АРХЕОЛОГИЯ

Geoarchaeology, Age and Chronology of the Zhokhov Site

V. V. Pitulko, E. Y. Pavlova

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Vladimir V. Pitulko — PhD (History), Senior Research Fellow, Institute of the History of Material Culture, RAS, 18, Dvortsovaya nab., St Petersburg, 191186, Russian Federation; Peter the Great Museum of Anthropology and Ethnography, RAS, 3, Universitetskaya nab., St Petersburg, 199034, Russian Federation; pitulko.vladimir@gmail.com

Владимир Викторович Питулько — канд. ист. наук, ст. науч. сотр., Институт истории материальной культуры РАН, Российская Федерация, 191186, Санкт-Петербург, Дворцовая наб., 18; Музей антропологии и этнографии им. Петра Великого, РАН, Российская Федерация, 199034, Санкт-Петербург, Университетская наб., 3; pitulko.vladimir@gmail.com

Elena Y. Pavlova — Research Fellow, Arctic and Antarctic Research Institute, 38, ul. Beringa, St Petersburg, 199397, Russian Federation; pavlovaelena759@gmail.com

Елена Юрьевна Павлова — науч. сотр., Арктический и антарктический научно-исследовательский институт, Российская Федерация, 199397, Санкт-Петербург, ул. Беринга, 38; pavlovaelena759@gmail.com

Investigations of the Zhokhov site that yielded the results discussed here were conducted during the Zhokhov-2000 research project in 2000–2005 with the support of a private research foundation, the Rock Foundation of New York, NY, USA Currently, our research is developing under support of the Russian Science Foundation, project No. 16-18-10265P and No. 21-18-00457. The authors are deeply grateful to all Zhokhov Island fieldwork participants: their hard work gave us the varied materials representing the culture of ancient inhabitants of the High Arctic. The authors want to thank Natalia Slobodina for helping with the English translation of the initial draft of the article. Finally, special thanks due to John F. Hoffecker for his comments on the manuscript and for kindly providing assistance with the editing of the final version of the article.

Обсуждаемые здесь результаты получены в результате исследований Жоховской стоянки, предпринятых в рамках исследовательского проекта «Жохов-2000» в 2000–2005 гг. при поддержке частного исследовательского фонда Rock Foundation of New York, NY, USA. Их обработка продолжается при поддержке Российского научного фонда (проекты № 16-18-10265П и № 21-18-00457). Авторы выражают глубокую признательность всем участникам полевых работ на острове Жохова, благодаря нелегкому труду которых получены разнообразные материалы, характеризующие древнюю культуру насельников высокоширотной Арктики. Авторы признательны Наталье Слободиной за помощь в переводе первоначального варианта статьи на английский язык. Особая благодарность Джону Ф. Хоффекеру за его комментарии к рукописи и за помощь в редактировании ее окончательной версии.

The Zhokhov site, investigated in 1989–1990 and 2000–2005, is located at 76° N in a remote part of the East Siberian Arctic. Excavations yielded tens of thousands of artifacts and faunal remains including the oldest anthropological remains known in the high arctic regions up to date. The culture-bearing deposits appear to represent the backfill of ice wedge casts formed after the site was abandoned when the island area became isolated due to the development of the post-glacial marine transgression. A large sample of radiocarbon ages obtained on various materials (n = 102) provides a chronology for the site, which was occupied 8300–7800 ^{14}C years ago. There were multiple occupation episodes, but it is not possible to estimate their duration with precision (within less than 50–100 years). The most intense human activity occurred within the interval 8050–7900 radiocarbon years BP, or ca. 9000 calBP but overall human occupation of the site spans roughly 2000 years. This is the oldest known archaeological site in the high-latitude Arctic. The identification and analysis of habitation episodes at the Zhokhov site has important implications for the study of Palaeolithic sites. The radiocarbon chronology indicates that repeated / cyclic human habitation at the same place is possible for up to 2000 years and possibly longer. Repeated or cyclic human occupation in the Zhokhov island area was possible due to locally available food and material resources. Thus, the radiocarbon dates provide more than chronomentric or chronological data; they are a source of information source about human ecology and its role in the evolution of culture.

Keywords: Zhokhov site, arctic Stone Age, geoarchaeology, site formation, radioacarbon dating, chronometry, chronology, habitation episodes, human behavior, cultural complexity, subsistence patterns.

Геоархеология, возраст и хронология Жоховской стоянки

В. В. Питулько, Е. Ю. Павлова

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Жоховская стоянка, исследованная в 1989–1990 и 2000–2005 гг., расположена под 76° с. ш. в труднодоступной части Восточно-Сибирской Арктики. Раскопки дали десятки тысяч предметов и фаунистических остатков. Культуросодержащие отложения представляют собой заполнение протаявших верхних частей повторно-жильных льдов. Они образовались после того, как стоянка была полностью оставлена. Радиоуглеродные датировки, полученные по различным материалам, образуют большую коллекцию (n = 102), которая проанализирована для установления летописи использования стоянки человеком. Присутствие человека на Жоховской стоянке, на основании множественных датировок, соответствует интервалу 8300–7800 радиоуглеродных лет назад. Показано, что данный интервал состоит из отдельных крупных циклов и более мелких эпизодов, определение границ которых с точностью, превосходящей 50–100 лет, оказалось невозможно. Наиболее интенсивная человеческая деятельность человека на стоянке относится ко времени 8050–7900 радиоуглеродных лет назад, или около 9000 лет в калиброванных значениях возраста. Это древнейший из известных археологических памятников в высоких широтах Арктики. Опыт выявления эпизодов обитания на Жоховской стоянке имеет важные последствия для изучения палеолитических памятников. Так, показано, что фактически пребывание человека на территории памятника составляет примерно 2000 лет. Изучение рядов датировок из Жоховской стоянки показывает, что повторное/циклическое проживание человека на одном и том же месте возможно в течение примерно 2000 лет и даже дольше, если для этого есть основания. Таким образом, повторное или циклическое заселение человеком территории острова

Жохова обусловлено исключительно пищевыми и физическими ресурсами, наличие которых обеспечивается географией его расположения. Таким образом, радиоуглеродные даты — это не просто хронометрические или хронологические данные; это специфический источник информации, интегрирующий различные аспекты сложного человеческого поведения как движущей силы эволюции человеческой культуры.

Ключевые слова: Жоховская стоянка, арктический каменный век, геоархеология, процессы формирования культуросодержащих отложений, радиоуглеродное датирование, хронометрия, хронология, эпизоды обитания, поведение человека, культурная сложность, система жизнеобеспечения.

Introduction

The chain of the New Siberian Islands between the Laptev and East Siberian Seas is one of the most remote and inaccessible areas of the eastern Arctic (Fig. 1A). Because of that, it took almost three hundred years to explore and map them: first reported in the early eighteenth century by a Russian Government survey team (*Cossacks*), they were only occasionally visited for hundreds of years.

A pioneer exploration party led by Matvey Gedenshtrom was sent by the Russian Government in 1808–1811. Together with practical knowledge on the area and maps of known islands, all uninhabited, Gedenshtrom reported the presence of an undiscovered land mass farther north in the Arctic Ocean. Honoring his travelling companion, he named that island after him. Since then, it has been known as Sannikov's Land. In 1820–1824, Lt. Anjou produced the first nautical chart of the area. Although Anjou was convinced that Sannikov's Land did not exist, this did not preclude further attempts to locate it, and its existence remained in question for next one hundred fifty years until the late 1940s when Soviet airborne expeditions finally resolved the issue (in the negative).

Exploration of the islands thus has long and dramatic history including an American nautical expedition on the USS *Jeanette* led by Lt. George Washington De-Long in 1879–1880, who discovered three islands of the group named after him, and Russian Polar Expedition of prominent Russian geologist Edward von Toll in 1901–1902 that continued his previous work in New Siberian Islands performed together with Russian naturalist and physician Alexander von Bunge in 1885 and 1886. Results of this work were of enduring value. Thus, based on field observations, von Bunge[1] first hypothesized frost-crack nature of ice-wedge formation which became widely recognized in the second half of the 20th century[2]. Von Toll's research on the geology of the New Siberian Islands[3] represents a lasting achievement.

Initial exploration of the islands ended with discovery of Zhokhov Island in 1914 by the Russian Navy Hydrography Expedition of the Arctic Ocean. In addition to Vilkitsky and Zhokhov islands of the De-Long group in the New Siberian Archipelago, the expedition of the *Taimyr* and *Vaigach* ice-class steamboats discovered new land north of the

1 *Von Bunge A. A.* Einige Worte zur Bodeneisfrage // Verhandlungen der Russisch-kaiserlichen Mineralogischen Gesellschaft: Die zweite Serie. 1903. Vol. 40, Bd. 1. S. 203–209.

2 *Shur Y., Fortier D., Jorgenson M. T., Vasiliev A., Ward J. M.* Yedoma Permafrost Genesis: Over 150 Years of Mystery and Controversy // Frontiers in Earth Science. 2022. Vol. 9. Article 757891.

3 *Von Toll E. V.:* 1) Ocherk geologii Novo-Sibirskikh ostrovov i vazhneishie zadachi issledovaniia poliarnykh stran // Izvestiia Imperatorskoi akademii nauk. 1899. Vol. IX. P. 1–20; 2) Kratkii otchet prezidentu Imperatorskoi akademii nauk // Ibid. 1904. Vol. XX. P. 158, 159.

Taimyr Peninsula. It had been thought to be a single landmass and was originally named after Emperor Nicholas II, but the name was changed to the Severnaya Zemlya islands during Soviet times. It was the last undiscovered land mass in the world, and its discovery marked the end of the Age of Discovery[4].

Physical features of the study area

Zhokhov Island is located at 76° N latitude; it is a part of the De Long group of the New Siberian Archipelago which is part of the East Siberian Arctic Shelf. The nearly level topography of the sea floor represents the De Long Plateau. This is a shallow water area; the depth around the De Long Islands only slightly exceeds 20 m. A large sea-floor depression lies between the De-Long and Anjou islands, namely, the Vilkitsky 'trough' / rift zone[5].

Zhokhov Island is one of the smallest among the New Siberian Islands and was the last to became known. It was discovered during the expedition of *Taimyr* and *Vaigach* ice-class steamboats on August 29, 1914, and named then after Lt. Novopashennyi[6]; its present name was assigned to it during Soviet times. With this discovery, the history of mapping of the New Siberian Islands ended after three hundred years of geographic exploration of the region.

Zhokhov Island measures approximately 7 by 11 km (Fig. 1B). Elevations observed in the island are typically within 30–40 m above sea level except for its central part[7]. Zhokhov Island is thought to represent an eroded stratovolcano possibly indicating Quaternary (Cenozoic) volcanism in the area[8] and thus its topography is largely formed by the remnants of volcanic structures. At present, this is tectonically stable region. There are several hills, the height of which reaches 120 m. Generally, the island is a cone-shaped structure, which is also confirmed by the bathymetry of the surrounding sea floor. Thus, there are gently sloping areas between the –20 and –10 m depth contour lines adjoining the island, while the 20-meter contour runs 60 km south of Zhokhov Island, near Vilkitskiy Island.

The topography of the island determines the radial pattern of its hydrography: there are a number of short streams running from the most elevated central part to the coast basically following the topography of bedrock. Some streams are relatively deeply incised into frozen unconsolidated deposits next to the slopes of the hills. These streams are primarily ephemeral water collectors fed by snowmelt and atmospheric moisture. Mostly, they cease flowing in early August as snow patches disappear and frost conditions become typical at night. There are two permanent freshwater streams which have relatively large water catchment areas; one is in the southern part of the island, while the other is found in

[4] *Savatyugin L. M.* Novosibirskii arkhipelag. Istoriia, imena i nazvaniia. St Peterburg, 2019.

[5] *Drachev S. S., Savostin L. A., Groshev V. G., Bruni I. E.* Structure and geology of the continental shelf of the Laptev Sea, Eastern Russian Arctic // Tectonophysics. 1998. Vol. 298. P. 357–393; *Sekretov S. B.* Northwestern margin of the East Siberian Sea, Russian Arctic: Seismic stratigraphy, structure of the sedimentary cover and some remarks on the tectonic history // Tectonophysics. 2001. Vol. 339. P. 353–383; *Mazarovich A. O., Sokolov S. Y.* Tectonic subdivision of the Chukchi and East Siberian Seas // Russian Journal of Earth Sciences. 2003. Vol. 5 (3). P. 185–202.

[6] *Starokadomsky L. M.* Otkrytie novykh zemel' v Severnom Ledovitom okeane. Petrograd, 1915.

[7] Novosibirskie ostrova / ed. by Y. Y. Gakkel. Leningrad, 1967.

[8] *Sakhno V. G., Krymsky R. S., Belyatsky B. V., Shevchenko S. S., Sergeev S. A.* Mantle sources of Quaternary volcanism on Zhokhov Island (De Long Islands, East Arctic): isotope-geochemical features of the basalts and spinel lherzolite xenoliths // Doklady Earth Sciences. 2015. Vol. 460. P. 123–129.

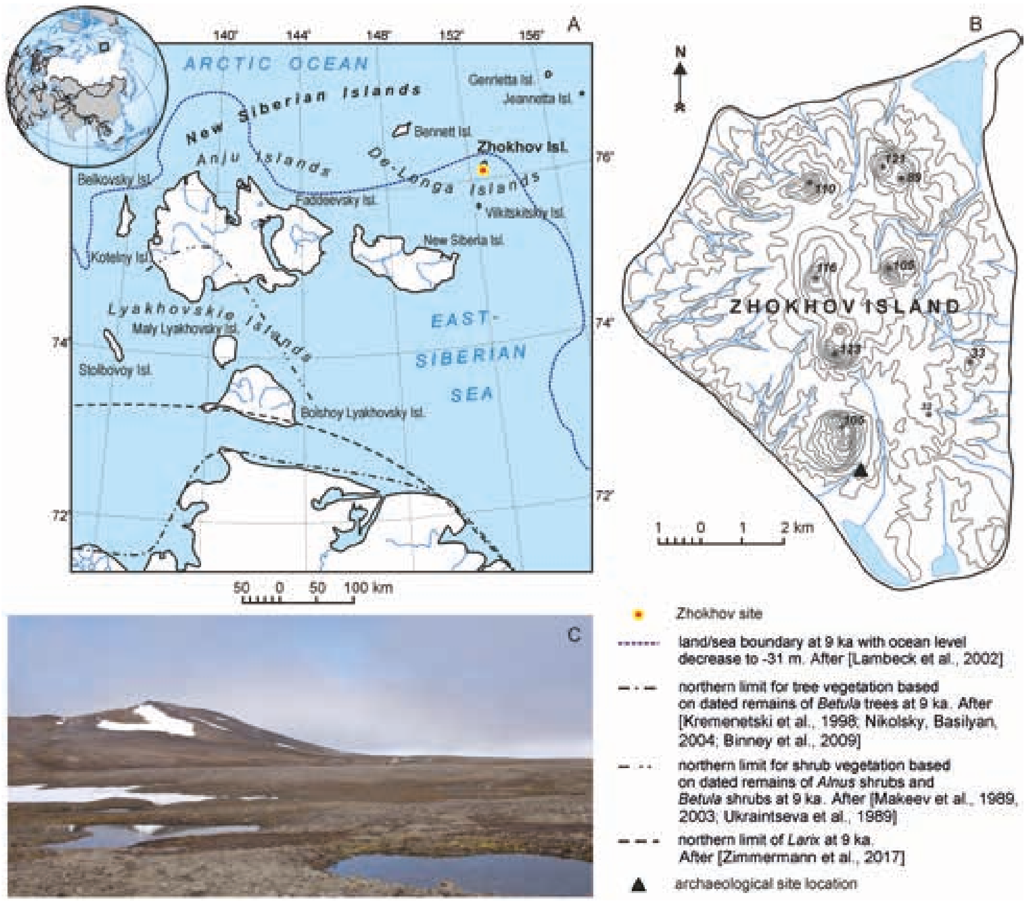

Fig. 1. Geographic position of the Zhokhov site in the arctic north-eastern Siberia:

A — schematic map of the New Siberian islands; B — schematic map of the Zhokhov island; C — site location viewed from the south in the late July of 2004 (note the snow patch sitting on the hill slope). Illustration prepared by Elena Pavlova

the northeastern part of the island. The latter has a true channel formed by headward erosion, apparently derived from some earlier hydrological system. Both of the large streams stop running with freezing temperatures in late August / early September.

Quaternary deposits on the island consist of colluvial, alluvial-pluvial and marine sediments which comprise a relatively thin mantle underlaid by the bedrock represented by effusive rocks (local basalt rocks). Known depth of the Quaternary sediment cover reaches as much as 10m but its thickness varies significantly. While they are absent on hilltops and relatively thin on the slopes, they thicken down slope and accumulate at the base of the slopes. These are permafrost deposits that reflect several cycles of aggradation and thawing. In its present form, the permafrost comprises ground ice of various origin and age[9].

[9] *Pitulko V. V., Pavlova E. Y., Ivanova V. V., Girya E. Y.* Zhokhov Site: Geology and Stone Industry (Preliminary Report on the Excavations of 2000 through 2005) // Stratum Plus. 2012. Vol. 1. P. 211–256.

The coast of the island is mostly sloping except for several areas in which 10–12 m high rocky cliffs are observed. The highest cliff is Taimyr Cape in the southern part of the island, which reaches 32 m in elevation. During summer, these cliffs are occupied by sea bird colonies. In the northern part of the island, there are some terrace-like landforms. These are possibly remnants of old marine terraces; however, their age is unknown. Except for these marine formations there are three lagoons, separated from the sea by gravel spits, all formed in the Holocene (see: Fig. 1B). Two of them, located in the southern part of the island, are small and shallow, and thus freeze to the bottom in winter. The northern lagoon is significantly larger: its length exceeds 3.5 km and the depth is 11.5 m (see: Fig. 1B). It is formed at the edge of a marine terrace created by the deposition of two gravel spits around its perimeter by coastal currents[10]. All year round the island is surrounded by sea ice, either pack ice or dense concentrations of pack ice.

Zhokhov Island lies within the Siberian climatic region of the Arctic[11]. The observed value of total solar radiation varies 65–70 kcal/cm^2 per year. Average temperatures are 28–30 degrees below freezing in Celsius in January and vary from slightly below freezing to +1 °C in July, and thus the frostless period is generally absent, while summer temperatures of the day may reach about +10 °C in July. Average annual precipitation is 135–180 mm / year, with a large contribution from oceanic evaporation. A stable snow cover with an average thickness of 20–35 cm forms in mid-September and melts by the beginning of July.

According to the botanical and geographical zonation of the Arctic[12], Zhokhov Island belongs to the Yana-Kolyma sub-province of the East Siberian Arctic. This is a sub-zone of the high-Arctic tundra; generally speaking, this is a polar desert region. Local vegetation develops under conditions of marine Arctic climate with low temperatures. Because of that, a thin plant cover forms on poorly developed rubble, loamy and clay soils. The vegetation forms a single layer generally 5–10 cm high and covers about 40–60 % of the surface[13]. Snow cover plays an important role in the animal and plant life. For most of the year, the island is covered by snow, redeposited and compacted by wind. For Zhokhov Island, Gakkel[14] reports 119 still days per year, but suggests that this value is overestimated as 1–2 knot winds may have not been counted. By December, snow density reaches 0.30 g/cm^3 and further increases to 0.35–0.36 g/cm^3 in the second half of winter. Together with wind deflation of the elevated portions of the surface, this contributes to extra cooling of the top part of the deposits hosting the plant roots.

The present-day wildlife of Zhokhov Island is extremely poor and exists mostly in the summer. These are largely birds, either colonial sea birds and shore birds represented by several species of charadriiformes. Waters of the island are inhabited by walrus and seals. Year-round terrestrial mammalian species are absent, but the island provides shelter to migrating arctic foxes and polar bears. Since the topography of the island provides good

[10] *Anisimov M. A., Ivanova V. V., Pushina Z. V., Pitulko V. V.* Lagunnye otlozheniia ostrova Zhokhova, ikh vozrast, usloviia formirovaniia i znachenie dlia paleogeograficheskikh rekonstruktsii regiona Novosibirskikh ostrovov (Vostochnosibirskii sektor Arkticheskogo shel'fa Evrazii) // Izvestiia Rossiiskoi Akademii Nauk, Seriia Geograficheskaia. 2009. No. 5. P. 107–119.

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[13] *Samarskii M. B., Sokolova M. V., Zhurbenko M. P., Afonina O. M.* O flore i rastitel'nosti ostrova Zhokhova (Novosibirskie ostrova) // Botanicheskii Zhurnal. 1997. Vol. 82 (4). P. 62–70.

[14] Novosibirskie ostrova / ed. by Y. Y. Gakkel. Leningrad, 1967.

options den making, polar bears stay on the island over winter for hibernating and reproduction, producing newborn cubs in February.

Zhokhov site: location, geology, and site formation processes

The archaeological site, namely the Zhokhov site (76°06´20.3″ N and 152°42´42.2″ E), is located at the southwest corner of Zhokhov Island[15]. It appears to be a level surface comprising late Pleistocene syngenetic Yedoma-type deposits[16] underlaid by basalt bedrock and covered by a complex of taberal deposits formed in the Holocene; we use the term *taberal* deposits in the sense of the process of in-situ thawing Yedoma under a large water body, following Kaplina[17] and Strauss et al.[18] This level area has a gentle southward inclination. Based on radiocarbon dating, the formation of deposits composing the Yedoma plain with absolute elevations of 16–23 m took place at the end of Late Pleistocene. Next to the Zhokhov site, these deposits have produced ages of 22,260 ± 80 ^{14}C years ago (Beta-173077) at a depth of 0.95 m, and 19,650 ± 70 ^{14}C years ago (Beta-216800) at a depth of 0.2 m, respectively. The surface of the plain is heavily eroded by several episodes of thermokarst indicated by peat accumulations of varying age[19] which is confirmed by the pollen record[20] and proxy-data retrieved from a lagoon sediment core[21]. Additionally, there are multiple present-day thermokarst ponds of varying size.

The site is at the junction of this surface and ~120 m — high isometric hill which stretches southwest to northeast. This landform is volcanic in origin and composed of volcanic conglomerates and tuffs. The slope angle varies 15–30 degrees. The unconsolidated sediment cover exhibits various patterned ground such as small, unsorted circles and polygons, small sorted rock polygons and sorted lines, formed by intense cryogenic processes.

The site's location is convenient in that a vantage point is available nearby, providing an overview of tens of square kilometers, and offering the settlement natural protection from the north and northwest winds. Importantly, thick snow drifts accumulate on the leeward slope, thus creating a freshwater source in the summer and providing an excellent setting for den-making by hibernating polar bears. In the late June, the snow patch is at

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16 *Schirrmeister L., Froese D., Tumskoy V. et al.* Yedoma: Late Pleistocene ice-rich syngenetic permafrost of Beringia (Chapter 6.12) // The Encyclopedia of Quaternary Science: in 4 vols. Vol. 3. Amsterdam, 2013. P. 542–552; *Wetterich S., Tumskoy V., Rudaya N. et al.* Ice Complex formation in arctic East Siberia during the MIS3 Interstadial // Quaternary Science Reviews. 2014. Vol. 84. P. 39–55.

17 *Kaplina T. N.* Istoriia merzlykh tolshch Severnoi Yakutii v pozdnem kainozoe // Istoriia razvitiia mnogoletnemerzlykh porod Evrazii. Moscow, 1981. P. 153–181.

18 *Strauss J., Schirrmeister L., Grosse G. et al.* Deep Yedoma permafrost: A synthesis of depositional characteristics and carbon vulnerability // Earth-Science Reviews. 2017. Vol. 172. P. 75–86.

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

21 *Anisimov M. A., Ivanova V. V., Pushina Z. V., Pitulko V. V.* Lagunnye otlozheniia ostrova Zhokhova… P. 107–119.

least two meters deep, and thus it should be 3–4 m thick in the winter (Fig. 1C). In fact, some specific features of the Zhokhov site culture are defined by the site location[22].

As it is common with unique archaeological sites, the first concentrations of artifacts were discovered accidentally by staff members of the now abandoned weather station[23]. Systematic investigation of the Zhokhov site began in 1989–1990 as a part of the Arctic and Antarctic Research Institute A-162 project focused on the New Siberian archipelago[24]. The work was halted and resumed in 2000 as a part of the Zhokhov-2000 research project[25]. During several excavation campaigns at the site, it was established that culture-bearing deposits occupy at least 8000 square meters based on spatial distribution of the surface finds. During the excavations of 1989 and 1989, followed by substantial work in 2000–2005, an area of 571 m^2 was exposed. This appears to represent slightly less than 10 % of the entire site area. Samples were collected from numerous stratigraphic profiles for radiocarbon dating, particle size analysis, and geochemical analyses. It should be emphasized that the culture-bearing deposits at the Zhokhov site exhibit a complex cryo-lithology characterized by varying sediment composition and varying types of ground ice[26].

Excavations followed the methodology developed for permafrost conditions which is described in detail elsewhere[27]. The entire Zhokhov collection contains tens of thousands of objects, including over 54,000 faunal elements (approximately 22,000 are identifiable), about 19,000 artifacts that characterize the lithic industry based on highly developed microprismatic technology and ground tools[28], more than 300 artifacts of worked antler, mammoth ivory and bone (various tools, needles, hunting equipment based on organic tools with side blades) with approximately 1000 objects made of wood including sled parts[29], and a few woven and birch bark artifacts. Remarkably, the Zhokhov site presents

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[24] *Pitulko V. V., Makeyev V. M.* Ancient Arctic Hunters. P. 374; *Pitulko V. V., Kasparov A. K.* Ancient Arctic hunters: material culture and survival strategy // Arctic Anthropology. 1996. Vol. 33 (1). P. 1–36; *Pitulko V. V.* Zhokhovskaia stoianka; *Makeyev V. M., Ponomareva D. P., Pitulko V. V., Chernova G. M., Solovyeva D. V.* Vegetation and climate of New Siberian Islands… P. 28–35.

[25] *Pitulko V. V.* O rabotakh ekspeditsii "Vysokoshirotnaia Arktika: priroda i chelovek" (proekt Zhokhov-2000») na Novosibirskikh o-vakh v 2000–2005 gg. // Polar Almanac. Moscow, 2011. P. 77–91.

[26] *Pitulko V. V., Pavlova E. Y., Ivanova V. V., Girya E. Y.* Zhokhov Site. P. 211–256; *Pitulko V. V., Pavlova E. Y.* Opyt radiouglerodnogo datirovaniia kul'turosoderzhashchikh otlozhenii Zhokhovskoi stoianki (Novosibirskie o-va, Sibirskaia Arktika) // Zapiski IIMK RAN. 2015. No. 12. P. 27–55; *Pavlova E. Y., Ivanova V. V., Meyer H., Pitulko V. V.* Izotopnyi sostav iskopaemykh l'dov kak indikator paleoklimaticheskikh izmenenii na severe Novosibirskikh ostrovov i zapade Iano-Indigirskoi nizmennosti // Fundamental'nye problemy kvartera, itogi izucheniia i osnovnye napravleniia dal'neishikh issledovanii. Irkutsk, 2015. P. 349–351.

[27] See, for instance: *Pitulko V. V.* Principal excavation techniques under permafrost conditions (based on Zhokhov and Yana Sites, Northern Yakutia) // Archaeology, Ethnology & Anthropology of Eurasia. 2008, Vol. 2. P. 26–33; *Pitulko V. V.* Digging through permafrost in Siberia // Field Archaeology from Around the World. Ideas and Approaches. [S. l.], 2015. P. 111–113; *Pitulko V. V.* Permafrost Digging // Encyclopedia of Global Archaeology. Cham, 2019. P. 1–29.

[28] *Pitulko V. V.* Zhokhovskaia stoianka; *Pitulko V. V., Pavlova E. Y., Ivanova V. V., Girya E. Y.* Zhokhov Site. P. 211–256.

[29] *Pitulko V. V., Kasparov A. K.* Ancient Arctic hunters: material culture and survival strategy. P. 1–36; *Pitulko V. V., Kuzmin Y. V., Glascock M. D., Pavlova E. Y., Grebennikov A. V.* "They come from the ends of the

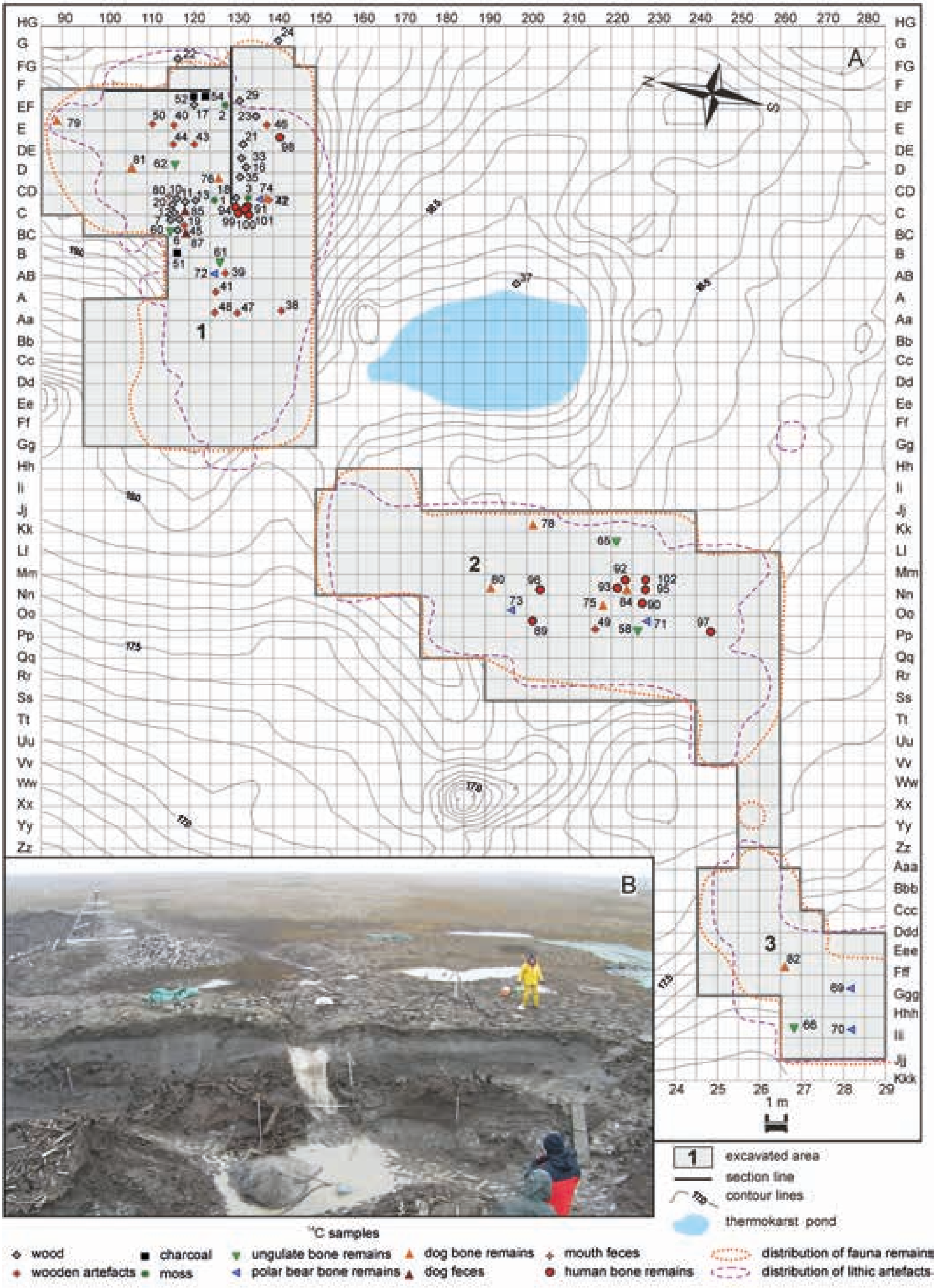

Fig. 2. Map of the Zhokhov site area; spatial distrubution of radiocarbon-dated samples within the excavation. Left bottom: central part of the excavated area (Area 2) viewed from SW, July 2004. Illustration and photo image prepared by Elena Pavlova

the oldest known archaeological example of systematic using of driftwood as a raw material.

This valuable data set revealed the principal components of the subsistence economy practiced by the Zhokhov settlers[30] and their annual economic cycle. It was also found that the Zhokhov inhabitants used a highly developed land transportation system (sleds of sophisticated construction powered by dog teams) which greatly facilitated their economic activities[31] allowing long-distance travel[32]. Importantly, the ancient sled-dog breed of Zhokhov Island is ancestral to all sled dogs known at present[33].

The cultural material, including stone, bone, ivory, and wood artifacts, as well as the large collection of faunal remains, is not confined to a single layer. The cultural remains exhibit clear traces of short-term movement by surface and ground water, as evidenced by scattered wood charcoal, as well as fur in clumps or isolated hairs. Sediment transport and redeposition are indicated by numerous peat and sod lenses, in various layers at various depths. This pattern is noted for all stratigraphic profiles within the excavation (Figs 2, 3). At the same time, despite the apparent evidence of running water contributing to the formation of cultural deposits, we should stress that signs of long-distance transport of cultural remains are absent. It had been determined[34] that the formation of culture-bearing *deposits* at the Zhokhov site began around 7380 ± 130 ^{14}C years BP (LE-6479) but the human habitation that produced the cultural material is significantly older.

Based on the spatial organization of the culture-bearing deposits, lithology of the sediment matrix, geocryology of these deposits, and their relationship with underlying sincryogenic Yedoma deposits, it is concluded that the formation of the culture-bearing deposits is largely due to increased atmospheric heat and moisture[35], but also to fundamental changes in the geography of the area at the onset of the Holocene, linked with the development of post-glacial marine transgression. All these factors triggered active development of geomorphic processes and influenced active thermokarst development, thermo-erosional and slope processes, as well as the effects of temporary meltwater streams.

As mentioned above, the culture-bearing accumulations start forming 7380 ± 130 ^{14}C years BP which corresponds to a change in sea-level. A portion of dry land which included the present-day Zhokhov Island became separated from the larger land mass around 7730 ± 40 ^{14}C years BP (Beta-204886) due to gradual postglacial transgression. The transgression is indicated by the penetration of sediment containing diatoms associated with

earth": long-distance exchange of obsidian in the early Holocene of the High Arctic (Zhokhov site, eastern Siberia) // Antiquity. 2019. Vol. 93 (367). P. 28–44.

30 *Pitulko V. V.* The Bear-Hunters of the Zhokhov Island, East Russian Arctic // Hunter-Gatherers of the North Pacific Rim. Senri Ethnological Series. 2003. No. 63. P. 141–152; *Pitulko V. V., Ivanova V. V., Kasparov A. K., Pavlova E. Y.* Reconstructing Prey Selection… P. 120–157.

31 *Pitulko V. V., Kasparov A. K.* Archaeological dogs from the Early Holocene Zhokhov site in the eastern Siberian Arctic // Journal of Archaeological Science: Reports. 2017. Vol. 13. P. 491–515.

32 *Pitulko V. V., Kuzmin Y. V., Glascock M. D., Pavlova E. Y., Grebennikov A. V.* "They come from the ends of the earth". P. 28–44.

33 *Leathlobhair M. N., Perri A. R., Irving-Pease E. K. et al.* The Evolutionary History of Dogs in the Americas // Science. 2018. Vol. 361. P. 81–85; *Sinding M.-H. S., Gopalakrishnan S., Ramos-Madrigal J. et al.* Arctic-adapted dogs emerged at Pleistocene-Holocene transition // Science. 2020. Vol. 368. P. 1495–1499.

34 *Pitulko V. V., Pavlova E. Y., Ivanova V. V., Girya E. Y.* Zhokhov Site. P. 211–256.

35 *Makeyev V. M., Ponomareva D. P., Pitulko V. V., Chernova G. M., Solovyeva D. V.* Vegetation and climate of New Siberian Islands… P. 28–35.

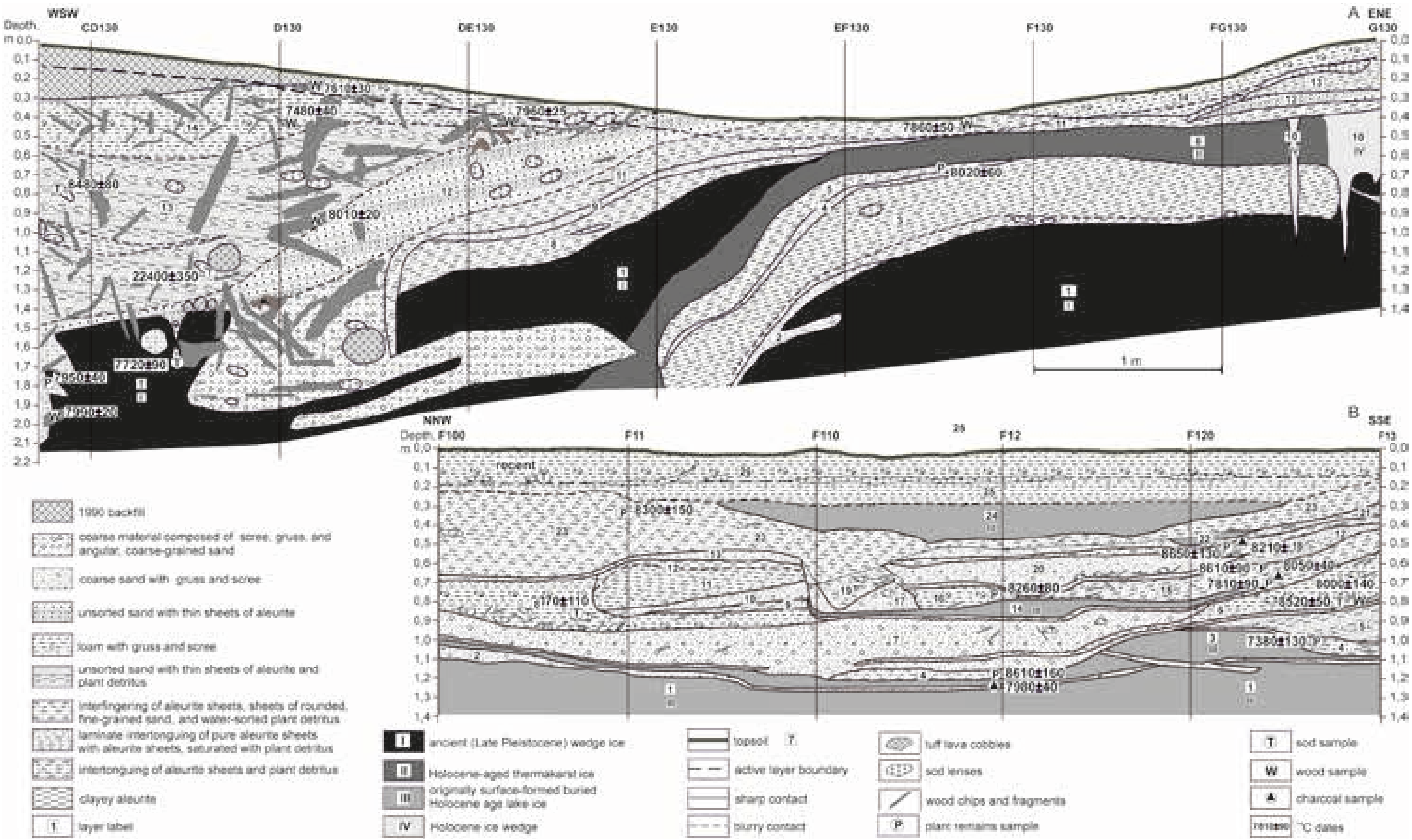

Fig. 3. Zhokhov site, excavations of V. V. Pitulko (2000–2005). Excavation area: 1. Schematic geological profiles LZ2-7S, from F100 to F13 (A), and LZ3-130-4 from CD130 to G130 (B):

1 — dump left after the excavations of 1990; 2 — coarse deposit composed of rock debris, gravel, and coarse-grained sand; 3 — diverse grain size sand with rock debris and gravel; 4 — diverse grain size sand with thin silt slices; 5 — clay loam with rock debris and gravel; 6 — diverse grain size sand with thin slices of silt and plant detritus; 7 — a band of interstratified slices of silt, fine grained sand, and water washed plant detritus; 8 — thin sliced interstratifications of silt with silt saturated with plant detritus; 9 — interstratifications of silt and plant detritus; 10 — clayey silt; 11 — portions of old (Pleistocene age) ice wedge; 12 — thermokarst-cave ice of Holocene age; 13 — layer of originally surface ice (buried lake ice of Holocene age); 14 — Holocene ice wedges; 15 — active layer; 16 — bottom of seasonally-thawed layer; 17 — tuff rubbles; 18 — peat lenses; 19 — wooden splinters, diverse wood fragments; 20 — layer index; 21 — location of granulometric samples. Location and material of dated samples: 22 — plant remains (detritus); 23 — peat; 24 — wood; 25 — charcoal; 26 — radiocarbon ages. Illustration prepared by Elena Pavlova, based on [Pitulko et al., 2012]

marine conditions into the Northern lagoon of Zhokhov Island[36]. The area becomes a relatively large island located near the shore of the coastal plain. Some of the frozen deposits developed on the newly formed island gradually disappear due to coastal erosion which was the most important factor in the modern geography of the New Siberian shelf area, i. e., erosion and denudation were more important than direct inundation of the area by the post-glacial marine transgression[37].

Based on the relevant changes observed in the lagoon core proxy data, sea level decreased after 7400 years BP; the island area was presumably close to that of the present time. Frozen cliffs formed by coastal erosion began to erode at that time. At present, the same process can be observed in the New Siberian Islands; in some cases, this leads to their complete disappearance[38]. Generally, this involves retrogressive thaw slumps widely known at present on the banks of the rivers flowing through the permafrost regions[39]. In turn, this accelerated thermokarst erosion induced by increased heat and moisture reflected in regional pollen proxies that post-date 8.2K event on the regional scale including fast erosion of the upper parts of ice wedges with formation of polygon troughs and other features of permafrost topography[40].

These processes thawed the sediment on the surface of Pleistocene ice-wedges, probably at locations heavily used by people during the occupation episodes. Vast hollows, pockets, thermal wells and canals formed in the ice wedges subsequently filled with numerous objects from the cultural layer, mixed with scree (including small rocks), washed downslope from the elevated areas located next to the site. The accumulation of culture-bearing deposits clearly displays a rhythmic pattern signaling climate / hydrology oscillations[41].

The vertical distribution of ^{14}C dates, obtained from various materials (wood, peat, plant remains, bones, and charcoal) within the excavated part of the Zhokhov site, indicates that the excavated deposits contain radiocarbon dates inconsistent with their stratigraphic position (see: Fig. 3). They often are in reverse order and younger dates underlie

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36 *Anisimov M.A., Ivanova V.V., Pushina Z.V., Pitulko V.V.* Lagunnye otlozheniia ostrova Zhokhova… P. 107–119.

37 See, for instance: *Romanovskii N.N., Gavrilov A.V., Tumskoy V.E. et al.* Environmental Evolution in the Laptev Sea Region during Late Pleistocene and Holocene // Polarforschung. 1998. Vol. 68. P. 237–245; *Gavrilov A.V., Romanovskii N.N., Hubberten H.-W.* Paleogeographic Scenario of the Postglacial Transgression on the Laptev Sea shelf // Earth's Cryospere. 2006. Vol. X (1). P. 39–50; *Günther F., Overduin P.P., Sandakov A.V., Grosse G., Grigoriev M.N.* Short- and Long-Term Thermo-Erosion of Ice-Rich Permafrost Coasts in the Laptev Sea Region // Biogeosciences. 2013. Vol. 10. P. 4297–4318; *Overduin P.P., Wetterich S., Günther F. et al.* Coastal dynamics and submarine permafrost in shallow water of the central Laptev Sea, East Siberia // The Cryosphere. 2016. Vol. 10. P. 1449–1462.

38 *Günther F., Overduin P.P., Yakshina I.A. et al.* Observing Muostakh disappear: permafrost thaw subsidence and erosion of a ground-ice-rich island in response to arctic summer warming and sea ice reduction // The Cryosphere. 2016. Vol. 9. P. 151–178.

39 See, for instance: *Kanevskiy M., Shur Y., Strauss J. et al.* Patterns and rates of riverbank erosion involving ice-rich permafrost (Yedoma) in northern Alaska. Geomorphology. 2016. Vol. 253. P. 370–384; *Morgenstern A., Overduin P.P., Günther F. et al.* Thermo-erosional valleys in Siberian ice-rich permafrost // Permafrost and Periglacial Process. 2021. Vol. 32. P. 59–75; *Pitulko V.V., Pavlova E.Y.* Structural Properties of Syngenetic Ice-Rich Permafrost, as Revealed by Archaeological Investigation of the Yana Site Complex (Arctic East Siberia, Russia): Implications for Quaternary Science // Frontiers in Earth Science. 2022. Vol. 9. Article 744775.

40 *Pavlova E.Y., Pitulko V.V.* Late Pleistocene and Early Holocene climate changes… P. 5–25.

41 *Pitulko V.V., Pavlova E.Y.* Opyt radiouglerodnogo datirovaniia… P. 27–55.

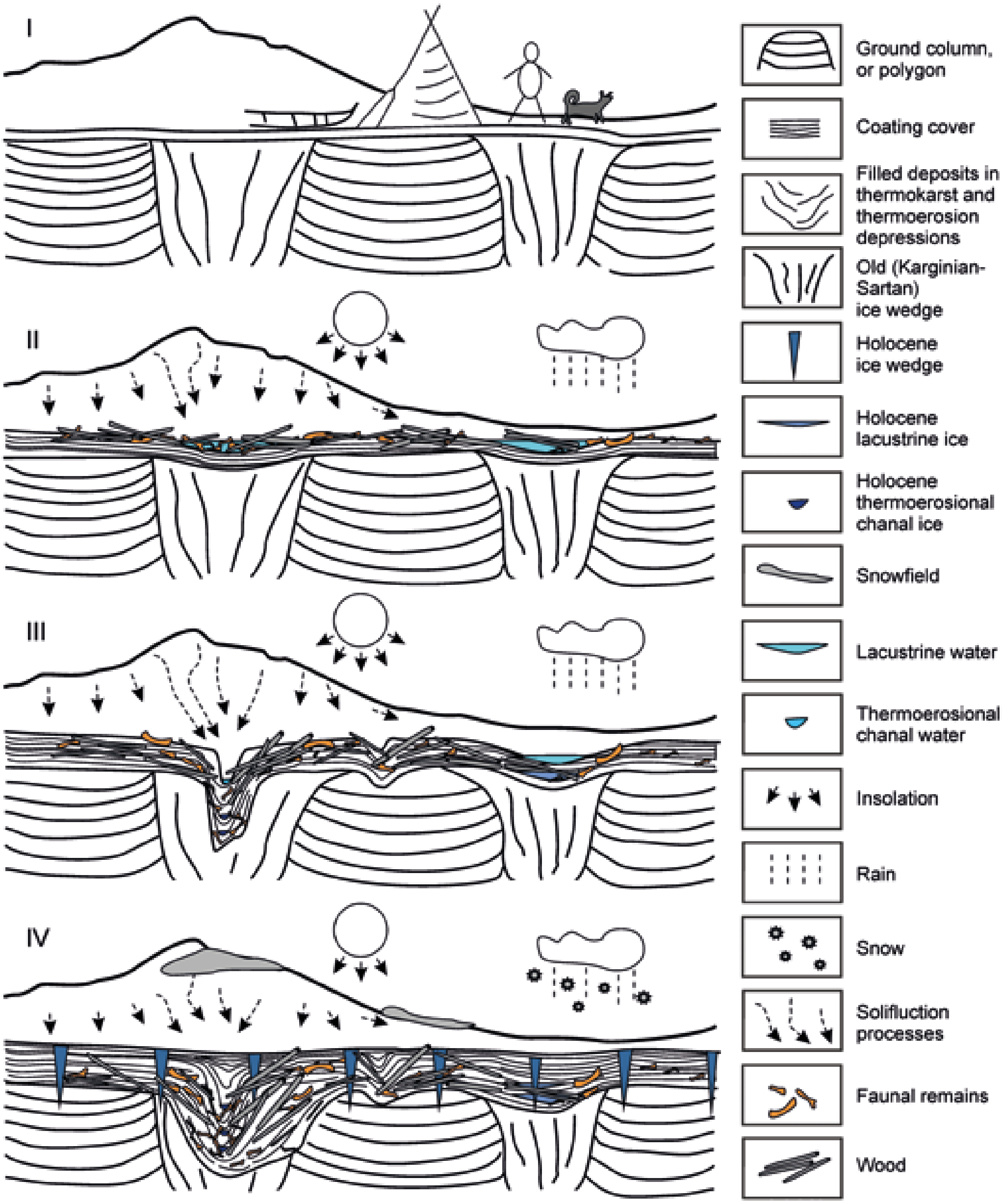

Fig. 4. Accumulation model for frozen culture-bearing deposits of the Zhokhov site, New Siberian islands, from the artifact and bone rain evolved due to human habitation, to ice wedge casts filled with cultural material together with matrix sediments. Illustration prepared by Alla Mashezerskaya and Elena Pavlova. Modified from [Pitulko V. V., 2019]

the older ones[42]. This is evidence of the cultural layer gradually filling surface depressions: younger deposits reworked into the lower part while the older ones would follow them

[42] Ibid.

with the next portion of material to settle above the younger ones. Cultural material was buried by slope deposits in several stages with diminishing intensity and refrozen after redeposition.

As a result, the archaeological material preserved in secondary concentrations as artifact-bearing sediment masses filled thermokarst and thermo-erosional depressions on the landscape. Nevertheless, the cultural remains retain fundamental elements of the original spatial structure of the site, as indicated by the horizontal distribution of the most numerous categories of finds, the spatial distribution of the lithic material[43], and the remains of polar bear and reindeer[44].

Based on these observations, we conclude that the distribution of occupation debris was displaced by several meters, but that overall site structure is still recognizable, although at low resolution. The movement of artifacts due to gravity and/or water transport probably does not exceed 10 m from their original position. In fact, the original cultural layer of the site, along with sediment from the polygon body deposits, was transformed into ice wedge pseudomorph filling (Fig. 4). The thawed top of the ice wedge has been stripped in the lower part of the section. The horizontal position of material concentrations within the Zhokhov site excavation mirrors the polygonal ice-wedge pattern[45]. This is backfill of the ice wedge casts (pseudomorphs) which contain material from the cultural layer formed on the surface occupied by the humans and later re-worked by thermokarst processes (see: Figs 3, 4).

Most likely, the Zhokhov site is a rare example of complete destruction of the original archaeological context, followed by its re-burial and re-freezing in ice wedge casts[46]. At the same time, ice wedge casts provide evidence of paleo-cryogenesis and geological features, which are well represented in the profiles of Quaternary deposits containing archaeological materials in former permafrost areas[47].

Paleoenvironments of the Zhokhov site

At a time of the human occupation of Zhokhov Island, the territory of the island was a part of the Siberian arctic coastal plain created by regression of the Arctic Ocean. Paleogeographically, this area is known as Western Beringia, and Zhokhov Island is one of its rare northernmost remnants. Postglacial global sea-level rise[48] caused inundation of the continental shelf area exposed in the late Pleistocene, and its destruction by complex interplay of coastal erosion/thermoabrasion, hydrological changes, climate change,

[43] *Pitulko V. V., Pavlova E. Y., Ivanova V. V., Girya E. Y.* Zhokhov Site. P. 211–256.

[44] *Pitulko V. V., Ivanova V. V., Kasparov A. K., Pavlova E. Y.* Reconstructing Prey Selection… P. 120–157.

[45] *Pitulko V. V., Pavlova E. Y., Ivanova V. V., Girya E. Y.* Zhokhov Site. P. 211–256; *Pitulko V. V., Ivanova V. V., Kasparov A. K., Pavlova E. Y.* Reconstructing Prey Selection… P. 120–157.

[46] *Pitulko V. V.* Cultural layer in the Stone Age sites of Northeastern Siberia // Vestnik of Saint Petersburg University. History. 2021. Vol. 66 (3). P. 867–889.

[47] See, e. g.: *Velichko A. A., Grekhova L. V., Gubonina Z. P.* Sreda obitaniia pervobytnogo cheloveka Timonovskikh stoianok. Moscow, 1977; *Velichko A. A., Grekhova L. V., Gribchenko Y. N., Kurenkova E. I.* Pervobytnyi chelovek v ekstremal'nykh usloviiakh sredy. Stoianka Eliseevichi. Moscow, 1997; *Vandenberghe J., French H. M., Gorbunov A. et al.* The Last Permafrost Maximum (LPM) map of the Northern Hemisphere: permafrost extent and mean annual air temperatures, 25–17 ka BP // Boreas. 2014. Vol. 43. P. 652–666; *Pitulko V. V., Pavlova E. Y.* Structural Properties of Syngenetic Ice-Rich Permafrost…

[48] *Clark P. U., Dyke A. S., Shakun J. D. et al.* The Last Glacial Maximum // Science. 2009. Vol. 325. P. 710–714.

thermokarst development and denudation processes[49]. The pace of the marine transgression slowed near the Pleistocene-Holocene boundary although the dynamics of this process remain largely unknown.

Thus, a radiocarbon date on mammoth remains collected in Zhokhov Island indicates that the island remained attached to the mainland at 10,120 ± 42 ^{14}C years BP (AAR-20987), or ~11,600 years ago. Based on the study of cores retrieved from the northern lagoon[50], Zhokhov Island has a complex history of fluctuating sea-level changes after the marine transgression that reduced the dry land mass in the area. The connection with the mainland was permanently severed after ~8500 years ago. It is reflected by the abrupt termination of human habitation of the island which is demonstrated by the radiocarbon dates from the archaeological site, as the accumulation of the cultural material ceases after 8500 years ago[51]. At this time, dry land connection to the mainland became ephemeral or fully terminated, and the island was formed.

In any case, 9000 years ago the island was located near the shoreline. This is indicated by the huge number of driftwood fragments found in the culture-bearing deposits of the site, which was used for manufacturing a variety of equipment including parts of sled frames, arrow shafts, and home utensils. In high Arctic areas, driftwood available from accumulations along the shore is the only source of that important material. Environmental indicators from the bird fossils[52] also indicate nearby coastal habitat. Finally, the close proximity of the shoreline is indicated by the mass procurement of polar bear, used as a food resource by the occupants of the Zhokhov site[53]. The specialized hunting of polar bears is unknown anywhere else, as this is the largest terrestrial predator of subaquatic life mode inhabiting coastal marine ecosystems and the polar ice habitat[54].

In addition to a large number of the polar bear bones, the nearly complete absence of bird remains, including marine colonial species and their eggshells, is a salient feature of the faunal remains[55]. They would inevitably be found in large quantity if this resource was available. Bird colonies nowadays inhabit the coastal rocky cliffs in the southeast portion of Zhokhov Island and were absent at the time that humans occupied the island, which means that it was still joined to the mainland.

Late postglacial and Holocene environmental changes in the territory of the New Siberian Islands were driven by two main factors, that is by global climate change and a gradual change in conditions from continental to coastal due to the marine transgression

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49 *Degtyarenko Y.P., Puminov A.P., Blagoveshchenskiy M.G.* Beregovye linii vostochnoarkticheskikh morei v pozdnem pleistotsene i golotsene // Kolebaniya urovnia morei i okeanov za 15 000 let. Moscow, 1982. P. 179–185; *Romanovskii N.N., Gavrilov A.V., Tumskoy V.E. et al.* Environmental Evolution… P. 237–245; *Bauch H.A., Mueller-Lupp T., Spielhagen R.F. et al.* Chronology of the Holocene transgression at the northern Siberian margin // Global and Planetary Change. 2001. Vol. 31. P. 125–139; *Gavrilov A.V., Romanovskii N.N., Hubberten H.-W.* Paleogeographic Scenario… P. 39–50; *Anisimov M.A., Ivanova V.V., Pushina Z.V., Pitulko V.V.* Lagunnye otlozheniia ostrova Zhokhova… P. 107–119.

50 *Anisimov M.A., Ivanova V.V., Pushina Z.V., Pitulko V.V.* Lagunnye otlozheniia ostrova Zhokhova… P. 107–119.

51 *Pitulko V.V., Ivanova V.V., Kasparov A.K., Pavlova E.Y.* Reconstructing Prey Selection… P. 120–157.

52 *Makeyev V.M., Ponomareva D.P., Pitulko V.V., Chernova G.M., Solovyeva D.V.* Vegetation and climate of New Siberian Islands… P. 28–35.

53 *Pitulko V.V.* Zhokhovskaia stoyanka; *Pitulko V.V.* The Bear-Hunters of the Zhokhov Island… P. 141–152.

54 *Kischinskiy A.A.* Belyi medved' // Krupnye khishchniki. Moscow, 1976. P. 154–197; *Belikov S.E.* Belyi medved' // Medvedi: Buryi medved', belyi medved', gimalaiskii medved'. Moscow, 1993. P. 42–478.

55 *Pitulko V.V., Ivanova V.V., Kasparov A.K., Pavlova E.Y.* Reconstructing Prey Selection… P. 120–157.

and reduction in dry land mass. The warmest period on the islands falls in the interval 11,500–10,200 years ago; however, the climate remained significantly warmer than the current one for a long time[56]. Between 9000 and 8000 years ago woody plants spread north beyond their modern limits reaching the position of the present-day arctic shoreline (see: Fig. 1A). Nevertheless, several hundred kilometers south of Zhokhov Island were diverse treeless tundra landscapes.

The interval from 9000 to 7800 years ago is characterized by diverse, but generally favorable conditions for human life, which were significantly better than those of the present day. In the southern part of the New Siberian Islands pollen data indicate a general tendency for the development of vegetation from arctic shrub tundra with sedge-wormwood herbaceous associations to tundra associations with shrub and dwarf shrub vegetation[57]. Despite the scarcity in pollen data for Zhokhov Island, however, it can be noted that at this time, herbaceous, moss-herbaceous and shrub-herbaceous tundra associations with a solid plant cover, in which sedge-grass associations played the main role, grew on the island, with a gradual reduction in diversity and decreasing role of herbaceous plants[58].

Knowledge of Zhokhov Island environments during the period of human occupation has been significantly enhanced by analysis of the site. Thus, among numerous osteological remains yielded by the excavations, there is a small collection of bird bones[59], the most interesting of which are the tundra swan, bean goose, and white-fronted goose. There is no doubt that these birds were caught near the camp in the summer. First of all, this indicates that humans were in the area at least during summer months. In addition, this allows a direct assessment of the environmental conditions in the area based on the integrated ecological characteristics of the habitat of the listed species according to their known recent ecology[60]. The overlap among the three bird habitats provides high resolution environmental indicators.

None of the listed bird species populate the New Siberian Islands at present. The area of their joint habitation occupies a narrow strip of the coastal tundra in the Yana-Indighirka Lowland[61]. Importantly, an extended frostless period spanning about 60 days is the key condition for their nesting. These conditions correspond to the present-day habitat of the inland area of the coastal tundra, where temperature of the warmest month (July) averages + 4–11 °C, while the temperature of the coldest month varies minus 32–38 °C. Annual precipitation in such regions amounts to ~230–300 mm/year[62]; mostly during the summer time. Thus, in the Lena River Delta, where the swan population is constantly observed by the staff of the Ust-Lena State Reserve, it thrives under similar conditions[63]. Winter climates in the vicinity of the Zhokhov site did not change much for 9000 years[64].

56 *Makeyev V. M., Ponomareva D. P., Pitulko V. V., Chernova G. M., Solovyeva D. V.* Vegetation and climate of New Siberian Islands… P. 28–35.

57 Ibid.

58 *Pavlova E. Y., Pitulko V. V.* Late Pleistocene and Early Holocene climate changes… P. 5–25.

59 *Pitulko V. V., Ivanova V. V., Kasparov A. K., Pavlova E. Y.* Reconstructing Prey Selection… P. 120–157.

60 *Makeyev V. M., Ponomareva D. P., Pitulko V. V., Chernova G. M., Solovyeva D. V.* Vegetation and climate of New Siberian Islands… P. 28–35.

61 *Labutin Y. V., Germogenov N. I., Pozdnyakov V. I.* Ptitsy okolovodnykh landshaftov Nizhnei Leny. Novosibirsk, 1988.

62 Atlas Arktiki / ed. by A. F. Treshnikov. Moscow, 1985.

63 *Pozdnyakov V. I.* Status and Breeding Ecology of Bewick's Swans in the Lena Delta, Yakutia, Northern Asia // Waterbirds: The International Journal of Waterbird Biology. 2002. Vol. 25. P. 95–99.

64 *Pavlova E. Y., Ivanova V. V., Meyer H. et al.* Izotopnyi sostav iskopaemykh l'dov… P. 349–351.

Generally, they were similar to those found in present-day Zhokhov Island[65]; however, summer temperature and moisture conditions 9000 years ago, as shown by avian ecological indicators ago were significantly milder.

In sum, early Holocene Zhokhov site environments were quite comfortable for the Arctic regions providing favorable conditions for humans. Open landscapes with dense snow cover were the most important element of their habitat. This facilitated unlimited on-land travel opportunities for the effective movement of people, as well as the long-distance transport of goods, knowledge, and genes[66].

Zhokhov Radiocarbon Date Series: its temporal limits, structure and limitations

Due to permafrost conditions, the Zhokhov site does not lack for datable materials. Rather, the problem concerns the selection of material to date, which requires careful attention to the dating results. Here, we focus on dates obtained from objects and materials directly associated with past human activities. Some of these dates were previously published[67]; however, there also are dates published here for the first time. A set of 102 radiocarbon dates directly related with past human activity are currently available (see: Table).

The sample is large relative to the total sample obtained for Western Beringia, which slightly exceeds 400 published dates[68]; the Zhokhov collection of radiocarbon dates outnumbers even the large sample from the Berelekh geoarchaeological complex[69], the Yana site[70], and some other recently studied arctic Western Beringia archaeological sites with numerous radiocarbon dates[71]. The variety and a number of dates received for the Zhokhov site is explained by the nature of the deposits containing cultural materials that fill the permafrost casts, the need to assess the cultural homogeneity of the complex, and the desire to obtain dates for special research tasks such as the paleo-genetics of humans and non-human species[72]. Overall, the dates provide a reliable chronometry for the cultural context of the Zhokhov site.

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65 Novosibirskie ostrova / ed. by Y. Y. Gakkel. Leningrad, 1967.

66 *Lee E. J., Merriwether D. A., Kasparov A. K. et al.* A genetic perspective of prehistoric hunter-gatherers in the Siberian Arctic: ancient DNA analysis of human remains from 8,000 years ago // Journal of Archaeological Science: Reports. 2018. Vol. 17. P. 943–949; *Pitulko V. V., Kuzmin Y. V., Glascock M. D., Pavlova E. Y., Grebennikov A. V.* 'They come from the ends of the earth'. P. 28–44.

67 *Pitulko V. V.* Zhokhovskaya stoianka; *Pitulko V. V., Pavlova E. Y., Ivanova V. V., Girya E. Y.* Zhokhov Site. P. 211–256; *Pitulko V. V., Pavlova E. Y.* Opyt radiouglerodnogo datirovaniia… P. 27–55.

68 *Pitulko V. V., Pavlova E. Y.* Geoarchaeology and Radiocarbon Chronology of Stone Age Northeast Asia. College Station, 2016.

69 *Pitulko V. V., Basilyan A. E., Pavlova E. Y.* The Berelekh Mammoth Graveyard: New Chronological and Stratigraphical Data from the 2009 field season // Geoarchaeology. 2014. Vol. 29. P. 277–299.

70 *Pitulko V., Nikolskiy P., Basilyan A., Pavlova E.* Human habitation in the Arctic Western Beringia prior the LGM // Paleoamerican Odyssey. College Station, 2013. P. 13–44.

71 *Pitulko V. V., Pavlova E. Y., Basilyan A. E.* Mass accumulations of mammoth (mammoth 'graveyards') with indications of past human activity in the northern Yana-Indighirka lowland, Arctic Siberia // Quaternary International. 2016. Vol. 406. P. 202–217.

72 E. g., *Leathlobhair M. N., Perri A. R., Irving-Pease E. K. et al.* The Evolutionary History of Dogs in the Americas. P. 81–85; *Sinding M.-H. S., Gopalakrishnan S., Ramos-Madrigal J. et al.* Arctic-adapted dogs emerged at Pleistocene-Holocene transition. P. 1495–1499.

Radiocarbon *dates* from the Zhokhov site, obtained using the scintillation and ^{14}C AMS methods

No.	Laboratory code	Raw ^{14}C date BP	Calibrated age, calBP (95.4 % probability)[1]	Location (excavation units, profiles, other)	Sample details[2]	Publication source[3]
1	Beta-190092	8150 ± 40	(15.9 %) 9252–9166 (79.5 %) 9146–9006 9085	C13	P	3
2	Beta-190088	8020 ± 60	9030–8646 8878	EF130	P, with strong fish smell	2
3	Beta-190087	7950 ± 40	8983–8646 8822	C130	Moss from the polar bear skull	2
4	LE-3533	9010 ± 140	10511–9688 10118	"Dwelling structure" 8	W	1
5	LE-4048a	8930 ± 180	10432–9547 10005	Surface find, 1987	W	1
6	LE-6826	8550 ± 50	9604–9465 9526	BC12 unit	W	3
7	LE-6827	8220 ± 40	9304–9028 9186	BC12 unit	W	3
8	GIN-6399	8200 ± 40	9279–9027 9158	B1–B5 profile	W	1
9	LE-6459	8150 ± 30	(3.1 %) 9243–9218 (3.9 %) 9205–9175 (88.4 %) 9138–9009 9076	A4 unit	W	3
10	LE-6814	8150 ± 25	(1.5 %) 9239–9222 (1.8 %) 9199–9179 (92.0 %) 9135–9010 9073	C12 unit	W	3
11	LE-6817	8050 ± 60	(92.0 %) 9126–8715 (0.2 %) 8667–8663 8919	C12 unit	Charred wood	3
12	LE-6818	8050 ± 60	(92.0 %) 9126–8715 (0.2 %) 8667–8663 8919	C12 unit	W	3
13	LE-6816	8030 ± 40	(92.0 %) 9025–8755 (0.2 %) 8732–8729 8899	C120 unti	Charred wood	3
14	LE-6476	8020 ± 35	9014–8768 8890	A2 unit	W	3
15	LU-2499	8020 ± 50	(94.7 %) 9025–8702 (0.7 %) 8669–8658 8882	B1–B5 profile	W	1
16	LE-6821	8010 ± 20	(63.3 %) 9002–8857 (32.1 %) 8835–8777 8884	D130 unit	W	2

No.	Laboratory code	Raw ^{14}C date BP	Calibrated age, calBP (95.4 % probability)[1]	Location (excavation units, profiles, other)	Sample details[2]	Publication source[3]
17	LE-6475	8000 ± 140	(92.0 %) 9292–8537 (0.2 %) 8539–8521 8867	EF120 unit	W	2
18	LE-6823	7990 ± 20	8994–8774 8880	C130 unit	W	2
19	LE-6828	7960 ± 60	9009–8648 8826	CB12 unit	W	3
20	LE-6815	7960 ± 25	8998–8762 8851	C12 unit	W	3
21	LE-6825	7960 ± 25	8998–8762 8851	DE130 unit	W	2
22	LE-6832	7940 ± 30	(41.8 %) 8979–8824 (53.6 %) 8813–8642 8786	GF12 unit	W	3
23	Beta-173068	7920 ± 40	(19.8 %) 8978–8879 (10.8 %) 8870–8826 (64.8 %) 8810–8607 8749	E14 unit	W	3
24	LE-6830	7920 ± 30	(15.5 %) 8977–8881 (9.6 %) 8869–8827 (69.2 %) 8798–8626 (1.1 %) 8620–8609 8735	G140 unit	Charred wood	3
25	LE-3535	7910 ± 180	9263–8391 8783	“Dwelling structure” 9	W	1
26	LE-4534б	7890 ± 150	9124–8405 8752	Surface find, 1987	W	1
27	LE-4048б	7880 ± 180	(2.6 %) 9253–9164 (92.8 %) 9150–8375 8751	Surface find, 1987	W	1
28	LU-2432	7870 ± 60	(12.1 %) 8978–8879 (6.6 %) 8870–8826 (76.7 %) 8810–8545 Median 8691	B1–B5 profile	W	1
29	LE-6822	7860 ± 50	(4.7 %) 8973–8915 (0.9 %) 8897–8884 (3.8 %) 8865–8829 (86.0 %) 8791–8543 8662	EF130 unit	W	2
30	LE-2433	7860 ± 40	(0.6 %) 8933–8922 (1.8 %) 8860–8834 (93.0 %) 8779–8546 8645	B1–B5 profile	W	1
31	LE-6466	7810 ± 25	8632–8545 8586	A4 unit	W	–

No.	Laboratory code	Raw ¹⁴C date BP	Calibrated age, calBP (95.4 % probability)[1]	Location (excavation units, profiles, other)	Sample details[2]	Publication source[3]
32	LE-3532	7640 ± 55	8546–8366 8439	"Dwelling structure" 7	W	1
33	LE-6824	7610 ± 30	8449–8372 8404	D130 unit	W	2
34	LE-3531	7520 ± 150	8601–8011 8323	"Dwelling structure" 6	W	1
35	LE-6820	7480 ± 40	8378–8199 8304	CD130 unit	W	2
36	LE-4534a	7450 ± 220	(0.2 %) 8849–8839 (95.0 %) 8775–7821 (0.2 %) 7810–7796 8266	Surface find, 1987	W	1
37	LE-6460	7385 ± 25	8316–8165 8210	A20 unit, 1990	W	3
38	Beta-216806	8200 ± 40	9279–9027 9158	Aa140 unit	large basket	3
39	Beta-177033	8040 ± 50	(2.5 %) 9086–9050 (92.9 %) 9034–8719 8905	BA13 unit	wooden container fragment	3
40	Beta-177034	8030 ± 50	(94.8 %) 9031–8702 (0.6 %) 8669–8658 8892	E12 unit	wooden container fragment	3
41	Beta-177030	8030 ± 50	(94.8 %) 9031–8702 (0.6 %) 8669–8658 8892	A13 unit	stick with a shaped head and a chopped off end, wood	3
42	Beta-177031	8020 ± 50	(94.7 %) 9025–8702 (0.7 %) 8669–8658 8882	C14 unit	stick with a shaped head, perpendicular cut and a chopped off end	3
43	Beta-177026	8000 ± 60	9013–8649 8861	DE120 unit	Sled runner with driller holes and little wear, wood	3
44	Beta-177025	7990 ± 60	9009–8648 8852	DE12 unit	Sled runner, heavily worn, wood	3
45	Beta-177027	7970 ± 60	9000–8640 8835	BC12 unit	preform (?) of a tool used to bend the runners (?), no wear from running. wood	3

No.	Laboratory code	Raw ^{14}C date BP	Calibrated age, calBP (95.4 % probability)[1]	Location (excavation units, profiles, other)	Sample details[2]	Publication source[3]
46	Beta-173069	7970 ± 40	(91.8 %) 8996–8696 (3.6 %) 8675–8650 8849	E14 unit	birch bark box (?)	3
47	Beta-177024	7960 ± 50	8992–8646 8831	Aa130 unit	shaft of an arrow or drill	2
48	Beta-177028	7940 ± 60	(94.8 %) 8992–8627 (0.6 %) 8615–8610 8799	Aa13 unit	Sled upright (frame part), wood	3
49	Beta-177029	7910 ± 50	(19.4 %) 8978–8878 (10.3 % 8872–8825 (65.7 %) 8812–8598 8743	Pp22 unit	Sled upright (frame part), wood	3
50	Beta-177032	7890 ± 40	(7.1 %) 8975–8911 (1.6 %) 8900–8882 (5.8 %) 8868–8827 (80.9 %) 8795–8590 8696	E110 unit	Wooden container / dish fragment	3
51	LE-3527	8563 ± 180	(93.8 %) 10158–9200 (1.65 %) 9180–9138 9596	B12 unit	charcoal	1
52	Beta-173074	8210 ± 50	(0.7 %) 9395–9386 (0.6 %) 9371–9363 (94.1 %) 9307–9020 9175	EF120 unit	Charcoal	2
53	Beta-173073	8060 ± 60	(95.1 %) 9132–8704 (0.3 %) 8668–8660 8953	A30 unit	Charcoal	3
54	Beta-173072	8050 ± 40	(1.8 %) 9078–9055 (93.6 %) 9033-8772 8952	EF120 unit	Charcoal	2
55	Beta-173075	7980 ± 40	(93.6 %) 8999–8700 (1.8 %) 8671–8656 8859	EF110 unit	Charcoal	2
56	Beta-173071	7920 ± 40	(19.8 %) 8978–8879 (10.8 %) 8870–8826 (64.8 %) 8810–8607 8749	A3 unit	Charcoal	3
57	LE-3536	8610 ± 220	10222–9132 9672	"Dwelling structure" 13	Reindeer antler	1
58	Beta-177017	8110 ± 40	(1.4 %) 9242–9220 (1.8 %) 9204–9176 (92.3 %) 9137–8984 9052	Pp23 unit	Reindeer bone fragment	3
59	LE-3529	8050 ± 70	9130–8647 8917	Eastern part of the excavation, 1990	Reindeer bone fragments	1

No.	Laboratory code	Raw ^{14}C date BP	Calibrated age, calBP (95.4 % probability)[1]	Location (excavation units, profiles, other)	Sample details[2]	Publication source[3]
60	Beta-231441	7980 ± 40	(93.6 %) 8999–8700 (1.8 %) 8671–8656 8859	BC12 unit	Reindeer bone (right humerus bone)	3
61	Beta-177018	7960 ± 40	(89.7 %) 8990–8694 (0.5 %) 8687–8684 (5.2 %) 8677–8649 8837	AB13 unit	Reindeer bone	3
62	GIN-13183	7940 ± 120	(0.8 %) 9122–9100 (93.5 %) 9094–8511 (0.8 %) 8497–8476 (0.3 %) 8469–8460 8800	D12 unit	Red deer antler	3
63	LE-4533b	7940 ± 170	9264–8416 8813	Surface find, 1987	Reindeer bone fragments	1
64	GIN-6400	7930 ± 40	8981–8631 8769	B1–B5 profile	Reindeer bone fragments	1
65	Beta-216805	7850 ± 40	(0.3 %) 8846–8840 (95.1 %) 8775–8543 8631	Ll220 unit	Elk bone	3
66	Beta-177022	7830 ± 40	(95.1 %) 8761–8538 (0.3 %) 8527–8523 8608	Iii260 unit	Reindeer bone	3
67	LE-3534	7810 ± 180	(94.5 %) 9130–8301 (0.9 %) 8257–8214 8670	"Dwelling structure" 9	Reindeer bone fragments	1
68	LE-3528	8740 ± 90	(8.1 %) 10148–10058 (3.7 %) 10041–9988 (83.7 %) 9956–9541 9761	Western part of the excavation, 1989	Polar bear bone fragments	1
69	Beta-177021	8680 ± 40	9736–9542 9622	Ggg28 unit	Polar bear bone	3
70	Beta-231442	8680 ± 40	9736–9542 9622	Iii28 unit	Polar bear bone (left ulna)	3
71	Beta-177016	8650 ± 40	9690–9537 9598	Pp23 unit	Polar bear bone	3
72	Beta-177023	8640 ± 70	(0.5 %) 9885–9877 (1.1 %) 9866–9848 (0.7 %) 9817–9805 (93.1 %) 9795–9495 9618	AB13 unit	Polar bear bone	3
73	Beta-177020	8500 ± 80	9629–9304 9496	Oo20 unit	Polar bear bone	3
74	Beta-177019	8440 ± 40	9531–9406 9473	C14 unit	Polar bear bone	3

No.	Laboratory code	Raw ^{14}C date BP	Calibrated age, calBP (95.4 % probability)[1]	Location (excavation units, profiles, other)	Sample details[2]	Publication source[3]
75	Beta-190086	8910 ± 50	(93.5 %) 10204–9887 (0.2 %) 9873–9869 (1.2 %) 9843–9818 (0.5 %) 9805–9795 10035	Oo22 unit	Dog bone	3
76	Beta-231448	8710 ± 50	(4.8 %) 9887–9544 (90.6 %) 9831–9546 9665	CD13 unit	Dog bone	3
77	MAMS 24239	8529±30	(95.4 %) 9543–9486 9519	C14 unit	Dog bone	4
78	MAMS 24242	8477±29	(95.4 %) 9533–9463 9498	Kk200 unit	Dog bone	4
79	MAMS 24240	8170±30	(20.1 %) 9253–9166 (75.3 %) 9145–9018 9099	E9 unit	Dog bone	4
80	MAMS 24235	8026±30	(67.5 %) 9013–8851 (27.9 %) 8838–8776 8901	Nn190 unit	Dog bone	4
81	MAMS 24237	7998±29	(95.2 %) 9005–8761 (0.2 %) 8732–8729 8879	D11 unit	Dog bone	4
82	MAMS 24238	7975±28	(95.4 %) 8995–8716 8867	Fff260 unit	Dog bone	4
83	MAMS 24241	7971±29	(95.0 %) 8994–8705 (0.5 %) 8667–8662 8861	surface find	Dog bone	4
84	MAMS 24236	7791±29	(93.3 %) 8633–8516 (2.2 %) 8494–8480 8571	Nn220 unit	Dog bone	4
85	Beta-190095	8520 ± 50	9551–9454 9511	C12 unit	DF, dog feces (preserved hair was dated)	3
86	Beta-173076	8270 ± 40	9415–9127 9267	A3 unit	DF, dog feces (preserved hair was dated)	3
87	Beta-190094	8190 ± 40	9269–9024 9137	BC12 unit	DF, dog feces (preserved hair was dated)	3
88	Beta-190093	7960 ± 40	(89.7 %) 8990–8694 (0.5 %) 8687–8684 (5.2 %) 8677–8649 8837	C12 unit	RF, mouse feces	3
89	Beta-190106	8640 ± 40	9685–9535 9591	Pp200 unit	human metacarpal	3

No.	Laboratory code	Raw ^{14}C date BP	Calibrated age, calBP (95.4 % probability)[1]	Location (excavation units, profiles, other)	Sample details[2]	Publication source[3]
90	Beta-190105	8350 ± 40	9471–9277 9374	Oo23 unit	human metacarpal	3
91	Beta-190098	8260 ± 40	(94.5 %) 9410–9120 (0.9 %) 9103–9093 9246	C130 unit	Human radius	3
92	Beta-204878	8110 ± 40	(1.4 %) 9242–9220 (1.8 %) 9204–9176 (92.3 %) 9137–8984 9052	Nn220 unit	Human skull fragment (NN220-2)	3
93	Beta-204877	8060 ± 40	(6.0 %) 9089–9045 (72.2 %) 9037–8848 (17.2 %) 8840–8775 8989	Nn220 unit	Human skull fragment (NN220-1)	3
94	Beta-190100	8050 ± 50	(94.3 %) 9091–8746 (1.1 %) 8741–8725 8927	C130 R1 unit	Human rib	3
95	Beta-190108	7980 ± 40	(93.6 %) 8999–8700 (1.8 %) 8671–8656 8859	Nn23 unit	human ulna	3
96	Beta-190104	7970 ± 40	(91.8 %) 8996–8696 (3.6 %) 8675–8650 8849	Nn200 unit	Human rib	3
97	Beta-190107	7960 ± 40	(89.7 %) 8990–8694 (0.5 %) 8687–8684 (5.2 %) 8677–8649 8837	Pp240 unit	Fragmented diaphysis of the human bone	3
98	Beta-190103	7950 ± 40	8983–8646 8822	DE140 unit	Human rib	3
99	Beta-190101	7900 ± 60	8981–8591 8738	C130 R2 unit	Human rib	3
100	Beta-190102	7900 ± 40	(9.5 %) 8976–8910 (2.2 %) 8901–8882 (7.3 %) 8868–8827 (76.3 %) 8796–8595 8712	C130 unit	Human rib	3
101	Beta-190099	7830 ± 40	(95.1 %) 8761–8538 (0.3 %) 8527–8523 8608	C130 unit	Human rib	3
102	Beta-204879	7830 ± 40	(95.1 %) 8761–8538 (0.3 %) 8527–8523 8608	Nn23 unit	human humerus bone	3

Notes: [1] Calibrations are given based on OxCal v4.3 [Ramsey, 2017] with IntCal13 atmospheric curve [Reimer et al., 2013].

[2] Code for dated material: P — plant remains; W — wood; C — wood charcoal; B — bone; DF — dog feces; RF — small rodent feces.

[3] Sources: 1 — from [Pitulko, 1998], with additions; 2 — from [Pitulko et al., 2012]; 3 — from [Pitulko, Pavlova, 2015]; 4 — from [Leathlobhair et al., 2018].

The pattern of the radiocarbon dataset requires discussion. It includes several large groups of ^{14}C age values obtained from various materials, including:

- wood (in the broad sense of the word, that includes age determinations for birch-bark artifacts and basketry, n = 47, see Table for details; the dated wood samples are not simply wood remains but humanly-modified pieces, artefacts or wastes, as they retain the evidence of modification);
- charcoal (n = 6);
- bone remains of ungulates, mostly reindeer (n = 11), polar bear (n = 7), dogs (n = 10);
- human bone remains (n = 14).

In addition, the selection includes ^{14}C dates obtained from moss balls and other plant remains (n = 3), conterminous to human activities and buried within the site deposits with cultural remains, as well as the results of dating some unique substances, namely, excrement of dogs (n = 3) and that of a small rodent (n = 1) (Fig. 5, see: Table). Although all these materials yield reasonably authentic dates, in some cases the dating results must be used with caution.

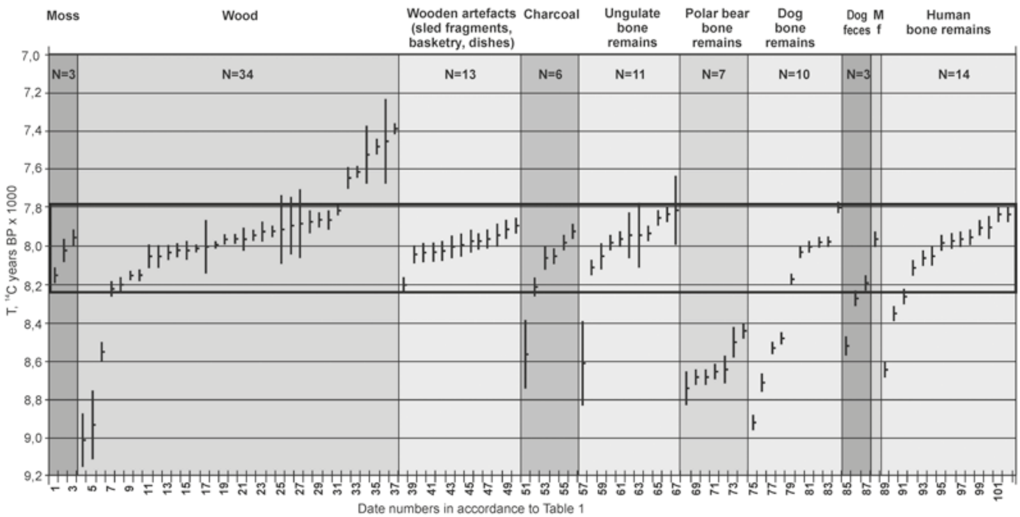

Fig. 5. Summary of the sample of ^{14}C dates (n = 102) from the Zhokhov site obtained on various organic materials. Modified from [Pitulko, Pavlova, 2015]

These subsamples of the age values are plotted in Fig. 5. Within each subsample, they are shown left to right in the order of decreasing ^{14}C age values: from older to younger dates which allows us to see the trend. The dates on wood, wooden artifacts, charcoal, and ungulate bone remains (mostly represented by reindeer) show a clear tendency to concentrate between 8250 and 7800 radiocarbon years BP. Dates obtained from bone remains of a polar bear, dogs (from bones and excrement), and, to some extent, from human remains, yield a different picture with ages older than 8250 ^{14}C years BP (see: Fig. 5). Despite the shift their sequence exhibits the same graphic pattern.

There are obvious preconditions which should be considered. We begin with the series obtained from wood remains and charcoal. Any piece of wood (splinter, fragment, or another item some way modified) from the Zhokhov site is an artifact, because its presence in the deposit is a result of human activity (i. e., was brought and used there). At the time of site occupation, there was no woody vegetation in its vicinity, and the early Holocene tree line was located at approximately the latitude of the current continental coast, hundreds of kilometers to the south (see: Fig. 1A). Only tree and shrubs species, including big alder stands on Kotelny Island[73] were growing on the large southern islands of the current New Siberian Archipelago, and thus, the overwhelming majority of wood remains at the site represent driftwood accumulating at the shoreline near the hunting camp on Zhokhov Island[74].

The age of wood fragments (manufacturing waste) and charcoal may differ therefore from the true age of the site (i. e., be somewhat older), since ^{14}C dating establishes the age of tree death marked by the end of isotope exchange. Besides, any tree has its individual age, which can reach or exceed ~100 years even at the tree line. On top of that, at some unknown date, a tree trunk that had been transported by a river flowing to the ocean or into the river's tributary, was moved from its original location to the coast where it was found by people and brought to the site. The last time interval has to be relatively short, because presumably the least damaged driftwood trunks were used; however, together, these error sources may produce a value significantly different from the actual time of site occupation. In absolute terms, it might be significant, reaching thousands of years (see: Fig. 5). For example, dates No. 4–6 and 51 (see: Fig. 5, Table) probably should be ignored as unrelated to the site age estimate, albeit they are related to human activities at the Zhokhov site. Alternatively, they may indicate the earliest occupation in the island area, given the evidence for human presence in the northern part of the New Siberian Island some 150 km south[75], which dates older than 8500 radiocarbon years before present.

It might appear that the grouping of ^{14}C age values obtained from faunal remains of polar bear, dog, and, to some extent, human (see: Fig. 5) supports the validity of older dates obtained from wood samples. However, this is not true, because the age of the samples obtained from the above-mentioned materials reflects inherent bias in the dating of the material (see below).

The samples providing the youngest group of ^{14}C ages are obtained exclusively from wood fragments (see: Fig. 5, Table, dates No. 32–37). These dates are not consistent with the series obtained from other materials (see: Fig. 5) and may thus be excluded from further consideration as possibly invalid due to error caused by some past bacterial contamination. Alternatively, these dates may represent the traces of occasional human visits to the area after the active use of the Zhokhov Island area ceased and a human presence became ephemeral.

Exceptionally interesting are the dates obtained from bone remains of polar bear, dog, and human (see: Fig. 5, Table). They present a special case, since their ages are often

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[73] *Makeyev V. M., Arslanov K. A., Baranovskaya O. F. et al.* Stratigrafiia, geokhronologiia i paleogeografiia pozdnego pleistotsena i golotsena o-va Kotelnyi // Biulleten' Komissii po izucheniiu chenvertichnogo perioda. 1989. No. 58. P. 58–69; *Makeyev V. M., Ponomareva D. P., Pitulko V. V. et al.* Vegetation and climate of New Siberian Islands… P. 28–35.

[74] *Pitulko V. V.* Zhokhovskaia stoianka.

[75] *Pavlova E. Y., Pitulko V. V.* Late Pleistocene and Early Holocene climate changes… P. 5–25.

older than the lower temporal limit of the occupation history of the site (see: Fig. 5). These deviations are easy to understand when the peculiarities of the trophic chains defining the biochemistry of these species are taken into account.

The diet of polar bears, the largest terrestrial carnivore with a semi-aquatic lifestyle, is associated with the consumption of sea mammal meats; primarily, they subsist on circum-Arctic ringed seal. In the absence of humans, this carnivore is the top predator, consuming various maritime bioresources with subsequent acquisition and accumulation of "old" carbon in the tissues, which leads to age distortion due to the marine reservoir effect[76]. Humans, in turn, take the top of the top of the trophic chain, and thus distortion of the true age of human bone samples should be expected.

As demonstrated long ago, the reservoir effect to radiocarbon age values can be estimated using the stable carbon and nitrogen isotope composition of the dated faunal remains[77]. These methods are widely known and applied to the study of diets in various human populations[78]. In some cases, reindeer remains that represent ancient hunting prey, provide useful control values[79].

When assuming the super carnivore food niche, humans acquire "old" carbon of marine origin previously accumulated by the polar bears, who inherited it from the seals. Based on the species representation of the osteological remains, the polar bear contribution to the diet of the Zhokhov site population was significant[80]. However, of no less importance was another major food resource — reindeer, a species completely tied to the terrestrial biome. Dog diets utilize food leftovers provided by humans, thus largely mirror the human diet. Consequently, sample age distortion towards older dates can be expected in dogs, too.

This may be seen from Fig. 6 which shows the compositions of stable isotopes in bone remains of the site's human population, their companions, and prey. The graph uses values of $\delta^{13}C$, i. e., values of isotope fractioning ($^{13}C/^{14}C$ ratios) in parts per thousand, relative to the V-PDB standard. Values of $\delta^{15}N$ were calculated the same way[81].

The stable isotope composition of the human and dog bone remains from the Zhokhov site resulted from their consumption of both the marine and terrestrial trophic chains, and plots between the terrestrial and the highest maritime feeding structures (see: Fig. 6). The remains of reindeer and polar bears obtained by the site inhabitants, and the opportunity to control dating terrestrial organisms with dates on wood samples allowed us

[76] *Wagner G. A.:* 1) Age Determination of Young Rocks and Artifacts: Physical and Chemical Clocks in Quaternary Geology and Archaeology (Natural Science in Archaeology). Berlin; Heidelberg, 1998; 2) Nauchnye metody datirovaniia v geologii, arkheologii i istorii. Moscow, 2006.

[77] *DeNiro M. J.* Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to paleodietary reconstruction // Nature. 1985. Vol. 317. P. 806–809.

[78] See, e. g.: *Schoeninger M. J.* Stable isotope evidence in human evolution // Evolutionary Anthropology. 1995. Vol. 4. P. 83–98; *Byers D. A., Yesner D. R., Broughton J. M., Coltrain J. B.* Stable isotope chemistry, population histories and Late Prehistoric subsistence change in the Aleutian Islands // Journal of Archaeological Science. 2011. Vol. 38. P. 183–196; *Kuzmin Y. V., Richards M. P., Yoneda M.* Palaeodietary Patterning and Radiocarbon Dating of Neolithic Populations in the Primorye Province, Russian Far East // Ancient Biomolecules. 2002. Vol. 4 (2). P. 53–58; *Kuzmin Y., Panov V., Gasilin V., Batarshev S.* Paleodietary Patterns of the Cherepakha 13 Site Population (Early Iron Age) in Primorye (Maritime) Province, Russian Far East, based on Stable Isotope Analysis // Radiocarbon. 2018. Vol. 60 (5). P. 1611–1620.

[79] *Coltrain J. B., Hayes M. G., O'Rourke D. H.* Sealing, whaling and caribou: the skeletal isotope chemistry of Eastern Arctic foragers // Journal of Archaeological Science. 2004. Vol. 31. P. 39–57.

[80] *Pitulko V. V., Ivanova V. V., Kasparov A. K., Pavlova E. Y.* Reconstructing Prey Selection… P. 120–157.

[81] *Coltrain J. B., Hayes M. G., O'Rourke D. H.* Sealing, whaling and caribou. P. 39–57.

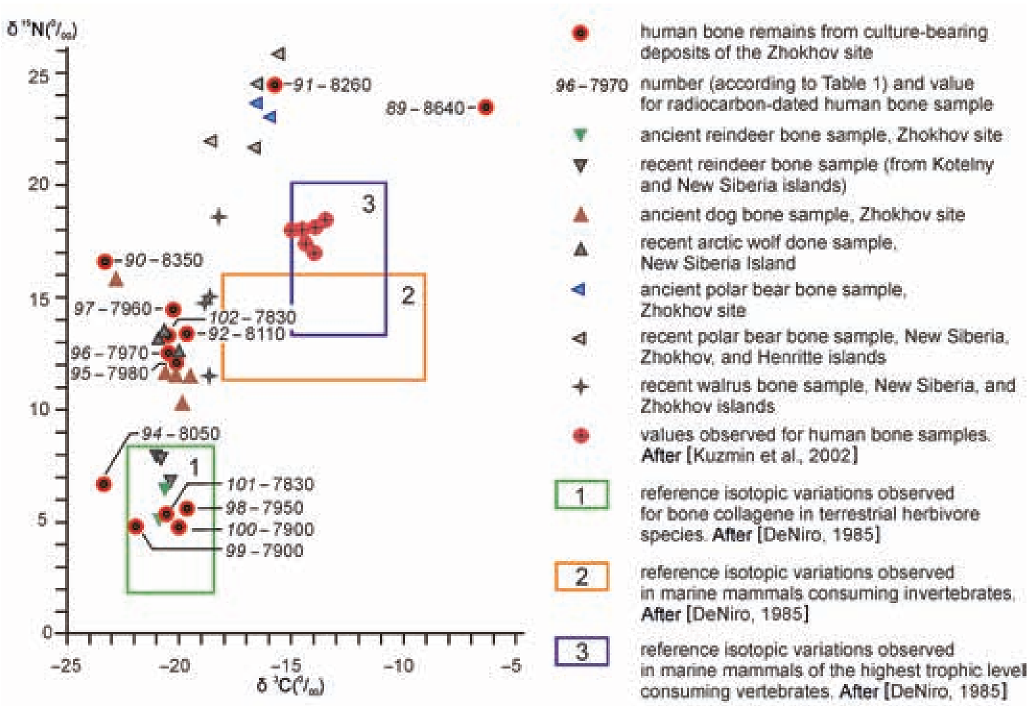

Fig. 6. Ratios of δ^{13}C and δ^{15}N (‰) for prehistoric faunal remains of humans, reindeer, dog, polar bear and for contemporary faunal remains of polar wolf, polar bear, and walrus. Modified from [Pitulko, Pavlova, 2015]

to estimate the marine reservoir effect (ΔR) for the area of De Long islands. Based on average age values of "terrestrial" and "maritime" samples, the ΔR value in the Zhokhov site samples may be considered about 400 years, but needs to be further explored due to the species-specific variations[82] and also to search for reliable grounds for geological age corrections of the human remains as well as for a clearer picture of paleodietary patterns[83].

This average estimate appears quite close to the value of ΔR = 451 years found by Bauch et al.[84] for the Laptev Sea area by comparative dating of bivalve shells, which testifies to its stability in space and time. Unfortunately, values measured for anthropological remains cannot be simply "adjusted" by 451 years, since the extent to which every specific sample has to be adjusted remains unknown. It would only be possible if the human diet had been exclusively maritime, which was clearly not the case as the Zhokhov site occupants, depending on season of the year, made heavy use of reindeer as well[85].

82 *Dury J., Eriksson G., Savinetsky A. et al.* Species-specific reservoir effect estimates: A case study of archaeological marine samples from the Bering Strait // The Holocene. 2021. Article 095968362110417.

83 See, e. g.: *Kuzmin Y., Panov V., Gasilin V., Batarshev S.* Paleodietary Patterns of the Cherepakha 13 Site Population… P. 1611–1620; *West D., Khasanov B., Krylovich O. et al.* Refining the Paleo-Aleut to Neo-Aleut transition using a new ΔR for the eastern Aleutian Islands, Alaska // Quaternary Research. 2019. Vol. 91 (3). P. 972–982; *Dury J., Eriksson G., Savinetsky A. et al.* Species-specific reservoir effect estimates.

84 *Bauch H. A., Mueller-Lupp T., Spielhagen R. F. et al.* Chronology of the Holocene transgression at the northern Siberian margin. P. 125–139.

85 *Pitulko V. V., Kasparov A. K.* Ancient Arctic hunters: material culture and survival strategy. P. 1–36; *Pitulko V. V., Ivanova V. V., Kasparov A. K., Pavlova E. Y.* Reconstructing Prey Selection… P. 120–157.

Dates from human remains clearly are distorted by the reservoir effect to varying degree. They contain values both close to the mean (around 7900 ^{14}C years BP) and significantly older (see: Figs 5, 6; Table). They correspond to varying composition of nitrogen and carbon isotopes. The observed difference may testify primarily to the biological age of the individual[86], but also to gender and status difference in individual diets[87].

Thus, we assume that the most accurate dates have been obtained from bone remains of people's terrestrial hunting prey: reindeer, red deer (?), and moose (see: Fig. 5; Table). But, most probably, even these species are not completely free from the reservoir effect due to their coastal lowland habitat, where they may feed on coastal wetland meadow vegetation in search of salt licks, mushrooms, and seaweed from the beach.

It is known for the Southern Hemisphere that due to evaporation of the ocean water containing "old" carbon, the local composition of atmospheric carbon changes, and wood samples systematically appear 30 years older than their true age[88]. Something similar may happen to carbon isotope compositions in reindeer remains by virtue of the feeding pattern in maritime areas; however, such error in our case is insignificant. Consequently, the ^{14}C age of reindeer remains obtained by the Zhokhov site inhabitants, can serve as a reliable reference point for estimating validity of other dates in the series.

The age of one of the reindeer dates, No. 57, is significantly older than the rest of the samples in the series. However, this date was obtained from a reindeer antler sample, which explains the nature of the deviation because reindeer antlers, a material highly valued for manufacturing hunting and other tools, were an object of gathering. The overwhelming majority of antlers from the excavation had been shed[89]. Gathering this material was a necessity because the site inhabitants hunted reindeer mainly in spring and summer[90] when antlers are not firm enough to work on. At the same time, this date overlaps with a subsample of 'abnormally' old dates obtained on wood. Together, they may represent an ephemeral habitation episode.

The bones of Pleistocene mammals, primarily of mammoth also were an important source of raw material widely used by Zhokhov settlers for manufacturing various tools[91]. Similar to reindeer antlers, mammoth tusks and long bones were available in the Zhokhov island area and might have been collected from the exposures along the eroding shoreline. Dating of the mammoth ivory artifacts yielded by the excavations of the site shows that this material can provide virtually any date, and these dates have no correlation with the human occupation event(s) at Zhokhov Island. For instance, there are dates

86 *Prowse T. L., Schwarcz H. P., Saunders S. R., Macchiarelli R., Bondioli L.* Isotopic evidence for age-related variation in diet from Isola Sacra, Italy // American Journal of Physical Anthropology. 2005. Vol. 128. P. 2–13.

87 See, e. g.: *Ambrose S. H., Buikstra J., Krueger H. W.* Status and gender differences in diet at Mound 72, Cahokia, revealed by isotopic analysis of bone // Journal of Anthropological Archaeology. 2003. Vol. 22. P. 217–226; *Reitsema L. J., Vercellott G.* Stable Isotope Evidence for Sex- and Status-Based Variations in Diet and Life History at Medieval Trino Vercellese, Italy // American Journal of Physical Anthropology. 2012. Vol. 148. P. 589–600; *Yoder C.* Let them eat cake? Status-based differences in diet in medieval Denmark // Journal of Archaeological Science. 2012. Vol. 39. P. 1183–1193.

88 *Lerman J. C., Mook W. G., Vogel J. C.* ^{14}C in tree rings from different localities // Radiocarbon variation and absolute chronology. Ahquist: Wicksell: Uppsala, 1970.

89 *Pitulko V. V.* Zhokhovskaia stoianka.

90 *Pitulko V. V., Ivanova V. V., Kasparov A. K., Pavlova E. Y.* Reconstructing Prey Selection… P. 120–157.

91 *Pitulko V. V.* Zhokhovskaia stoianka.

≥37,100 years ago (AA-22593) and ≥36,500 years ago (AA-22594) reported by Sher et al.[92] Another date recently obtained for a tusk fragment collected at the site produced an age of 10,120 ± 42 ^{14}C years BP (AAR-20987), which corresponds to the time of decline of the local mammoth population soon after 10,000 years ago[93]. Two mammoth ivory artifacts discovered in the New Siberian Islands also produced similar ages[94], that is, 10,340 ± 40 (Beta-514073). For this reason, Zhokhov archaeological specimens produced from mammoth-related material, or potentially made of any Pleistocene osseous materials have not been used for dating the cultural context of the Zhokhov site.

Thus, the age of the Zhokov cultural remains is reliably determined by the series of ^{14}C dates between 8400 and 7750 ^{14}C years ago (see: Fig. 5), obtained from various materials directly related to past human activities (wood and wooden implements, ungulate bone remains, direct dates from artifacts). As discussed above, direct dates from human remains are somewhat older due to the marine reservoir effect. Considering ΔR = 451 years, the age values for anthropological remains fall in the 8400–7750 ^{14}C years ago interval.

Even for the early Holocene Stone Age sites, the established time range is a relatively short period of occupation, which saw no archaeologically visible changes, as reflected in the site assemblage. Here we should emphasize that the anthropological remains[95] found during the Zhokhov Site excavations can definitely be correlated with its material culture. This conclusion is an important indirect result of site's ^{14}C dataset analysis.

Length of the occupation interval and its inner structure

We analyzed the set of radiocarbon dates from the Zhokhov site, rejected some age determinations as inaccurate, and explained the nature of the age discrepancy in samples from polar bear, dogs, and humans. Based on the most reliable sets of dates, we determined the length of the site occupation as 8300–7750 ^{14}C years BP.

In a geological sense, it is but an instant; however, as archaeologists we want to understand if the site was continuously inhabited or if the established interval contained separate peopling episodes. This issue is of great importance for a number of Paleolithic settlements, especially in cases when such episodes are stratigraphically indivisible. The Zhokhov site appears ideal in this sense, because its cultural deposits were transformed into culture-bearing facies filling the ice- wedge casts. Therefore, the internal chronology of the occupation history can be estimated only on the basis of ^{14}C dating series.

Based on this assumption, we further analyzed the Zhokhov radiocarbon dataset to determine if any short habitation episodes took place within the overall span of occupation. To identify them, all dates with large standard deviation values (specifically, all dates with sigma of 120–220 years) were excluded from the sample. The latter include 6 dates

[92] *Sher A. V., Kuzmina S. A., Kuznetsova T. V., Sulerzhitsky L. D.* New insights into the Weichselian environment and climate of the East Siberian Arctic, derived from fossil insects, plants, and mammals // Quaternary Science Reviews. 2005. Vol. 24. P. 533–569.

[93] *Nikolskiy P. A., Sulerzhitsky L. D., Pitulko V. V.* Last straw versus Blitzkrieg overkill: Climate-driven changes in the Arctic Siberia mammoth population and the Late Pleistocene extinction problem // Quaternary Science Reviews. 2011. Vol. 30. P. 2309–2328.

[94] *Pavlova E. Y., Pitulko V. V.* Late Pleistocene and Early Holocene climate changes… P. 5–25.

[95] *Pitulko V. V., Khartanovich V. I., Timoshin V. B. et al.* The oldest anthropological finds of the High Arctic (Zhokhov site, New Siberian Islands) // Ural Historical Journal. 2015b. Vol. 2 (47). P. 62–73.

obtained on wood samples and 3 produced by ungulate bone samples. All of these dates are standard conventional dates obtained with the liquid scintillation method during in the 1990s. Next, dates older than 8400 radiocarbon years BP were also excluded from the sample for the following reasons: thus, wood (n = 1), charcoal (n = 1), and reindeer antler sample (n = 1) can be potentially not consistent with the immediate time of human habitation (see above); and furthermore, ages produced by the polar bear bones (n = 7), dog bones (n = 4), human bones (n = 1) and dog coprolites (n = 2) are not the true ages relevant to human habitation as they are distorted by the marine reservoir effect (see above, and see also: Figs 5, 6, 7F-H). Thus, 74 dates falling within the interval 8400–7400 radiocarbon years BP were further analyzed to identify shorter occupation episodes.

For this purpose, simple research procedures were followed. First of all, it should be noticed that the standard deviation of a sample ^{14}C age ($T_{yrs} \pm 1\sigma$) is an interval with equally probable upper and lower margins. Because we are looking for relatively short episodes of human presence at the site (see: Fig. 5), it makes sense to use the upper and lower limits of the standard deviation of each date. This approach also allows us to double the sample.

For each set of dates obtained from a specific material, we graphed the marginal values of the sample age (T) within the time frame of 9000–7200 radiocarbon years BP (Fig. 7). On the y-axis are the minimal age values ($T - 1\sigma$); on the x-axis are the maximal age values ($T + 1\sigma$). We used all dates on all materials, including those with values distorted by the marine reservoir effect. In this context, the latter is of no importance, because in these cases on one hand, some dates have relatively small upper and lower limits (e. g., on wooden artifacts) and on the other hand, many dated materials exhibit wide marginal values (polar bear, dog).

The combined values are presented in Fig. 8, including a summary graph (see: Fig. 8A). These graphs were constructed identically to the Fig. 7 graphs. We excluded as inauthentic the values outside the site occupation interval, defined by the dated reindeer bone remains, which can be considered the control group, as well as direct dates on the artifacts made from materials whose age, with a high degree of probability, completely matches the time of human occupation (wooden utensils, basket, birch-bark articles, sled fragments).

In order to eliminate the noise emerging from the juxtaposition of graphs of results from dating a variety of materials, after excluding inauthentic values, the time range was narrowed to 8300–7750 radiocarbon years BP. We created graphs for maximal and minimal values graphs of various dated materials (see: Figs 8B, 8C). We also created a graph of maximal and minimal value distribution within the time range of 8400–7400 radiocarbon years BP with the bin width of 25 years (see: Fig. 8D). It is apparent that, even on the summary graph, which combines all possible dates within the time frame of 8300–7750 years ago (see: Fig. 8A), three clusters are observable: the "ancient", the "middle", and the "young." The "middle" cluster is formed by two merging intervals. This pattern is especially clear if all age values obtained from anthropological remains and wooden artifacts are excluded (see: Fig. 8B).

Comparison of human dates with those from wooden artifacts (see: Fig. 8C) shows that the ages of the anthropological remains overlap slightly with the direct dates from artifacts. The age of human bone remains is somewhat biased towards older dates. This is

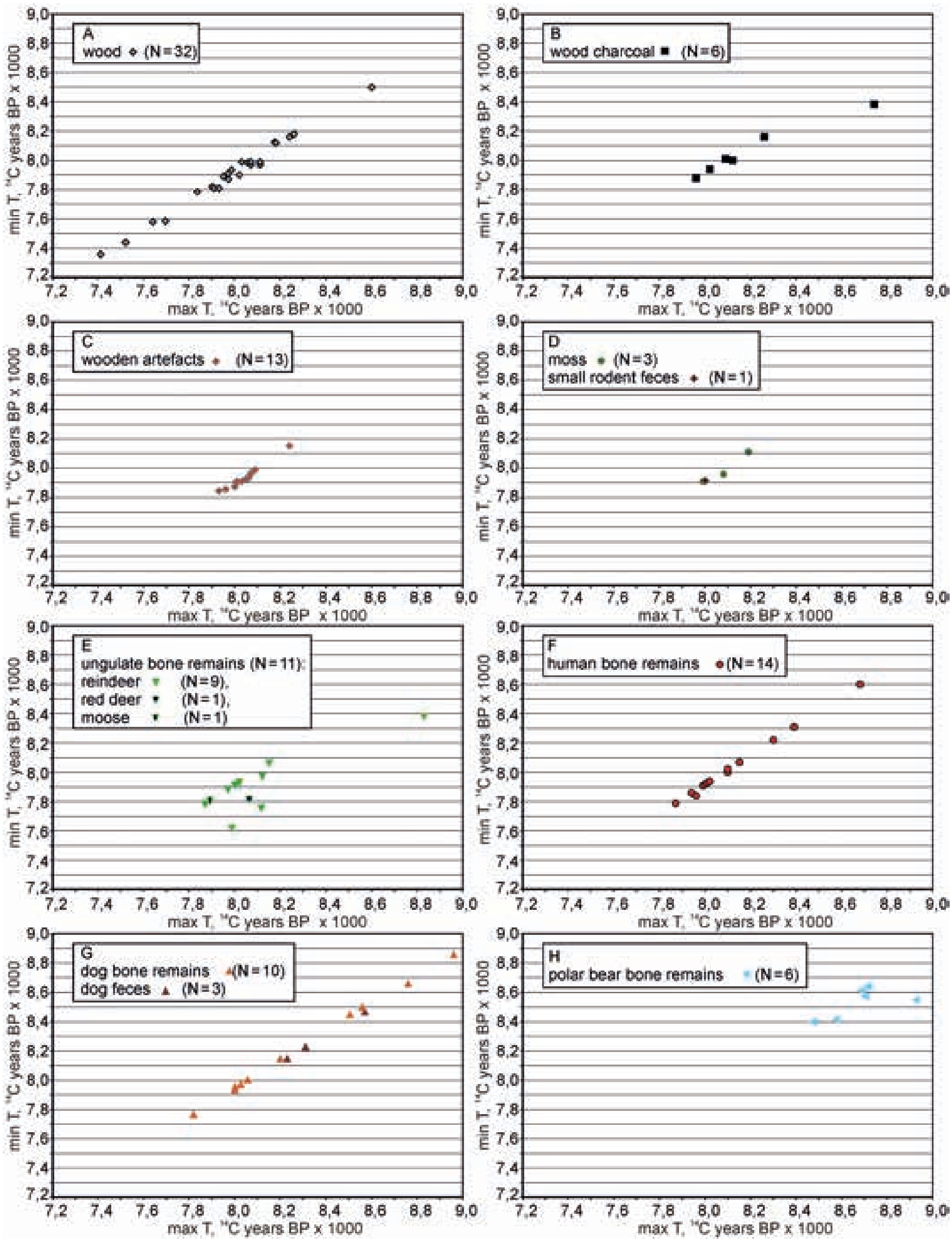

Fig. 7. Distribution of minimal and maximal values of uncalibrated ^{14}C dates within groups based on the material dated (interval is 9000–7200 years ago). Modified from [Pitulko, Pavlova, 2015]

caused by the maritime reservoir effect (see above). When all series are presented on the same graph (see: Fig. 8A), dates on human bone act as the source of the noise.

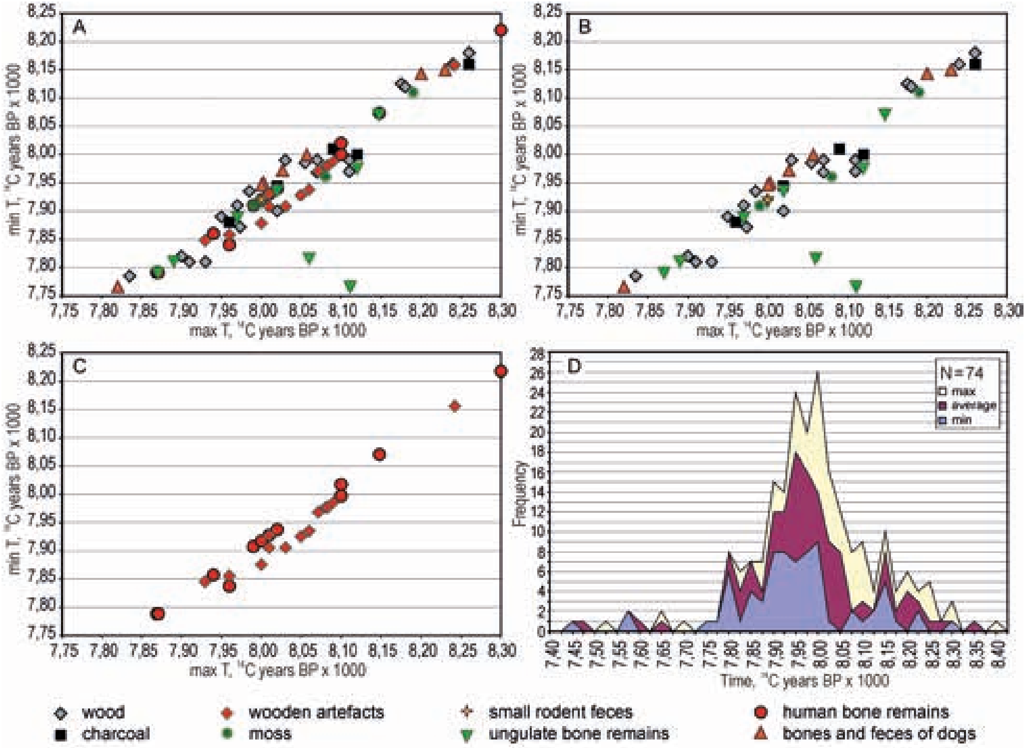

Fig. 8. Distribution of maximal and minimal values of uncalibrated ^{14}C dates in the intervalof 8300–7750 years ago in the groups of various dated substances (A–D) and the number of maximal and minimal values of dates (bin size is 25 years) in the interval of 8350–7450 years ago (D):

A — all dates within the mentioned interval; B — groups of dates on wood, charcoal, moss, ungulate and dog bones; C — groups of dates on wood artifacts and human faunal remains; 1 — wood; 2 — wood charcoal; 3 — wooden artefacts (sled fragments, basketry, dishes); 4 — moss and small rodent feces; 5 — ungulate faunal remains (reindeer, red deer, and moose); 6 — human faunal remains; 7 — bones and feces of dogs; 8 — number of dates. Modified from [Pitulko, Pavlova, 2015]

Finally, Fig. 8D shows the distribution of maximal and minimal dates for the time interval 8400–7400 radiocarbon years BP. The frequency diagram illustrates areas of minimum, average and maximum age values with certain concentrations (see: Fig. 8D). The pattern of distribution shows the changes in the number of dates over time, or their frequency, which allows us to identify the peaks of human activity corresponding to certain time intervals. In general, this is unimodal distribution which contains a few sets represented by several age groups.

Based on the analysis of radiocarbon dates, we conclude that the initial although ephemeral human presence in the Zhokhov island area occurs about 8300 radiocarbon years ago. Humans continued to visit the area episodically during 8300–8075 radiocarbon years BP, but with discernible occupation peaks at 8200, 8150, and 8100 ^{14}C years BP. Then the initial occupation stage ends.

It is followed by the main occupation phase. At that time, human presence at the Zhokhov site is supported by the dates falling within the time span from 8050 to 7800 radiocarbon years BP, with intense human activity on the site clearly visible between 8050 and 7900 radiocarbon years BP. This time interval includes the greatest number of dates obtained from household items and utensils made of wood and birch bark, wooden sled parts, bone remains of ungulates, dogs and humans. The diagram (see: Fig. 8D) shows a sharp decline in human activity at the site after 7900 radiocarbon years BP, but the presence of people can be observed until 7800 BP. There are few dates on wood samples falling within 7650–7450 radiocarbon years BP; most likely, this indicates sporadic, occasional visits to the Zhokhov site during this time. Significantly, this picture matches the occupation chronology based on average values (see: Fig. 8D).

For comparison, we used the calibrated age values. In this case they are useful because a relatively small number of dates (see: Table) provides many values from the numerous equiprobable intercepts with the calibration curve[96]. As a result, the selection becomes, on the one hand, large and on the other hand, unnecessarily varied. Since age values presented in radiocarbon or calendar years are like other numbers, it is possible to manipulate them with any reasonable mathematical operations.

One such operation is logarithmic transformation of data (see: Fig. 9). To build the graph, we used decimal logarithms of maximal and minimal values of the sample calendar (calibrated) age (see: Table) placed on a linear scale. Logarithmic transformation possesses a very useful property: logarithms of numbers of similar value are visually individualized, while the distances between dissimilar values are more compact on the axis. This exposes differences between values that belong to different sets. It should be emphasized that Fig. 9 only addresses the problem of concealed occupation episodes; their length can be found by the reverse calculation.

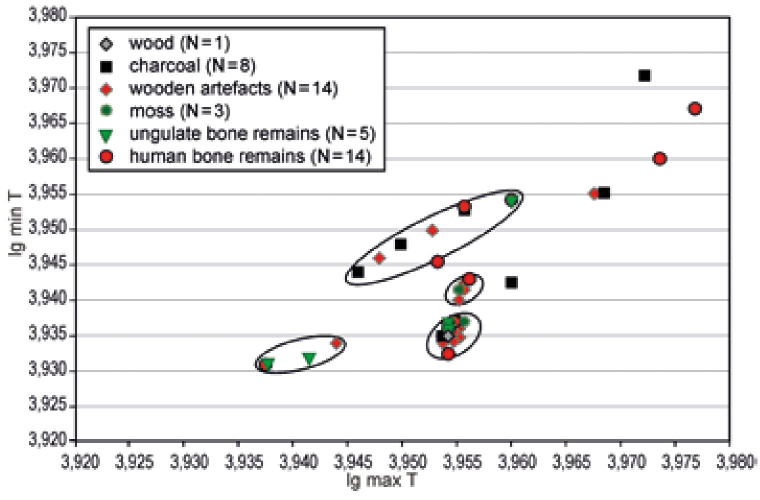

Fig. 9. Distribution of decimal logarithms for maximal and minimal values of calibrated ^{14}C dates from various materials:

1 — wood, 2 — wood charcoal, 3 — wooden artefacts (sled fragments, basketry, dishes); 4 — moss and small rodent feces, 5 — ungulate faunal remains, 6 — human faunal remains. Modified from [Pitulko, Pavlova, 2015]

96 *Wagner G. A.:* 1) Age Determination of Young Rocks and Artifacts; 2) Nauchnye metody datirovaniia v geologii, arkheologii i istorii.

As a result, the calibrated age values, although significantly fewer (compared with marginal values of "raw" dates), also yield a clear picture of the chronology of the Zhokhov site habitation, which comprises four relatively lengthy occupation periods. As with the uncalibrated radiocarbon ages, one can see some intervals of reduced occupation, although this may be caused by error.

Each of the occupation episodes lasted for about 100 years, although this does not indicate that people occupied the Zhokhov site continuously during those periods. Most probably, we are seeing a pattern of multiple visits that might result in a more-or-less continuous stay for a few years, followed by the absence of people in this area for about the same amount of time. There were also longer hiatuses that can be recognized based on the relative precision of the dating (see: Fig. 8).

Such a history of occupation seems consistent with the subsistence model of the Zhokhov hunters[97], who periodically used the local territory for year-round occupation, practicing den hunting in the winter. Polar bear females were a stable and predictable winter food resource, but over time, hunting pressure temporarily reduced the local population. Its numbers rebounded after 10–15 years, based on the radiocarbon dating of the site. Such intervals may represent necessary pauses to increase the den area productivity after a period of intensive use. Thus, they partition the discerned intervals of active occupation (see: Fig. 8).

Discussion and conclusions

We have presented above the pattern of the radiocarbon dating results; analyzing it, one can see the source of possible errors in dating and interpretation of results. Specifically, we have shown the impact of the marine reservoir effect on the age of the Zhokhov human remains and offered a conclusion on the constancy of the ΔR value for the area; this question, however, needs to be further explored.

In sum, we are able to date the interval of human activity at the Zhokhov site to 8300–7800 ^{14}C years ago and to identify major occupation episodes. The most intense human activity at the site took place 8050–7900 radiocarbon years BP, or some 9000 calibrated radiocarbon years ago. This is obviously the oldest known archaeological site in the high-latitude Arctic although there is evidence for older human habitation in the region[98]. However, initial human appearance in the Zhokhov site area may have taken place significantly earlier, possibly 9000 radiocarbon years BP, when the island area remained attached to the mainland. Use of the area ended after the formation of the island. The main occupation stage is probably followed by ephemeral visits with almost no archaeological traces; this stage starts after 7800 and ends at 7400 ^{14}C years BP. At that time, the culture-bearing deposits of the site start forming; this is a particular but not unique case of the formation of culture-bearing deposits in the permafrost regions and in areas that formerly lay within the permafrost zone[99].

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97 *Pitulko V. V., Ivanova V. V., Kasparov A. K., Pavlova E. Y.* Reconstructing Prey Selection… P. 120–157.

98 See, e. g.: *Pitulko V. V.* An Early Holocene site in the Siberian High Arctic. P. 13–21; *Pitulko V. V.* Terminal Pleistocene — Early Holocene Occupation in North East Asia and the Zhokhov Assemblage // Quaternary Science Reviews. 2001. Vol. 20. P. 267–275; *Pitulko V. V., Ivanova V. V., Kasparov A. K., Pavlova E. Y.* Reconstructing Prey Selection… P. 120–157; *Pitulko V. V., Pavlova E. Y.* Colonization of the Eurasian Arctic // Encyclopedia of the World's Biomes: in 5 vols. Vol. 2. London, 2020. P. 374–391.

99 See, e. g.: *Velichko A. A., Grekhova L. V., Gubonina Z. P.* Sreda obitaniia pervobytnogo cheloveka Timonovskikh stoianok; *Velichko A. A., Grekhova L. V., Gribchenko Y. N., Kurenkova E. I.* Pervobytnyi

Because of the Zhokov site geology and taphonomy, detection of human occupation episodes was possible only on the basis of ^{14}C dating. Despite the enormously large dataset and relatively young geological age of the site, the early Holocene, it is not possible to date more precisely than 50–100 years the duration of the episodes; it seems unlikely that they can be detected with better resolution. Here one should take into account the fact that the Zhokhov site is a relatively young one, with organic material ideally preserved in permafrost; additionally, the standard deviation of dates is relatively small.

Experience of detecting the habitation episodes at Zhokhov site has important implications for the study of Palaeolithic sites. Based on these observations, it seems likely that radiocarbon- datable Pleistocene occupations found elsewhere cannot be distinguished precisely as specific occupation events; there always will be some uncertainty.

This analysis represents an important and useful attempt at discriminating hidden (stratigraphically undistinguishable) occupation episodes at Stone Age sites. The issues of cultural deposit chronometry are addressed by L. D. Sulerzhitsky[100], who formulated the problem as the idea of evaluating the timing of human activities at Paleolithic settlements. This issue is quite important for the archaeology of various periods of the Stone Age[101] and crucial for developing the cultural layer theory, for understanding processes and phenomena which occurred in the remote past, and for establishing the temporal structure of the object under investigation.

Radiocarbon date series from cultural layers of ancient settlements allow construction of a model of cultural deposit formation and a basis for interpreting cultural remains[102]. The validity of such a model is supported if it correlates with the accumulation of sediments containing the cultural horizon. Thus, there is basis for a scientifically grounded primary critical evaluation of the set of dates.

At this stage, dates obtained from materials that fall outside the range of human occupation can be ignored as irrelevant; these particularly include the dates from fossil

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chelovek v ekstremal'nykh usloviiakh sredy; *Todisco D., Bhiry N.* Palaeoeskimo Site Burial by Solifluction: Periglacial Geoarchaeology of the Tayara Site (KbFk-7), Qikirtaq Island, Nunavik (Canada) // Geoarchaeology. 2008. Vol. 23. P. 177–211; *Zolnikov I. D., Deev E. V., Slavinskiy V. S. et al.* Afontova Gora II Archaeological Site: Geology and postdepositional deformation (Krasnoyarsk, Siberia) // Russian Geology and Geophysics. 2017. Vol. 58 (2). P. 190–198; *Pitulko V. V., Pavlova E. Y., Basilyan A. E.* Mass accumulations of mammoth… P. 202–217; *Pitulko V. V.* Cultural layer in the Stone Age sites of Northeastern Siberia. P. 867–889.

[100] *Sokoloff D. D., Sulerzhitskiy L. D., Tutubabin V. N.* Vremia aktivnosti liudei na paleoliticheskikh pamiatnikakh po dannym radiouglerodnogo datirovaniia // Russian Archaeology. 2004. No. 3. P. 99–102; *Sulerzhitskiy L. D.* Vremia sushchestvovaniia nekotorykh pozdnepaleoliticheskikh poselenii po dannym radiouglerodnogo datirovaniia kostei megafauny // Russian Archaeology. 2004. No. 3. P. 103–112.

[101] See, e. g.: *Amirkhanov K. A.* Issledovaniia paleolita v Zaraiske. 1999–2005. Moscow, 2009; *Amirkhanov K. A., Lev S. Y., Seleznev A. B.* Problema "paleoliticheskoi derevni" kostenkovskoi kul'tury v svete issledovanii Zaraiskoi stoianki. // Kratkie soobshcheniia IA RAN. 2001. Issue 211. P. 5–16; *Gavrilov K. N.* Arkheologicheskii kontekst novykh radiouglerodnykh datirovok stoianki Khotylevo 2, punkt V // Drevnie kul'tury Vostochnoi Evropy: etalonnye pamiatniki i opornye kompleksy v kontekste sovremennykh arkheologicheskikh issledovanii: Zamiatninskii sbornik. Issue 4. St Petersburg, 2015. P. 103–112; *Zaretskaya N. E., Gavrilov K. N., Panin A. V., Nechushkin R. I.* Geochronological Data and the Archaeological Ideas about the Duration of the Major Eastern Gravettian Sites on the Russian Plain // Russian Archaeology. 2018. No. 1. P. 3–16; *Pryor A. J. E., Beresford-Jones D. G., Dudin A. E. et al.* The chronology and function of a new circular mammoth-bone structure at Kostenki 11 // Antiquity. 2020. Vol. 94 (374). P. 323–341.

[102] *Malinsky-Buller A., Hovers E., Marder O.* Making time: 'Living floors', 'palimpsests' and site formation processes — A perspective from the open-air Lower Paleolithic site of Revadim Quarry, Israel // Journal of Anthropological Archaeology. 2011. Vol. 30. P. 89–101.

wood[103] and from bone remains from fossil fauna[104]. At the same time, these materials appear in the cultural layer as a result of human behavior. At the Pleistocene sites, there is another source of dating errors related to the effect of the 'bone rain', that is, incorporation into the cultural context the older remains of Pleistocene animals[105].

There is an observable sequence of events underlying formation of the culture-bearing deposits, for example, at the Yana site where about 2000 years of occupation history are 'packed' into a geological context some 15 cm thick[106], within which separate occupation episodes can be distinguished by radiocarbon dating. The radiocarbon dating of the Zhokhov site is of special importance in this discussion, as the longest concentration of dates is obtained exclusively on human-modified wood, wooden artefacts, or wood-related materials (bark, roots, twigs), and none of these items is made of local wood: it simply did not exist in the area, whereas the driftwood was collected and brought to the site by the human occupants, and thus every piece of wood represents human activity in the site area. And due to nature of the subsistence economy, repeated/cyclic human habitation at the same location was possible for about 2000 years and possibly longer. Thus, recurring or cyclic human occupation in the Zhokhov Island area is a function of the food and material resources provided by the location: wood as firewood and critical raw material, and polar bear hunting at dens providing stable food source for the winter[107].

In more recent times, there are examples of the same: thus, not many, but some of the Eskimo sites are found in the same place for about 2000 years, and in some cases they represent permanent occupations; there are also well known historical cities and other settlements that existed at the same location for millennia due to their geographic setting, economic reasons, and political role predetermined by the geographic/environmental limitations[108]. Similarly, radiocarbon records indicating long-term occupation events at some Stone Age archaeological sites including those dated to the Pleistocene reflect reasons for selection of the site location. As such, the radiocarbon dates are not simply data for assessing the chronometry or chronology of the site[109], they play a critical role in reconstructing the complexity of human behavior[110] which is the main driver for the evolution of human culture.

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[103] *Abramova Z. A.* K voprosu o vozraste aldanskogo paleolita // Sovetskaia Archaeologiia. 1979. No. 4. P. 5–14; *Pitulko V. V., Pavlova E. Y.* Geoarchaeology and Radiocarbon Chronology of Stone Age Northeast Asia.

[104] *Pitulko V. V., Ivanova V. V., Kasparov A. K., Pavlova E. Y.* Reconstructing Prey Selection… P. 120–157.

[105] *Haynes G.* Raining more than cats and dogs: Looking back at field studies of noncultural animal-bone occurrences // Quaternary International. 2018. Vol. 466. Part B. P. 113–130.

[106] *Pitulko V., Nikolskiy P., Basilyan A., Pavlova E.* Human habitation in the Arctic Western Beringia… P. 13–44.

[107] *Pitulko V. V.* Zhokhovskaia stoyanka; *Pitulko V. V.* The Bear-Hunters of the Zhokhov Island… P. 141–152; *Pitulko V. V., Ivanova V. V., Kasparov A. K., Pavlova E. Y.* Reconstructing Prey Selection… P. 120–157.

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