Bison priscus		
1	9450±100	LU-2801
2	12880±100	LU-2800
3	12990±95	Ua-21319
4	19400±210	Ua-21318
Ovibos moschatus		
1	15250±60*	GIN-8248
2	17670±215	Ua-21321
3	>40000	Ua-21320
4	>40000	Ua-21322
5	>40000	Ua-21323

*Sample collected by Dr. F. A. Romanenko (Faculty of Geography, Moscow State University, Moscow, Russia).

are indistinguishable from more ancient specimens. It remains unclear whether reindeer could cross Long Strait by ice, and such cases have not been recorded during the past 30 yr while the Wrangel Island Reserve has been in existence.

Four bison bones from Wrangel Island range in age from 19,400 to 9450 ^{14}C yr BP. The youngest of these has been dated to 9450±100 ^{14}C yr BP, which is arguably the youngest known bison from the Asian northeast. All three radiocarbon dated woolly rhinoceros finds from the island date to the Karga Interstadial, a warm period preceding the last, Sartan, glaciation. This suggests, indirectly, that during the Karga period the island was not yet separated from the continental mainland. The Wrangel Island woolly rhinoceros remains are currently the eastern-most known finds of this species in Asia (Tikhonov et al., 1999). Three of the five musk ox bones have ages >40,000 ^{14}C yr BP, whereas two samples were dated to 17,670 and 15,250 ^{14}C yr BP (Table 3).

Apart from the mammoths, there is no evidence that Wrangel Island functioned as a mid-Holocene refugium for other mammals of the Mammoth fauna complex. The late Pleistocene mammal fauna on the island was typical of the faunal composition throughout northern Asia as a whole.

Implications for the mammoth fauna

In the last third of the late Pleistocene, mammoths inhabited Wrangel Island, as well as elsewhere in western Beringia. However, during the Sartan glaciation optimal habitat for mammoths was shifted away from high latitude Arctic shelf regions. Mammoth herds migrated throughout this vast range, appearing in the more northerly portions of their range only during the warmer summer months.

The period from ~12,500 to ~8000 ^{14}C yr BP was critical for mammoths in northern Eurasia. Their Arctic range was reduced to a relatively narrow belt of recently exposed continental shelf, in areas not yet flooded by rising sea levels (Sulerzhitsky, 1995; Sulerzhitsky and Romanenko, 1997). Compared to their population during glacial periods, the relative abundance of mammoths increased in this portion of their range in post-glacial times. With Holocene warming came a northerly translocation of both the more southerly portion of tundra vegetation that was an important component in mammoth winter diet (Ukraintseva, 1993), and also a comparable northerly expansion of the taiga and forest tundra zones. These latter biomes, with vegetation similar to that now found in North Yakutia, were less useful to mammoths, and the northerly expansion of these biomes forced a contraction of the mammoth range far to the north.

On the Taymir and Gydan peninsulas mammoths became extinct no earlier than 10,000–9500 ^{14}C yr BP (Sulerzhitsky, 1995). Along the northern coast of western Chukotka and its exposed adjacent continental shelf, mammoths could have survived until roughly 8000 ^{14}C yr BP. It is from here that they could have reached Wrangel Island, but at this late date only as a species already somewhat diminished in body size. After 12,000 yr ago Wrangel Island started to become more inaccessible for large mammal species. By 9000 ^{14}C yr BP the island's mammoths became completely isolated, yet continued to survive on the island for the next 5000 yr under conditions very different from those that they experienced during late Pleistocene glacial periods. At 10,000 yr ago the former mammoth range in northern Eurasia must have been greatly fragmented. As the Wrangel Island and Pribilof Islands mammoths survived this fragmentation well into the Holocene, it is logical to suppose that other contemporary populations of mammoths could also have survived in comparable refugia elsewhere in the Arctic (Guthrie, 2004; Yesner et al., 2005).

Since this late post-glacial fragmentation of the late Pleistocene mammoth range was caused by the northern expansion and encroachment of taiga vegetation, it is also quite possible that isolated populations of mammoths could have survived in areas south of the taiga boundary as well. Some evidence in support of this comes from radiocarbon dates on cultural levels that contain mammoth bones from several late Upper Palaeolithic sites in southern Yakutia (Mochanov, 1977; Vartanyan and Pitul`ko, 1999). However, thus far, none of these radiocarbon dates has been generated directly on mammoth bones themselves.

With the late post-glacial fragmentation of the late Pleistocene mammoth range in Eurasia, isolated less-migratory populations of mammoths continued to exist in separate and unconnected refugia in the high Arctic. The ability to adapt to a less-migratory life style seems to have helped large mammal species to survive the transition into warmer interglacial times.

It is possible to predict that small isolated mammoth populations were easily overhunted by humans intruding into the Arctic. Two recently known Holocene mammoth populations (Wrangel Island and Pribilof Isands), however, both survived at human-free islands.

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