‘They come from the ends of the earth’: long-distance exchange of obsidian in the early Holocene of the High Arctic (Zhokhov site, eastern Siberia)

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Introduction

The determination of obsidian provenance for prehistoric cultural complexes is a powerful research tool that allows patterning of procurement and exchange of valuable raw material with high degree of certainty (e.g. Shackley 2005), and can also be used to study prehistoric human migrations. In eastern Russia, these studies have been conducted since the early 1990s (e.g. Kuzmin & Glascock 2014; Grebennikov & Kuzmin 2017; Grebennikov *et al.* 2018). At present, all major obsidian sources in these areas are mapped and analysed according to international standards (Glascock *et al.* 1998); this allows pinpointing obsidian artefacts to the place of their origin.

In mainland Northeastern (NE) Siberia, archaeological obsidian is common on Chukotka (Dikov 1997; Kiryak 2010), while further west and southwest its amount decreases significantly in the basins of Kolyma and Indighirka rivers, and on the Okhotsk Sea coast (see Kuzmin *et al.* 2018). The Indighirka River is the westernmost limit of obsidian distribution in continental Siberian Arctic (Fedoseeva 1980).

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The discovery in 1989 of the early Holocene site on the Zhokhov Island in High Arctic—76° 08′N, 152° 43′ E—completely changed the paradigm of the human presence north of the Arctic Circle in prehistory (Pitulko 1993; Makeyev *et al.* 1992; see also Pitulko 2013). The main results of several excavations campaigns are now published (Pitulko 2001, 2003, 2013; Pitulko & Kasparov 1996, 2017, Pitul'ko & Pavlova 2015, 2016; Pitulko *et al.* 2012, 2015; Girya & Pitulko 1994; Lee *et al.* 2015, 2018), and current study is based on these materials.

A few obsidian artefacts were found during the 1989–90 excavation campaign (Pitul'ko & Makeev 1991; Pitulko 1993: 18), and more items were recovered in the 2000s (Pitulko *et al.* 2012). This provides an opportunity to establish the primary source(s) for archaeological obsidian from the Zhokhov site, for better understanding possible human movements and acquisition of raw material in Siberian Arctic (e.g. Pitulko 2013; Kuzmin 2015). In this paper, we present the first results of obsidian provenance study for the insular Siberian Arctic which is one of the most remote parts of the world yielded archaeological materials.

The Zhokhov site: a brief overview

The Zhokhov site is located on the Zhokhov Island, part of the De Long group of the New Siberian Islands (Figure 1). Systematic investigation of the site began in 1989–90 (e.g. Pitulko 1993, 2003; Pitulko & Kasparov 1996; Makeev *et al.* 1992), and large-scale study took place in 2000–5. The total excavated area (571m^2) is divided into the zones 1–3 (northern, central, and southern, respectively; see Figure 2). The entire Zhokhov assemblage today counts to *c.* 19 160 lithic artefacts; over 54 000 faunal elements (*c.* 22 000 are identifiable to species); more than 300 objects made of antler, mammoth ivory and bone; *c.* 1000 items made of wood; and a few woven and birch bark artefacts.

In lithic collection there are 341 cores, 164 blades and blade fragments (> 5mm wide), 9187 microblades (< 5mm wide), and 90 formal tools (points, arrowheads, chisels and their preforms, mallet-like tools, hammerstones, and grindstones) (Pitulko 2013; Pitulko *et al.* 2012). It is important to notice that neither cores nor chisels and adzes were initially made at the site, as there is no *débitage* related to that. There are a few pieces of unworked raw material (n = 3) compared to the amount of cores; it seems that the latter were made somewhere outside the site and brought to it as a semi-product, and then finished/used, rejuvenated and re-used.

The composition of raw material is presented in Table 1. Rare ('exotic') rocks are chalcedony and obsidian. The dominant rock is flint/chert of brown, light brown and yellowish-brown colours. It is of local origin, and can be found in Quaternary deposits of the Zhokhov Island as pebbles and small boulders. Also, similar flint is common in the sediments at Mys Kamennyy (Stony Cape), the northeastern extremity of Novaya Sibir' Island, situated *c.* 180km south of the site (Basilyan & Nikolskiy 2007); and on the northern shore of Faddeyevskiy Island, *c.* 250km southwest of the Zhokhov site (Figure 1).

Analysis of faunal remains allows reconstruction of subsistence strategy practiced by the Zhokhov site's inhabitants (e.g. Pitulko *et al.* 2015). This is very unusual terrestrial-type adaptation based on mass procurement of reindeer and polar bear in a ratio of 2:1 (in total) while in winter polar bear was the major food source. Based on seasonality studies (Pitulko *et al.* 2015), it was possible to understand that the site was a base camp used all the year round. Summer activity was of minimal scale; in winter people hunted polar bears (mostly females) by taking them from the dens. In the spring and autumn, the hunting of reindeer was the main exercise which involved travelling within vast territory of the present-day New Siberian Archipelago (Pitulko *et al.* 2015), as is also indicated by raw material use. The results of the study of canid remains (Pitulko & Kasparov 2017), including ancient DNA (Lee *et al.* 2015), showed that people kept at the Zhokhov site fully domesticated dogs (*Canis familiaris*), and used them as both hunting assistants and draught animals.

Up to date, more than 90 ^{14}C dates were obtained on different material from the culture-bearing stratum of the Zhokhov site: driftwood; charcoal and charred wood; plant remains; bones, hair, and excrements of animals; and human bones. The result of analysis of the ^{14}C dataset (Pitulko & Pavlova 2015) allows conclusion that main occupation ranges from *c*. 8250 BP to *c*. 7800 BP, with possible later ephemeral visits at *c*. 7700–7400 BP; the main peak of human presence dates to *c*. 8000–7900 BP.

Obsidian artefacts from the Zhokhov site and their geochemical analysis

Collection of obsidian artefacts from the Zhokhov site consists of 79 items (Pitulko *et al.* 2012: 232), which is 0.54% of the total amount of lithics: 59 microblades, 12 flakes (nine of them are small), seven blades, and one fragment. Some of the artefacts retain edge retouch that results possibly from utilization but maybe also due to the site's taphonomy. The straight profile of microblades indicates that they were made by pressure flaking. In the absence of large obsidian tools, cores and waste products, and without cortex on flakes, we can assume that this 'exotic' raw material was brought to the site as ready preforms. Nevertheless, there was no special function for obsidian items, and they were used the same way as dominant kinds of raw material – flint, sandstone and quartzite (Table 1). Small amount of obsidian flakes in comparison to number of blades and microblades can be explained by fact that they appear as a result of core maintenance operations such as platform rejuvenation and preparation of knapping surface. In general, the size of raw material at the Zhokhov site is small, around 4cm long, and very rarely up to 6–7cm; the dimensions of obsidian blades and microblades are in accord with these numbers.

In total, 14 randomly selected obsidian artefacts with relatively flat surfaces found in 2001–5 were analysed for their provenance (Figures 3–4): Nos. 641, 1220, 2153, 3197, 3777, and 3858 from the Zone 1; Nos. 133, 923, 2428, and 2965 from the Zone 2; and Nos. 336, 1055, 3350, and 3661 from the Zone 3. Some of them have edge retouch which indicates that they served as side blades/microblades for inset tools widely known from the Zhokhov complex (Pitulko 2013).

These artefacts were examined by non-destructive X-ray Fluorescence (XRF) method, widely used today. The analysis was undertaken at the Archaeometry Laboratory, Research Reactor Center of the Missouri University (MURR). The XRF measurements were performed using a ThermoScientific ARL Quantx Energy-Dispersive XRF spectrometer. The instrument has a rhodium-based X-ray tube and thermoelectrically-cooled silicon-drift detector (SDD). The tube was operated at 35kV, and current was automatically adjusted to a fixed 30% deadtime for each item. The artefacts were counted for two minutes to measure the content of Mn, Fe, Zn, Rb, Sr, Y, Zr, Nb, and Th (Table 2). Normalization to the Compton scattering peak was used to account for differences in sample size and thickness. The XRF instrument was calibrated to analyse obsidian by measuring a set of 40 very well-characterised obsidian source samples previously analysed by Neutron Activation Analysis (NAA), XRF, and Inductively Coupled Plasma – Mass Spectrometry (ICP–MS).

The results of XRF analysis were compared with data available on geochemical composition of primary obsidian sources on Kamchatka and Chukotka. All specimens from primary sources were tested by NAA at the MURR (see details: Glascock *et al.* 2007), and comprehensive geochemical signature or each source based on composition of 28 elements was established (e.g. Grebennikov & Kuzmin 2017; Grebennikov *et al.* 2018). After that, it was possible to use the content of less than ten elements by XRF in order to detect the primary obsidian locale from where archaeological obsidian originated. This approach was successfully applied in eastern Russia (Kuzmin & Glascock 2014) and elsewhere (e.g. Glascock *et al*. 1998, 2007). Statistical grouping, based on bivariate plots, and cluster and discriminant classification analyses, was performed by using the GAUSS software (available from the MURR; http://www.missouri.edu/~glascock/profile.htm), to indicate within a 90% degree of probability the obsidian sources (see details: Glascock *et al*. 1998).

Results and discussion

Geochemical data on artefacts from the Zhokhov site were compared with known primary obsidian sources on Chukotka and Kamchatka (see Grebennikov *et al.* 2018), through the inspection of scatterplots of different element pairs; the most definitive plots are Rb *vs.* Sr and Mn *vs.* Y (Figure 5). The geochemistry of artefacts is in good agreement with the 90% confidence ellipse for the Cape Medzevhiy source, Lake Krasnoe on Chukotka (group KRASN-1 in Grebennikov *et al.* 2018) (see Figure 5, B and Table 2).

This result securely testifies about the super-long distance movement of obsidian from the source to utilisation site, *c*. 1500km as crow flies. While archaeological obsidians are well-known in the Anadyr River valley as well as north and east of it (Dikov 1997; Kiryak 2010), there are few localities with obsidian artefacts known elsewhere in the NE Siberian Arctic, between the source area on Chukotka and Zhokhov site. These are poorly dated surface and *in situ* contexts of Holocene age, namely Belaya Gora in the Indighirka River basin (Fedoseeva 1980); Starye Petushki and Konzaboi (Fedoseeva 1980), and

Pomazkino, Rodinka and Labuya (Kashin 2013) in the Kolyma River basin; and Tytyl cluster of sites in western Chukotka (Kiryak 2010).

The sites from two latter regions are of special interest. These are the Tytyl complex in the Malyy Anyuy River basin; and Starye Petushki and Konzaboi sites in the Kolyma River mouth. With all uncertainties in terms of their age, at least part of them may belong to the early Holocene while a large portion is younger which is not very important because exchange connections and logistics could be inherited from older times. The existence of the long-distance exchange systems in NE Siberia had been presumed for the late Holocene, *c.* 3000–4000 BP. It is poorly documented in the archaeological records but it still can be seen, for instance, using the appearance of metal tools on Chukotka (e.g. Arutiunov & Sergeev 2006).

It is unlikely that the inhabitants of the Zhokhov site procured obsidian directly from the Lake Krasnoe source as it lies far beyond the supply zone proposed by Renfrew (1975). According to that view, the direct supply zone is normally limited to roughly 300km, while longer transportation would be a result of exchange. Importantly, in Renfrew's (1975) model all transportations are thought to be done basically on foot, with connection points within the walking distance for which 300km is a reasonable limit as it requires 7–10 days to cover it one way, or about 2–3 weeks for roundtrip. In winter time, it requires certain technology and skills manifested in skiing and/or use of snow shoes which was quite common elsewhere in the Arctic and beyond starting at least from the early Holocene (Weinstock 2005). It may be unreasonable from the view of time/labour/energy cost but still leaves an opportunity to create exchange/trade network whose scale could be enlarged significantly by simple ways of transportations such as watercraft or diverse animal-powered systems. In the Arctic, this means sledge pulled by dogs or reindeer which expand considerably peoples' ability to travel.

At the Zhokhov site, we have the oldest evidence of wooden sledge runners and other parts of sledge in the world (Pitulko 2013; Pitulko & Kasparov 1996) (Figure 6). Reconstructions of dogs' body weight and size class show that they were similar to modern Siberian huskies (Pitulko & Kasparov 2017). Sledge transport was an important part of subsistence technology of Zhokhov site inhabitants. It should be stressed that occupants of the Zhokhov site were skilled voyagers whose everyday life involved regular journeys from present-day Zhokhov Island to New Siberia, Faddeyevskiy and Kotelnyy islands south and west of the site as indicated by raw materials procured.

For understanding the transportation routes of the Zhokhov's obsidian, it is important to take into account palaeoenvironmental situation at *c.* 8300–7800 BP in the today's insular Siberian Arctic. At the end of the Pleistocene, in post-glacial time (*c.* 15 000–10 000 BP), this region was a part of vast coastal plain spanning hundred kilometres north of the modern shore of the Arctic Ocean (Figure 7). The sea depth in this region usually do not exceed 50m; these isobaths lie near the Bennett Island, and around the Zhokhov Island the depth of sea is much less – between Vil'kitskiy and Zhokhov islands it is *c.* -20m (e.g. Pitulko *et al.* 2015). The process of inundation for this part of the Arctic during the Holocene rise of the sea level was of complex nature, and there are several reconstructions exist (e.g. Bauch *et al.* 2001; Gavrilov *et al.* 2006; Anisimov *et al.* 2009). Some of them do not take into account bottom topography; for example, according to Bauch *et al.* (2001) at the time of human presence at Zhokhov site it was already an island. Our data show that since *c*. 10 600 BP the Zhokhov Island situated on the margin of the shrinking Arctic coast (Anisimov *et al.* 2009) (see Figure 7); this is supported by the presence of large amount of driftwood at the Zhokhov site washed ashore. Environmental situation was quite favourable for humans: climate was warmer than today, and the Zhokhov Island was covered by Arctic tundra of the sedge grass – shrub birch association (Makeyev *et al.* 2003). These open landscapes were an essential part of survival strategy because it provided excellent opportunity for long-distance travel in winter. However, at *c*. 7800 BP connection of today's island to the mainland disappeared, and this corresponds to the end of site's occupation by humans, besides possible rare visits. The ^{14}C date of horse bone from the Vil'kitskiy Island is 7900 ± 40 BP (Beta-191338), and this signifies the end of any association of the De Long Islands to the mainland.

It is clear that visits of Zhokhov site's inhabitants to the Arctic mainland occurred in the early Holocene. Probably, the primitive 'trade fairs' existed at that time for exchange of valuable good (furs, raw material, and other items). As an analogue, the well-known Ostrovnoye (Ostrownoje, see Wrangell 1840) fair in the Malyy Anyuy River valley can be used. This was a large-scale (by regional standards) event in the seventeenth – nineteenth centuries AD in which both indigenous people and Russian merchants took part (Vakhtin *et al.* 2004). According to observations by Russian explorers (see Wrangell 1840: 114–28), native inhabitants of NE Siberia gathered here for trade in the early spring from very large area, the end points of which were Srednekolymsk in the Kolyma River basin, Gizhiga on the northern Sea of Okhotsk coast, and Markovo in the Anadyr River basin of Chukotka (Figure 7). The distances between these localities are *c*. 450–600km in a straight line, and the square covered by space between them is *c*. 1 200 000km^2. The fairs of secondary importance exited at the same time near the mouth of the Kolyma River, at the Panteleikha locale; and in the Anadyr River basin, near modern town of Markovo (Vakhtin *et al.* 2004). It is quite possible that ingenious populations of Siberia Arctic inherited the ancient tradition of gathering for trade/exchange/contacts.

It is noteworthy that obsidian artefacts were found in the Malyy Anyuy River basin (western Chukotka) and in the lower course of the Kolyma River (Fedoseeva 1980; Kiryak 2010; Kashin 2013); provenance determination shows that it originated from the single source of Lake Krasnoe (Kuzmin *et al.* 2018; Grebennikov *et al.* 2018). At the Malyy Anyuy River sites, the obsidian is more numerous compared to the Kolyma River locales, and formal tools (some with a cortex) and debitage is recorded for the former region (see Kiryak 2010). It is possible that obsidian raw material was transported to the Malyy Anyuy River basin as unmodified nodules; the distance between source and utilisation sites is *c*. 450–500km as crow flies. Fewer obsidian artefacts were found in the Kolyma River mouth and around it, with distance from the source of *c*. 850km (Figure 7).

Using ethnographic analogues and current knowledge of obsidian provenance for NE Siberia, it is possible to suggest the mechanism of obsidian procurement for insular High Arctic in the early Holocene. The first leg, *c*. 500–750km long, was from the primary source of the Lake Krasnoe to lower reaches of Malyy Anyuy and Kolyma rivers. The second leg was further to the west, the mouth of the Indighirka River, with distance of *c*. 550–700km. Here obsidian artefacts are so far unknown, and the only archaeological site is the Burulgino dated to *c*. 3000 BP (Fedoseeva 1980). From here, the last leg was to the Zhokhov Island located *c*. 600km away from the Indighirka River mouth in a straight line (Figure 7). The most suitable time for travel was the modern month of March, when snow is still solid and days are longer than in winter.

New data about the penetration of Lake Krasnoe obsidian into the High Arctic at *c*. 8250–7800 BP is a valuable addition to the existing knowledge on extremely wide distribution of this raw material in NE and northern North America, including Chukotka, Koryak Upland, Kolyma River basin, northern coast of the Okhotsk Sea, and St. Lawrence Island and mainland Alaska (see Grebennikov *et al.* 2018; Kuzmin *et al.* 2018).

Conclusions

For the first time in Siberian High Arctic, the provenancing of obsidian artefacts from the early Holocene Zhokhov site was carried out. It is demonstrated that this valuable raw material came from extremely remote locale of the Lake Krasnoe on Chukotka, with distance between source and place of utilisation around 1500km as a crow flies. Most possibly, site's inhabitants did not travel that far but they were a part of the long-distance exchange/trade network which existed in the NE Siberian Arctic as early as the beginning of the Holocene. Most probably, people visited the regional 'trade fair' where they could get the material through middlemen who, in their turn, would visit the initial 'market place'. Thus, we may suggest that in the early Holocene humans who lived in the NE Siberian Arctic maintained well-developed network which facilitated the information exchange and transmission of knowledge and covers a vast region of *c*. 3–4 000 000km^2. Surprisingly, it was almost as effective as communication systems of historical times known in different parts of the world, but its high reliability was based on the perfect combination of suitable environment – open tundra landscapes, snow cover in winter – early spring with frozen rivers which are directed to the north, and well-developed sledge technology. Prehistoric people truly "come from the ends of the earth" in order to obtain and trade in exotic raw material. Due to its high efficiency, this network could have continued in NE Siberian Arctic throughout the Holocene until the historic times.

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References

ANISIMOV, M.A., V.V. IVANOVA, Z.V. PUSHINA & V.V. PITULKO. 2009. Lagoon deposits of the Jokhov Island: age, conditions of formation and meanings for paleogeographical reconstructions of the region of Novosibirsk Islands. *Izvestiya Rossiiskoi Akademii Nauk, Seriya Geograficheskaya* 5: 107–19 (in Russian with English abstract).

ARUTIUNOV, S.A. & D.A. SERGEEV. 2006. *Ancient cultures of the Asiatic Eskimos: the Uelen cemetery*. Anchorage (AK): Shared Beringian Heritage Program.

BASILYAN, A.E. & P.A. NIKOLSKIY. 2007. The key section of the Quaternary deposits at the Cape Kamenny (New Siberia Island). *Bulleten Komissii po Izucheniyu Chetrevtichnogo Perioda* 67: 76–84 (in Russian with English title).

BAUCH, H.A., T. MUELLER-LUPP, E. TALDENKOVA, L.F. SPIELHAGEN, H. KASSENS, P.M. GROOTES, J. THIEDE, J. HEINEMEIR & V.V. PETRYASHOV. 2001. Chronology of the Holocene transgression at the North Siberian margin. *Global and Planetary Change* 31: 125–39.

DIKOV, N.N. 1997. *Asia at the juncture with America in antiquity (The Stone Age of the Chukchi Peninsula)*. Anchorage (AK): Shared Beringian Heritage Program.

FEDOSEEVA, S.A. 1980. *Ymyyakhtakhskaya kultura Severo-Vostochnoi Azii* (The Ymyyakhtakh culture of Northeast Asia). Novosibirsk: Nauka Publishers (in Russian).

GAVRILOV, A.V., N.N. ROMANOVSKII & H.-W. HUBBERTEN. 2006. Paleogeographic scenario of the postglacial transgression on the Laptev Sea shelf. *Kriosfera Zemli* 10(1): 39–50 (in Russian with English abstract).

GIRYA, E. YU. & V.V. PITULKO. 1994. High Arctic Mesolithic culture of Zhokhov Island: insert tools and knapping technology. *Arctic Anthropology* 31(2): 17–29.

GLASCOCK, M.D., G.E. BRASWELL & R.H. COBEAN. 1998. A systematic approach to obsidian source characterization, in M.S. Shackley (ed.) *Archaeological obsidian studies: method and theory*: 15–65. New York & London: Plenum Press.

GLASCOCK, M.D., R.J. SPEAKMAN & H. NEFF. 2007.Archaeometry at the University of Missouri Research Reactor and the provenance of obsidian artefacts in North America. *Archaeometry*49: 353–67.

GREBENNIKOV, A.V. & Y.V. KUZMIN. 2017. The identification of archaeological obsidian sources on Kamchatka Peninsula (Russian Far East) using geochemical and geological data: current progress. *Quaternary International* 442B: 95–103.

GREBENNIKOV, A.V., Y.V. KUZMIN, M.D. GLASCOCK, V.K. POPOV, S.Y. BUDNITSKIY, M.A. DIKOVA & E.A. NOZDRACHEV. 2018. The Lake Krasnoe obsidian source in Chukotka (Northeastern Siberia): geological and geochemical frameworks for provenance studies in Beringia. *Archaeological and Anthropological Sciences* 10: 599–614.

KASHIN, V.A. 2013. *Neolit srednei Kolymy* (The Neolithic of the middle Kolyma River). Novosibirsk: Nauka Publishers (in Russian).

KIRYAK (DIKOVA), M.A. 2010. *The Stone Age of Chukotka, Northeastern Siberia (new materials)*. Oxford: Archaeopress.

KUZMIN, Y.V. 2015. Northern and northeastern Asia: archaeology, in P.S. Bellwood (ed.) *The global prehistory of human migration*: 191–6. Chichester: Wiley-Blackwell.

KUZMIN, Y.V., A.N. ALEKSEYEV, V.M. DYAKONOV, A.V. GREBENNIKOV & M.D. GLASCOCK. 2018. Determination of the source for prehistoric obsidian artifacts from the lower reaches of Kolyma River, Northeastern Siberia, Russia, and its wider implications. *Quaternary International* 476: 95–101.

KUZMIN, Y.V. & M.D. GLASCOCK. 2014. The Neutron Activation Analysis of volcanic glasses in the Russian Far East and neighbouring Northeast Asia: a summary of the first 20 years of research, in A. Ono, M.D. Glascock, Y.V. Kuzmin & Y. Suda (ed.) *Methodological issues for characterisation and provenance studies of obsidian in northeast Asia*: 85–93. Oxford: Archaeopress.

LEE, E.J., D.A. MERRIWETHER, A.K. KASPAROV, V.I. KHARTANOVICH, P.A. NIKOLSKIY, F.K. SHIDLOVSKIY, A.V. GROMOV, T.A. CHIKISHEVA, V.G. CHASNYK, V.B. TIMOSHIN, E.Y. PAVLOVA & V.V. PITULKO. 2018. A genetic perspective of prehistoric hunter-gatherers in the Siberian Arctic: mitochondrial DNA analysis of human remains from 8000 years ago. *Journal of Archaeological Science: Reports* 17: 943–9.

LEE, E.J., D.A. MERRIWETHER, A.K. KASPAROV, P.A. NIKOLSKIY, M.V. SOTNIKOVA, E.YU. PAVLOVA & V.V. PITULKO. 2015. Ancient DNA analysis of the oldest canid species from the Siberian Arctic and genetic contribution to the domestic dog. *PLoS ONE* 10(5): e0125759; doi: 10.1371/journal.pone.0125759.

MACDONALD, G.M., D.W. BEILMAN, Y.V. KUZMIN, L.A. ORLOVA, K.V. KREMENETSKI, B. SHAPIRO, R.K. WAYNE & B. VAN VALKENBURGH. 2012. Pattern of extinction of the woolly mammoth in Beringia. *Nature Communications* 3: 893; doi: 10.1038/ncomms1881.

MAKEYEV, V.M., V.V. PITULKO & A.K. KASPAROV. 1992. Ostrova De-Longa: an analysis of palaeoenvironmental data. *Polar Record* 28: 301–6.

MAKEYEV, V.M., D.P. PONOMAREVA, G.M. CHERNOVA, V.V. PITULKO & D.V. SOLOVYEVA. 2013. Vegetation and climate of the New Siberian Islands for the past 15,000 years. *Arctic, Antarctic and Alpine Research* 35: 56–66.

MANLEY, W.F. 2002. Post-glacial flooding of the Bering Land Bridge: a geospatial animation. University of Colorado, INSTAAR; http://instaar.colorado.edu/qgisl/bering_land_bridge. Accessed 4 May 2018.

PITULKO, V.V. 1993. An Early Holocene site in the Siberian High Arctic. *Arctic Anthropology* 30(1): 13–21.

—2001. Terminal Pleistocene/early Holocene occupation in northeast Asia and the Zhokhov assemblage. *Quaternary Science Reviews* 20: 267–75.

—2003. The bear-hunters of the Zhokhov Island, east Russian Arctic, in J. Habu, J.M. Savelle, S. Koyama, H. Hongo (ed.) *Hunter-gatherers of the North Pacific Rim*: 141–52. Osaka: National Museum of Ethnology.

—2013. *The Zhokhov Island site and ancient habitation in the Arctic*. Burnaby (B.C.): SFU Archaeology Press.

PITULKO, V.V., V.V. IVANOVA, A.K. KASPAROV & E. YU. PAVLOVA. 2015. Reconstructing prey selection, hunting strategy and seasonality of the Early Holocene frozen site in the Siberian High Arctic: a case study on the Zhokhov site faunal remains, De Long Islands. *Environmental Archaeology* 20: 120–57.

PITULKO, V.V. & A.K. KASPAROV. 1996. Ancient Arctic hunters: material culture and survival strategy. *Arctic Anthropology* 33(1): 1–36.

— 2017. Archaeological dogs from the Early Holocene Zhokhov site in the eastern Siberian Arctic. *Journal of Archaeological Science: Reports* 13: 491–515.

PITUL'KO, V. & V. MAKEEV. 1991. Ancient Arctic hunters. *Nature* 349: 374.

PITULKO, V.V. & E. YU. PAVLOVA. 2015. Radiocarbon dating of culture-bearing deposits of the Zhokhov site (New Siberia Archipelago, Siberian Arctic). *Zapiski Instituta Istorii Materialnoi Kultury RAN* 12: 27–55 (in Russian with English abstract).

—2016. *Geoarchaeology and radiocarbon chronology of Stone Age Northeast Asia*. College Station (TX): Texas A&M University Press.

PITULKO, V.V., E.YU. PAVLOVA, V.V. IVANOVA & E.YU. GIRYA. 2012. The Zhokhov site: geology and stone industry (preliminary report on the excavations of 2000 through 2005). *Stratum plus* 1: 211–56 (in Russian with English abstract).

RENFREW, C. 1975. Trade as action at a distance: questions of integration and communication, in C. Lamberg-Karlovsky (ed.) *Ancient civilization and trade*: 3–59. Albuquerque (NM): University of New Mexico Press.

SHACKLEY, M.S. 2005. *Obsidian: geology and archaeology in the North American Southwest*. Tucson (AZ): University of Arizona Press.

VAKHTIN, N.B, E.V. GOLOVKO & P. SCHWEITZER. 2004. *Russkie starozhily Sibiri: sotsialnye i simvolicheskie aspekty samosoznaniya* (Russian Siberian old-settlers: social and symbolic aspects of identity). Moscow: Novoe Izdatelstvo (in Russian).

WEINSTOCK, J. 2005. The role of skis and skiing in the settlement of early Scandinavia. *The Northern Review* 25/26: 172 –96.

WRANGELL, F., VON. 1840. *Narrative of an expedition to the Polar sea, in the years 1820, 1821, 1822, & 1823*. London: James Madden & Co.

Figure captions

Figure 1. Position of the Zhokhov site and other localities in the insular NE Siberia.

Figure 2. Spatial distribution of obsidian artefacts at the Zhokhov site. A: 1–5 – obsidian artefacts (1 – piece of raw material; 2 – flake; 3 – microblade core; 4 – prismatic blade, > 5mm wide; 5 – microblade, < 5mm wide); 6 – other lithics (flakes and microblades made of chert, quartzite, and chalcedony); 7 – excavated grids. B: general view of the excavation from the WSW direction.

Figure 3. Obsidian artefacts from the Zhokhov site (numbers correspond to those in collection's inventory): A – No. 641, fragmented blade; B – No. 3192, medial blade fragment; C – No. 2965, proximal blade part; D – No. 2428, medial blade fragment with truncation; E – No. 1055, medial blade fragment (one of the longest in the lithic collection); F – No. 3350, distal blade fragment; G – No. 3858, proximal microblade fragment; H – No. 2153, proximal blade fragment; I – No. 133, proximal blade fragment; J – No. 923, medial blade fragment; K – No. 3661, proximal blade fragment; L – No. 336, medial microblade fragment (side blade).

Figure 4. Drawings of obsidian artefacts from the Zhokhov site analysed in this study: A – No. 2153; B – No. 3192; C – No. 641; D – No. 3858; E – No. 1055; F – No. 2428; G – No. 133; H – No. 3350; I – No. 3661.

Figure 5. Bivariate plots of NAA and XRF for the artefacts from Zhokhov site (red diamonds) and obsidian sources on Chukotka and Kamchatka (numbers for Kamchatkan sources correspond to those of KAM groups, see Grebennikov & Kuzmin 2017). Ellipses are 90% confidence areas. A – Rb. vs. *Sr; and B – Mn* vs. *Y.*

Figure 6. Sledge parts excavated from the Zhokhov site (see grid Nos. on Figure 2). A: sledge runner (grid Cc14) as found in situ*; B: sledge runner fragment (grid DE12); C: sledge runner (grid Ee13); D: upright (grid Aa13); E: upright (grid BC13); F: upright (grid E12); G: sledge runner fragment (B, other side); H: hole with a piece of rope made of animal hair (enlarged detail of G); I: possible reconstruction in which upright (F) is combined with a sledge runner (G).*

Figure 7. The eastern Siberian Arctic in the early Holocene and possible ways of obsidian transportation to Zhokhov site. Approximate position of the coastline at c. *8000 BP is based on Anisimov* et al. *(2009) and Manley (2002). 1 – primary obsidian source; 2 – possible 'hubs' of obsidian trade/exchange; 3 – possible route of obsidian transportation to Zhokhov site; 4 – selected sites with obsidian from the Lake*

Krasnoe source (after Grebennikov et al. *2018; Kuzmin* et al. *2018); 5 – exposed shelf (by grey colour) during the occupation of the Zhokhov site, dashed line – coastline at* c. *8000 BP*.

Table 1. The raw material composition of the Zhokhov site (after Pitulko *et al.* 2012, with modifications).

Rocks	No. (%)
Flint	17 210 (92.4)
Sandstone	1084 (5.9)
Quartzite	162 (0.97)
Obsidian	79 (0.54)
Chalcedony	56 (0.3)
Tuffa-basalt	7 (0.04)
Quartz	1 (0.01)
Undetermined	19 (0.1)
Total	*18 618 (100.0)*

Table 2. Mean and standard deviations for obsidian elemental composition measured by XRF from the Zhokhov site (this study) and the Chukotkan sources (after Grebenikov *et al.* 2018).

Element*	Zhokhov site (n = 14)	KRASN-1 (n = 33)	KRASN-2 (n = 8)	KRASN-3 (n = 1)	Vakarevo type (n = 5)
Mn	253 ± 4	176 ± 61	221 ± 5	560	247 ± 39
Fe (%)	0.76 ± 0.06	0.64 ± 0.03	1.11 ± 0.24	1.88	0.96 ± 0.04
Zn	56 ± 6	63 ± 16	112 ± 14	113	65 ± 15
Rb	220 ± 9	193 ± 8	144 ± 6	128	146 ± 3
Sr	3.0 ± 0.4	2.3 ± 0.8	1.3 ± 0.7	39	35 ± 2
Y	59 ± 2	54 ± 3	83 ± 4	56	41 ± 2
Zr	124 ± 3	116 ± 6	439 ± 12	451	135 ± 3
Nb	8.7 ± 0.4	7.3 ± 1.6	123.9 ± 1.3	8.3	5.7 ± 2.1
Th	17.4 ± 0.8	16.5 ± 2.2	14.1 ± 2.2	13.7	13.1 ± 1.4

*Content in parts-per-million (ppm), unless otherwise indicated.

Figure 1.

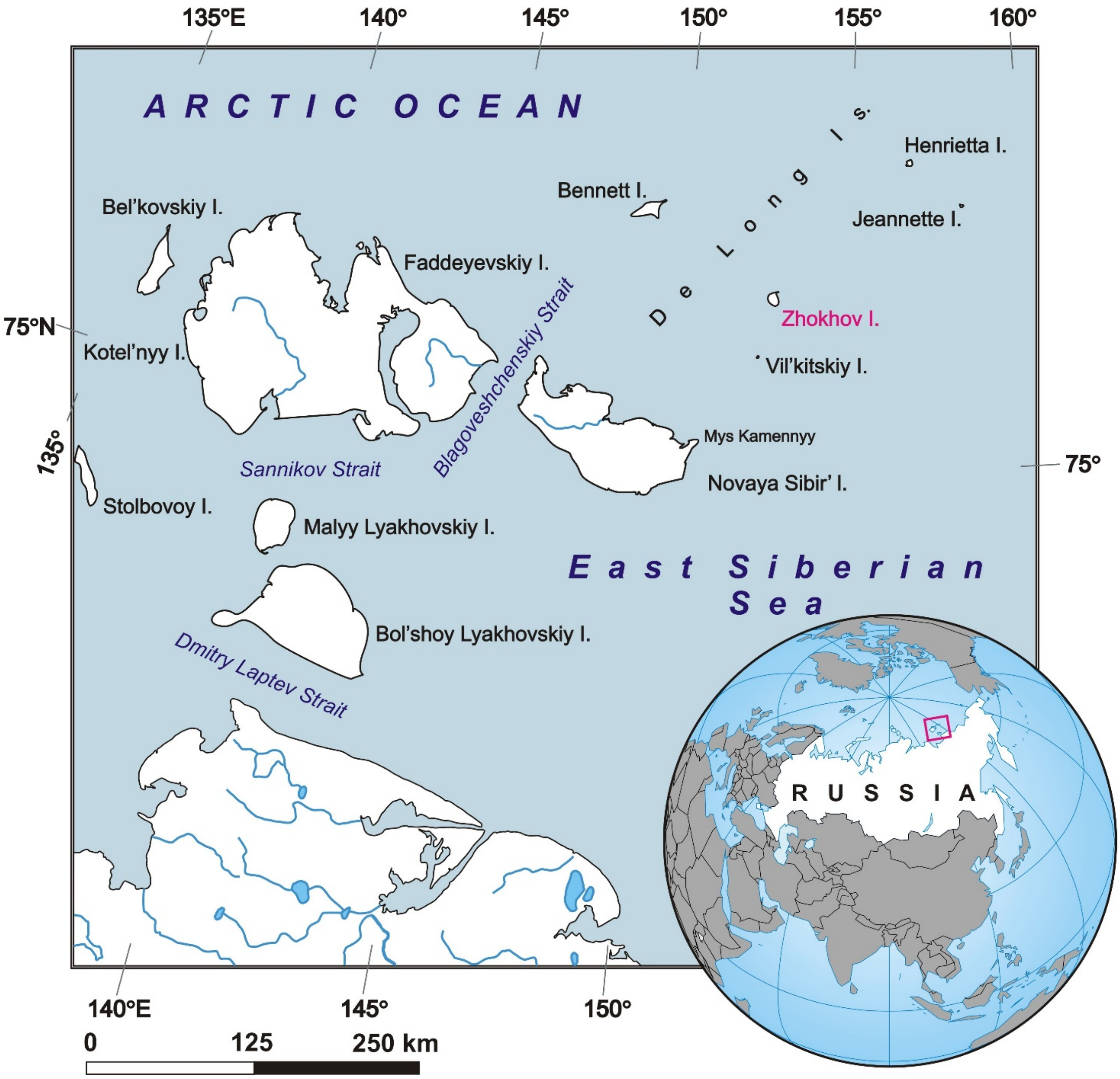
135°E
140°
145°
150°
155°
160°
ARCTIC OCEAN
De Long Is.
Henrietta I.
Bennett I.
Jeannette I.
Bel'kovskiy I.
Faddeyevskiy I.
Blagoveshchenskiy Strait
Zhokhov I.
75°N
Kotel'nyy I.
Vil'kitskiy I.
Mys Kamennyy
135°
75°
Sannikov Strait
Novaya Sibir' I.
Stolbovoy I.
Malyy Lyakhovskiy I.
East Siberian Sea
Bol'shoy Lyakhovskiy I.
Dmitry Laptev Strait
RUSSIA
140°E
145°
150°
0
125
250 km

Figure 2.