archaeometry

Archaeometry **63**, 6 (2021) 1141–1156 doi: 10.1111/arcm.12675

# SOURCING OF OBSIDIAN ARTEFACTS FROM THE OMOLON RIVER BASIN AND THE NEIGHBOURING REGION (NORTH-EASTERN SIBERIA): PREHISTORIC PROCUREMENT FROM KAMCHATKAN AND CHUKOTKAN SOURCES*

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*Obsidians sources used by prehistoric people in the Omolon River basin and neighbouring areas of north-eastern Siberia were determined for 112 artefacts from 30 sites by the energy-dispersive X-ray fluorescence (ED-XRF) method. The main suppliers were the primary obsidian sources in both the Chukotka (Lake Krasnoe) and Kamchatka (Itkavayam, Payalpan and KAM-8) regions, with distances from sources to sites up to about 300–900 km in a straight line. For the first time, the transport of obsidian from Kamchatkan sources has been detected outside of this territory. The mechanism of obsidian transport was most probably by down-the-line movement, especially in the case of the Lake Krasnoe source.*

*KEYWORDS:* OBSIDIAN, GEOCHEMISTRY, PROVENANCE, PREHISTORY, OMOLON RIVER BASIN, NORTHERN OKHOTSK SEA COAST, NORTH-EASTERN SIBERIA

## INTRODUCTION

The study of obsidian's provenance is a well-established field, and a plethora of research has been undertaken during the last 50 or more years in the Mediterranean region, Central Europe, Near East, North and South Americas, Mesoamerica, Oceania and New Zealand, insular Southeast Asia, and East Africa. It started in the 1960s with Colin Renfrew and colleagues (Cann and Renfrew 1964; Renfrew *et al*. 1968), and more research has taken place since that time. Today, the investigation of obsidian sources, including long-distance exchange, is a dynamic field (e.g., Dillian *et al*. 2007; Carter 2014; Le Bourdonnec *et al*. 2015; Martin and Hughes 2016;

*Received 28 September 2020; accepted 2 March 2021

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Méndez *et al*. 2018; Stern 2018; Barge *et al*. 2018; Campbell and Healey 2018; Carter *et al*. 2018; Freund 2018; see also Kuzmin *et al*. 2020b).

In Northeast Asia, the determination of obsidian sources was initiated in Japan in the late 1960s to early 1970s (e.g., Ono 1976; Suzuki 1973) and continued afterwards. In the Russian Far East, Korean Peninsula and north-east China (Manchuria), the sourcing of archaeological obsidian according to international standards of research (e.g., Glascock *et al*. 1998) began in the mid-1990s (Kuzmin *et al*. 1999; Shackley *et al*. 1996). One of the northernmost parts of Eurasia, namely north-eastern Siberia (Shahgedanova *et al*. 2002; Suslov 1961), was neglected for a long time, except for work by Cook (1995). Not until the mid-2000s were the first representative studies conducted (Glascock *et al*. 2006). This vast territory (about 2 140 000 km$^2$), which today is very sparsely populated, was the crossroads for different prehistoric human populations moving both within Northern Asia and toward North America (e.g., Kılınç *et al*. 2021; Kuzmin 2015, 2017; Sikora *et al*. 2019). This is why information on human contacts and migrations in north-eastern Siberia is very important for the prehistoric archaeology and physical anthropology of both Northern Asia and North America (e.g., Raghavan *et al*. 2014). One line of evidence in this respect is the obsidian exchange that was practiced in this part of the world since the final Palaeolithic–Mesolithic.

Investigations of the obsidian sources in the Kamchatka and Chukotka regions of north-eastern Siberia in mid-late 2000s (Glascock *et al*. 2006; Grebennikov *et al*. 2010, 2014, 2018; Grebennikov and Kuzmin 2017; Popov *et al*. 2017) made it possible to establish the peculiarities of obsidian use in these territories from the Late Palaeolithic to Neolithic–Bronze Age (Kuzmin *et al*. 2008, 2018, 2020a; Grebennikov *et al*. 2018; Pitulko *et al*. 2019; for a review, see Kuzmin 2019). However, the Omolon River basin and adjacent areas (Fig. 1) were studied only very preliminarily (Yoshitani *et al*. 2013). Here we present the first comprehensive data on the provenance of archaeological obsidian from this part of north-eastern Siberia, and discuss the implications of this information on the overall patterns of prehistoric obsidian exchange in Northern Eurasia. We determined the primary obsidians sources used by prehistoric people in the Omolon River basin and neighbouring areas of north-eastern Siberia by analysing 112 artefacts from 30 sites by an energy-dispersive X-ray fluorescence (ED-XRF) method.

## MATERIALS AND METHODS

For this study we selected 30 sites in Severo-Evensk county, Magadan province of Russia (Fig. 1 and Table 1). The sites are situated mainly in the basin of the Omolon River, the largest tributary of the Kolyma River (Arctic Ocean drainage), which is the main water artery in this part of Siberia. Some sites are located in the basins of smaller rivers: Gizhiga, Paren and Avekova. All flow into the Gizhiga and Penzhina bays of the Sea of Okhotsk (Pacific Ocean drainage). The territory under investigation covers about 67 400 km$^2$. Here, 40 archaeological sites with obsidian have been discovered up to date.

Archaeological investigations in the Omolon River basin began in 1979–80 by scholars from Yakutsk, and continued in the 1980s and early 1990s by researchers from Magadan. Active works ceased in 1995, and in the 2000s to early 2010s only limited surveys were conducted. The region under study is still relatively poorly studied. At a few sites, excavations with squares of about 80–100 m$^2$ were undertaken (Kiryak 1996; Vorobei 2003). The majority of sites were only briefly surveyed, and artefacts were collected from test pits and on the surface.

The sites belong to different periods of prehistory (Table 1). In the absence of radiocarbon ($^{14}$C) dates from archaeological contexts in this region, we rely on the chronological

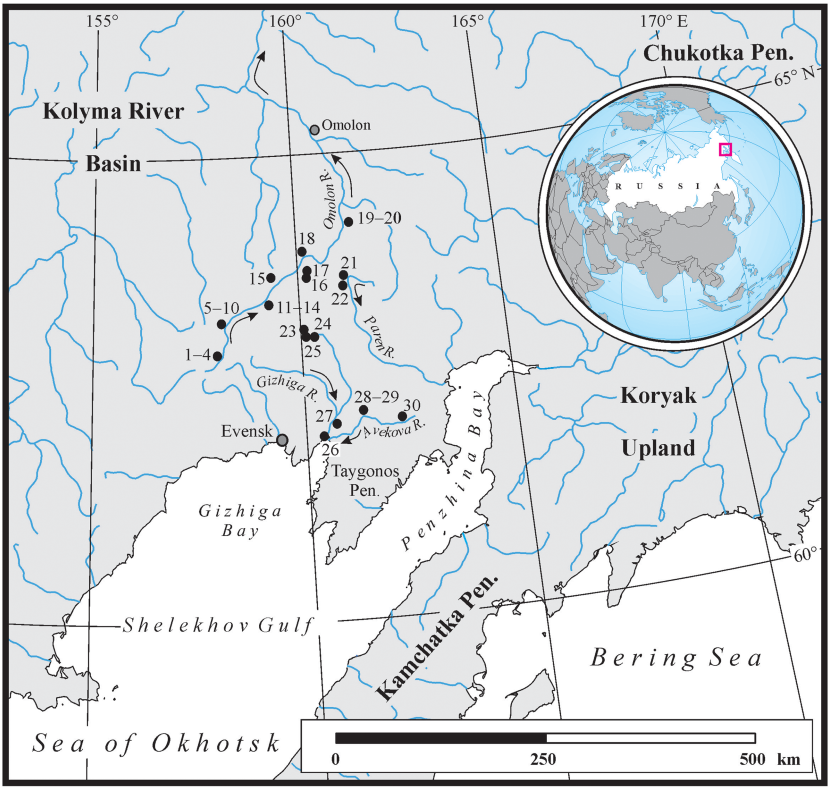


Figure 1 *Locations of the archaeological sites the Omolon River basin and neighbouring region analysed in this study. Site numbers correspond to those given in Table 1. [Colour figure can be viewed at wileyonlinelibrary.com]*

information from neighbouring territories: the western part of the Kolyma River basin, Yakutia, Kamchatka and Chukotka (Dikov 2004; Alekseyev and Dyakonov 2009; Kiryak 2010; Mochanov 2009; Pitulko and Pavlova 2016; for summaries, see Kuzmin 2000, 2010; Slobodin 2019). The compression of cultural materials from different periods into a single stratum because of the absence of simultaneous sedimentation (such as aeolian loess, for example) and cryogenic disturbance of deposits makes it impossible to separate artefacts belonging to repeated occupations. In such a situation, the main criterion for determining the periodization for a particular site is the typology of lithic artefacts. It should be noted that in Russian archaeology the presence of pottery allows one to determine the site as belonging to the Neolithic period (e.g., Kuzmin 2000; Oshibkina 1996). Most sites used in this study are associated with the Neolithic (Table 1) and do not contain any pottery, with a few exceptions, as indicated below.

The oldest site is Bolshoi Elgakhchan 2, which belongs to the final Palaeolithic (Kiryak 1996). Similar sites are found in the Gizhiga River basin (Vorobei 2003) and on Kamchatka (Dikov 1996, 2004). The assemblage is of wedge-shaped core type that is $^{14}$C dated in the neighbouring regions to about 11 000–9500 yr BP. The Bolshoi Elgakhchan 1 site is next to Bolshoi Elgakhchan 2 (Kiryak 1996), but it has an admixture of later materials that belong to the Mesolithic and Late Neolithic (Ymyakhtakh cultural complex; Kiryak 2010, 91–95, 119, pls 110–111). It is possible that some of the obsidian artefacts in Bolshoi Elgakhchan 1 come

Table 1 *Archaeological sites used in the study, with the obsidian artefacts analysed and primary sources identified*

| *No.* | *Site* | *Archaeological age* | *Coordinates* | *Number (%) of obsidian artefacts* | *Number of obsidian artefacts analysed* | *Obsidian source(s) identified* and number of associated artefacts†* |
|---|---|---|---|---|---|---|
| 1 | Geodezicheskaya 8 | Neolithic | 62° 49′ N, 158° 00′ E | 11 (2.3) | 2 | LK |
| 2 | Geodezicheskaya 12 | Neolithic | 62° 48′ N, 158° 00′ E | 5 (8.6) | 1 | LK |
| 3 | Lena 2 | Mesolithic–Neolithic | 62° 50′ N, 158° 00′ E | 51 (17.3) | 5 | LK |
| 4 | Beglaya 1 | Mesolithic | 62° 51′ N, 158° 03′ E | 28 (10.2) | 5 | LK (4), KAM-3 (1) |
| 5 | Malyutka | Neolithic | 63° 07′ N, 158° 09′ E | 34 (87.2) | 5 | KAM-3 |
| 6 | Pyataya | Neolithic | 63° 08′ N, 158° 09′ E | 4 (0.8) | 3 | LK |
| 7 | Vtoraya | Mesolithic–Neolithic | 63° 08′ N, 158° 09′ E | 1 (10.0) | 1 | LK |
| 8 | Shestaya | Mesolithic–Neolithic | 63° 08′ N, 158° 08′ E | 2 (50.0) | 2 | KAM-3 |
| 9 | Mysovaya | Neolithic | 63° 09′ N, 158° 07′E | 2 (1.8) | 2 | LK |
| 10 | Predzhdanka | Early Neolithic | 63° 10′ N, 158° 07′ E | 7 (20.0) | 4 | LK (2); Unk-A (1), Unk-B (1) |
| 11 | Verkhny Koargychan 1 | Neolithic | 63° 26′ N, 159° 10′ E | 1 (4.2) | 1 | Unk-C |
| 12 | Skalisty | Mesolithic–Neolithic | 63° 26′ N, 159° 06′ E | 1 (1.2) | 1 | LK |
| 13 | Nizhny Koargychan 1 | Late Neolithic | 63° 25′ N, 159° 15′ E | 156 (0.5) | 17 | KAM-3 (15); LK (2) |
| 14 | Nizhny Koargychan 3 | Mesolithic–Neolithic | 63° 24′ N, 159° 15′ E | 5 (26.3) | 4 | KAM-8 (3); LK (1) |
| 15 | Grisha 1 | Mesolithic–Neolithic | 63° 42′ N, 159° 25′ E | 302 (82.5) | 15 | KAM-3 (14); LK (1) |
| 16 | Kubaka-P | Mesolithic–Neolithic | 63° 37′ N, 159° 58′ E | 1 (3.3) | 1 | LK |
| 17 | Ust-Shchel | Neolithic | 63° 42′ N, 160° 03′ E | 5 (0.7) | 4 | KAM-5 (3); LK (1) |
| 18 | Mizinets 1 | Neolithic | 63° 55′ N, 159° 53′ E | 5 (0.4) | 4 | LK |
| 19 | Bolshoi Elgakhchan 1 | Final Palaeolithic–Neolithic | 64° 14′ N, 161° 07′ E | 56 (2.9) | 4 | LK |
| 20 | Bolshoi Elgakhchan 2 | Final Palaeolithic | 64° 14′ N, 161° 07′ E | 271 (64.5) | 9 | KAM-8 (6); LK (2); KAM-3 (1) |
| 21 | Parenskoe Ozero 1 | Mesolithic–Neolithic | 63° 43′ N, 161° 05′ E | 52 (5.9) | 9 | LK |
| 22 | Verkhovya Pareni 1 | Neolithic | 63° 38′ N, 161° 06′ E | 1 (2.4) | 1 | KAM-3 |
| 23 | Orochi 2 | Neolithic | 63° 04′ N, 160° 07′ E | 1 (5.9) | 1 | LK |
| 24 | Orochi 3 | Neolithic | 63° 01′ N, 160° 09′ E | 1 (3.1) | 1 | LK |
| 25 | Orochi 8 | Mesolithic–Neolithic | 62° 58′ N, 160° 14′ E | 1 (4.2) | 1 | KAM-3 |
| 26 | Staraya Gizhiga | Neolithic | 62° 03′ N, 160° 31′ E | 71 (0.9) | 5 | KAM-8 (3); LK (1), Unk-E (1) |
| 27 | Ust-Gizhiga 1 | Neolithic | 61° 57′ N, 160° 20′ E | 6 (0.5) | 1 | LK |
| 28 | Sobachy 1 | Neolithic | 62° 10′ N, 161° 18′ E | 1 (50.0) | 1 | Unk-D |
| 29 | Sobachy 2 | Neolithic | 62° 12′ N, 161° 16′ E | 1 (14.3) | 1 | KAM-3 |
| 30 | Avekova 3 | Neolithic | 62° 03′ N, 161° 58′ E | 4 (1.2) | 1 | KAM-3 |

Notes:
*LK, Lake Krasnoe (Chukotka); KAM-3, Itkavayam (Kamchatka); KAM-5, Payalpan (Kamchatka); KAM-8, north Kamchatkan source (with unknown precise location); and Unk-A, B, C, D and E, sources with unknown locations. In parentheses are the numbers of samples from particular sources when appropriate.
†In cases of two and more sources.

from the final Palaeolithic component, and we determined its age as a wide range from final Palaeolithic to Neolithic.

One site, Beglaya 1, is associated with the Mesolithic, using the presence of both microblades and blades, and without bifacial points and wedge-shaped cores. Based on comparisons with the neighbouring parts of Northeast Asia, the age of the Mesolithic can be roughly determined as about 9000–7000 yr BP.

Nine sites contain mixtures of artefacts belonging to two periods: Mesolithic and Neolithic (Table 1). At these sites, along with typical Mesolithic forms such as prismatic cores, Neolithic tools (bifacial artefacts and arrowheads) are also found. At the Parenskoe Ozero 1 site, a potsherd with surface decoration similar to a cord design was unearthed. Because it is impossible to distinguish the exact period to which the obsidian artefacts belong, we placed all these sites in a wide range from the Mesolithic to Neolithic (about 9000–2500 yr BP).

The Neolithic sites represent the major group (18 localities). It is possible to assign some of them to different stages of the Neolithic. The Predzhdanka site can be associated with the Early Neolithic (about 5900–4200 yr BP) (Alekseyev and Dyakonov 2009; Kistenev 1980). The Nizhny Koargychan 1 site contains pottery with a waffle design associated with the Ymyakhtakh cultural complex and also rims of pots with triangular rolls typical of the Ust-Mil’ complex of the Bronze Age in Yakutia (Alekseyev and Dyakonov 2009). The suggested age of this Late Neolithic site is about 4200–2500 yr BP, although Pitulko and Pavlova (2016) determined the timing of Ymyakhtakh culture as about 5000–1500 yr BP. The affiliation of 14 other sites can be determined as Neolithic in a broad sense, with a wide chronological interval of about 5900–2800 yr BP (Alekseyev and Dyakonov 2009).

The number of items made of obsidian at all 30 sites selected for this study was 1087 (out of a total of 48 193 lithics), that is, about 2.3%. The number of obsidian artefacts varies from site to site; the largest share is 87.2%; the smallest is 0.4% (Table 1). However, when we consider only sites with more than 100 artefacts, the percentage of obsidian is usually $< 3\%$. It is noteworthy that at some of these sites the amount of obsidian is quite high: 82.5% at Grisha 1 (of 366 items) and 64.5% at Bolshoi Elgakhchan 2 (of 420 items). For sites with the largest amount of lithics, the percentage of obsidian artefacts is relatively small: 2.9% at Bolshoi Elgakhchan 1 (of 1911 items), 0.9% at Staraya Gizhiga (of 7952 items), 0.5% at Nizhny Koargychan 1 (of 30 842 items) and Ust-Gizhiga 1 (of 1330 items), and 0.4% at Mizinets 1 (of 1337 items) (Table 1).

Typologically, obsidian artefacts from the Omolon River basin and adjacent region, as documented at the 40 sites, are represented mainly by flakes from prismatic and wedge-shaped cores (50.8% of total obsidian items), flakes from unclear contexts (24.4%), and prismatic spalls (blades and microblades) (22.4%). A single obsidian wedge-shaped core (0.1%) was found at the Bolshoi Elgakhachan 2 site (Kiryak 1996, 235; 2010, 270, pl. 113: 15). Prismatic spalls are found at all sites, with the largest amounts at Bolshoi Elgakhchan 1 (50 items), Parenskoe Ozero 1 (36 items), Nizhny Koargychan 1 (24 items), Bolshoi Elgakhchan 2 (21 items), Malyutka (18 items), and Beglaya 2 and Lena 2 (16 items each). Overall, products from core splitting constitute about 74% of lithic artefacts. The proportion of bifacial tools (mainly arrowheads and projectile points) is 2.3% of the total obsidians. The presence of obsidian prismatic core reduction at Bolshoi Elgakhchan 2 and Grisha 1 sites, and obsidian wedge-shaped core at the former site not analysed in this study allows us to assume that main purpose of obsidian use was to prepare different kinds of cores for making blades and microblades.

For our analysis we chose 112 artefacts, mainly with relatively flat surfaces (Fig. 2). Several factors were taken into account in order to select these items. First, this work represents the initial stage for the study of obsidian provenance in the Omolon River basin, and the main task was to

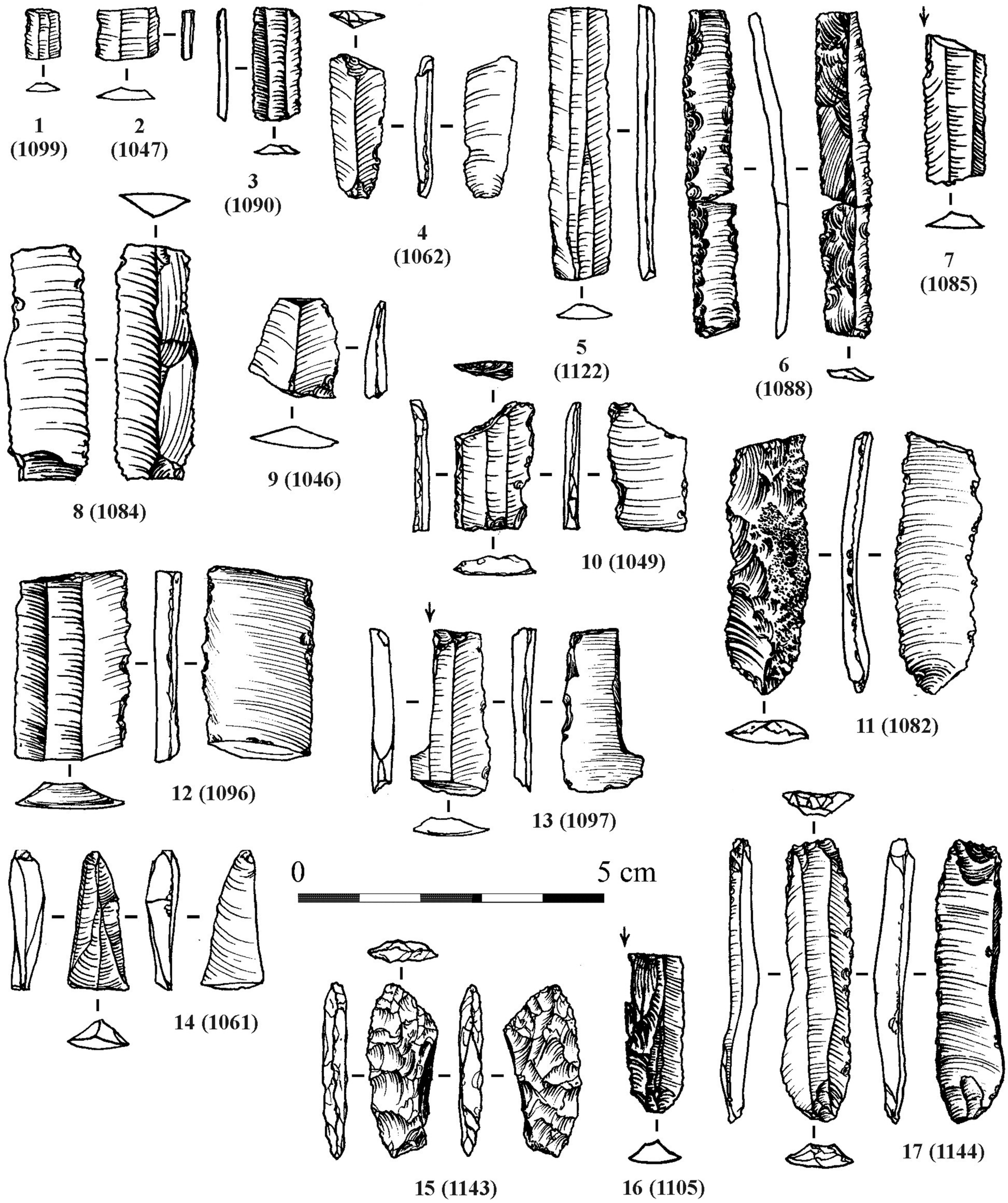


Figure 2 *Selected obsidian artefacts analysed in this study. Numbers in parentheses correspond to the KU numbers given in Table S1 in the additional supporting information: 1–5, microblades; 6, microblade with ventral and utilization retouches; 7, microblade with burin spall; 8–9, blades; 10, blade with oblique truncation and utilization retouch; 11–12, blades with utilization retouch; 13, 16, burins; 14, burin spall; 15, bifacial point; and 17, chisel. Drawings: K. V. Shtern.*

obtain the solid data from as many archaeological sites as possible without a complete analysis of obsidian artefacts which would require a massive effort and substantial funding. Second, there are organizational and technical limitations. They include the need to eliminate risk for the preservation of museum items (especially rare diagnostic categories), and the complexity of organizing a study of fragile artefacts outside the museum. Therefore, it was decided to choose samples primarily from the most common artefact types. The analysis did not include (with one exception) projectile points, including blades. Sampling was carried out in non-random way, but with the goal of including artefacts that differ from each other typologically, in size and visual characteristics, as well as items with the remains of cortex.

The obsidian specimens from the Omolon River basin and adjacent areas did not include artefacts from 10 sites (three of which were discovered after the sampling was done), but they accounted for only 1.9% (21 pieces) of the total amount in the region. Among the remaining 30 sites included into this study (Table 1), the localities with the small amount of obsidian (one to seven items) are best represented (65.5% of the total obsidian artefacts examined). Sites with a larger number of obsidian pieces (11–71 and 156–302 items) contain 5.6% and 11.6% of the overall corpus of specimens, respectively. In general, the ratio of obsidian artefacts analysed in this study is 10.3% of the total amount known from the Omolon River basin and the neighbouring territory.

Typologically, selected artefacts belong to the following categories: flakes and spalls ($n = 63$), prismatic blades and microblades ($n = 45$) (the latter category is up to 10–11 mm wide; Keates *et al*. 2019), including six items with secondary retouch (one chisel, three burins and two microblades with ventral edge retouch), one flake taken from the striking platform, one fragmented bifacial arrowhead, one burin spall and one notched tool. Seven artefacts have remains of cortex (Fig. 2: 11; see also Table S1 in the additional supporting information).

ED-XRF analysis of the obsidian artefacts was conducted at the Archaeometry Laboratory, Research Reactor Center, University of Missouri (MURR). Measurements were performed using a ThermoScientific ARL Quantx ED-XRF spectrometer. The instrument has a Rh-based X-ray tube and thermoelectrically cooled silicon-drift detector (SDD). The tube was operated at 35 kV, and the current was automatically adjusted to a fixed 30% dead time. The samples were counted for 2 min each permitting the determination of the following elements: K, Ti, Mn, Fe, Zn, Ga, Rb, Sr, Y, Zr, Nb and Th (Table 2; and see Table S1 in the additional supporting information). Normalization to the Compton scattering peak was used to account for differences in sample size and thickness (Hughes 2010). The Quantx ED-XRF spectrometer was calibrated for obsidian by measuring a set of 40 very well-characterized obsidian source samples previously analysed by neutron activation analysis (NAA), inductively coupled plasma-mass spectrometry (ICP-MS) and XRF methods.

Table 2 *Composition of geochemical groups for obsidian artefacts from the Omolon River basin and neighbouring region (parts per million, ppm), with 1 SD (standard deviation)*

| *Source* | *No.* | *K* | *Ti* | *Mn* | *Fe* | *Zn* |
|---|---|---|---|---|---|---|
| Lake Krasnoe (KRASN-1) | 50 | 36 564 ± 1398 | 538 ± 133 | 120 ± 52 | 6580 ± 810 | 44 ± 11 |
| Itkavayam (KAM-3) | 42 | 35 654 ± 1153 | 722 ± 141 | 417 ± 81 | 6262 ± 854 | 28 ± 8 |
| Payalpan (KAM-5) | 3 | 36 483 ± 779 | 690 ± 85 | 365 ± 35 | 4375 ± 498 | 22 ± 1 |
| KAM-8 | 12 | 34 650 ± 936 | 580 ± 44 | 163 ± 67 | 9633 ± 1007 | 32 ± 5 |
| Unknown-A | 1 | 35 576 | 443 | 49 | 8707 | 36 |
| Unknown-B | 1 | 39 369 | 278 | 96 | 7737 | 35 |
| Unknown-C | 1 | 34 311 | 395 | 117 | 9129 | 30 |
| Unknown-D | 1 | 34 195 | 768 | 176 | 10 731 | 40 |
| Unknown-E | 1 | 34 518 | 1027 | 169 | 13 114 | 64 |

Table 2 *(Continued)*

| *Source* | *Ga* | *Rb* | *Sr* | *Y* | *Zr* | *Nb* | *Th* |
|---|---|---|---|---|---|---|---|
| Lake Krasnoe (KRASN-1) | 17 ± 1 | 189 ± 13 | 8 ± 1 | 53 ± 5 | 117 ± 8 | 9 ± 1 | 15 ± 2 |
| Itkavayam (KAM-3) | 14 ± 0.1 | 70 ± 5 | 103 ± 9 | 16 ± 2 | 109 ± 9 | 11 ± 2 | 8 ± 1 |
| Payalpan (KAM-5) | 14 ± 0.1 | 88 ± 3 | 51 ± 7 | 13 ± 2 | 76 ± 6 | 13 ± 1 | 9 ± 1 |
| KAM-8 | 14 ± 0.1 | 109 ± 5 | 140 ± 7 | 15 ± 2 | 86 ± 9 | 5 ± 1 | 8 ± 1 |
| Unknown-A | 15 | 134 | 46 | 35 | 136 | 7 | 11 |
| Unknown-B | 16 | 146 | 28 | 42 | 96 | 10 | 12 |
| Unknown-C | 15 | 114 | 16 | 38 | 190 | 13 | 9 |
| Unknown-D | 15 | 109 | 145 | 16 | 115 | 7 | 8 |
| Unknown-E | 14 | 132 | 189 | 12 | 98 | 6 | 11 |

In order to find the most probable match to the primary source of obsidian, the geochemical data from Chukotka and Kamchatka regions studied earlier by our group were used for comparison (Glascock *et al*. 2006; Grebennikov *et al*. 2010, 2014, 2018; Grebennikov and Kuzmin 2017). We employed the approach developed by Glascock *et al*. (1998). All specimens from primary sources were previously tested by NAA at the MURR, and comprehensive geochemical ‘signatures’ based on the composition of 28 elements were established (e.g., Grebennikov *et al*. 2018; Grebennikov and Kuzmin 2017) (Fig. 3). Afterwards, it was possible to use the smaller number of elements measured by XRF to identify the particular obsidian source. Statistical grouping, based on bivariate plots, and cluster and discriminant classification analyses, were performed with the help of the GAUSS software (available from the MURR on request) to indicate the obsidian sources. Using this methodology, we were previously able to establish major obsidian sources for several archaeological sites on Kamchatka (Grebennikov *et al*. 2014; Grebennikov and Kuzmin 2017), Chukotka (Grebennikov *et al*. 2018), basins of Kolyma and Indigirka rivers (Kuzmin *et al*. 2018, 2020a), and the High Arctic (Pitulko *et al*. 2019).

For this study, we have several small artefacts, from 5 × 2 to 7 × 2 mm (e.g., KU-1099: 8.5 × 1.5 mm) (Fig. 2: 1). The following pairs of elements and element ratios were selected for sourcing: Sr/Zr versus Y/Zr; and Nb/Zr versus Rb (Fig. 3). The reason is that the concentrations of elements in ED-XRF are dependent on the volume of sample that interacts with the X-rays and returns a signal to the detector. Thus, both the thickness and cross-sectional area of the sample are extremely important. If the sample is large and thick, this issue can be ignored. However, when the artefact is small and thin, the problem is very significant. It is therefore more correct to examine elements that are adjacent to one another, for example, Rb and Sr, and Y and Zr. The best way to manage the problem with small artefacts is to create plots of element ratios of elements that are reasonably close on the periodic table; in our case, Sr/Rb, Rb/Zr, Y/Zr and Nb/Zr (Hughes 2010). Especially useful are Rb and Zr because they have the most counts (see Table S1 in the additional supporting information).

## RESULTS AND DISCUSSION

Bivariate plots were generated for obsidian artefacts from the Omolon River basin, and basins of the Gizhiga, Paren and Avekova rivers (Fig. 3). The compositions of geochemical groups, each representing either a known primary source or an unknown locality, are listed in Table 2. Ten

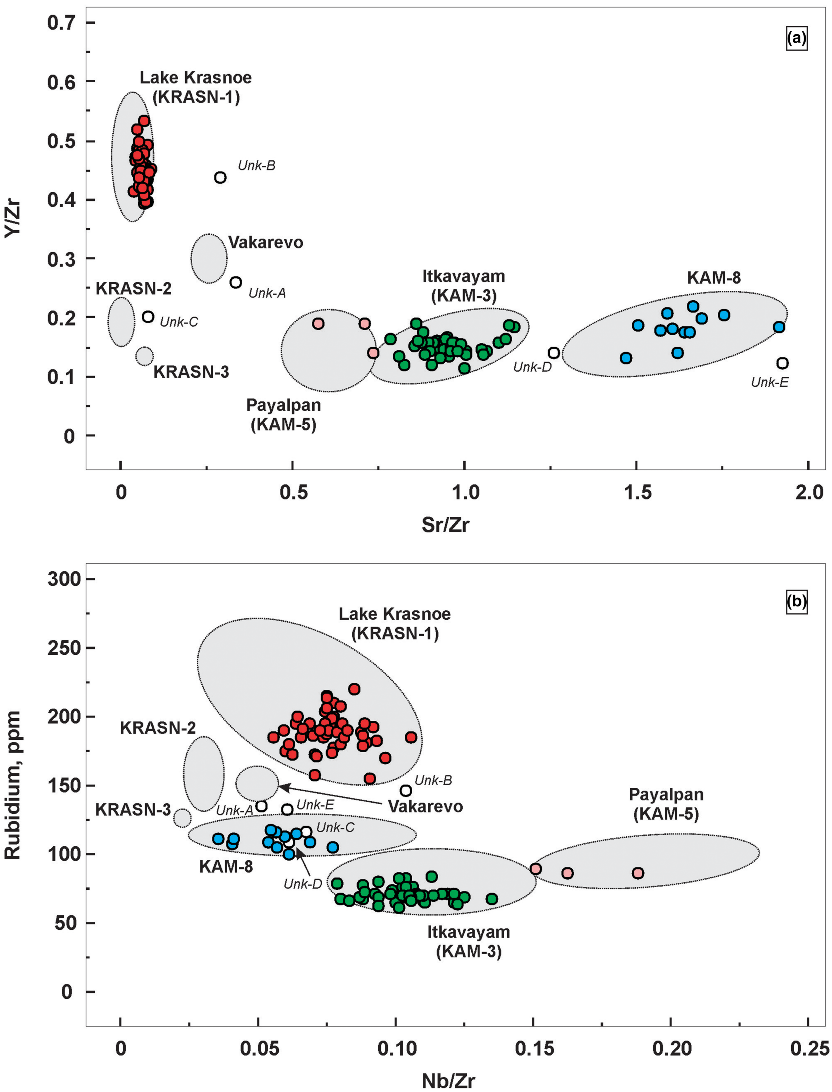


Figure 3 *Scatterplots of Sr/Zr versus Y/Zr (a) and Nb/Zr versus Rb (b) for obsidian artefacts in the Omolon River basin and adjacent areas, and major primary sources on Kamchatka and Chukotka. [Colour figure can be viewed at wileyonlinelibrary.com]*

artefacts used in this study were previously analysed by Yoshitani *et al*. (2013) with results similar to our source identifications. However, due to very limited knowledge about the geochemical composition of primary obsidian sources and their exact positions, the data generated by Yoshitani *et al*. (2013) should be considered as preliminary, and we do not discuss them here.

The main obsidian sources for sites in the Omolon River basin and neighbouring area were Lake Krasnoe (45.0% of total artefacts) on Chukotka, and Itkavayam (37.2%) on Kamchatka (Table 3). Some obsidian (11.0%) originated from the KAM-8 source in northern Kamchatka with a still unknown exact location (Grebennikov and Kuzmin 2017). The Payalpan source in central Kamchatka was used only occasionally (2.5%), but its remote position in relation to the

Table 3 *Distribution (%) of obsidian from the Omolon River basin and neighbouring region by sources and archaeological periods*

| *Sources/periods* | *Final Palaeolithic* | *Final Palaeolithic–Neolithic* | *Mesolithic* | *Mesolithic–Neolithic* | *Neolithic* | *Total* |
|---|---|---|---|---|---|---|
| Lake Krasnoe | 2 (1.8) | 4 (3.6) | 4 (3.6) | 19 (17.0) | 21 (19.0) | 50 (45.0) |
| Itkavayam (KAM-3) | 1 (0.8) | — | 1 (0.8) | 17 (15.1) | 23 (20.5) | 42 (37.2) |
| Payalpan (KAM-5) | — | — | — | — | 3 (2.5) | 3 (2.5) |
| KAM-8 | 6 (5.4) | — | — | 3 (2.8) | 3 (2.8) | 12 (11.0) |
| Unknown (A–D) | — | — | — | — | 5 (4.3) | 5 (4.3) |
| Total amount | 9 (8.0) | 4 (3.6) | 5 (about 4.5) | 39 (about 35.0) | 55 (about 48.9) | 112 (100.0) |
| Number of sources | 3 | 1 | 2 | 3 | 9 | 9 |

studied sites is noteworthy. Five artefacts (4.3%) were not assigned to any source in north-eastern Siberia known to us, and they are labelled as ‘unknowns’ (A–E).

The main source of obsidian for the Omolon River basin and adjacent territory is Lake Krasnoe (KRASN-1 geochemical group) in Chukotka. It was the major supplier of high-quality raw material for the entire prehistoric north-eastern Siberia, including Chukotka, Koryak Upland and basins of the Kolyma and Indigirka rivers (Fig. 4). The source is located about 650–850 km from the studied sites in a straight line. As for other parts of north-eastern Siberia, in several cases the distance between the Lake Krasnoe source and utilization sites > 1000 km as the crow flies (Kuzmin *et al*. 2018, 2020a) (Fig. 4), and in the case of Zhokhov site in the High Arctic it is about 1500 km (Pitulko *et al*. 2019). The second most important source, Itkavayam (KAM-3 group), is situated in northern Kamchatka, at about 500–700 km in a straight line (Fig. 4). Two other primary obsidian localities from Kamchatka, Payalpan (KAM-5 group) and KAM-8, are also located far from the Omolon River basin and territory around it, about 900 and about 300–500 km as crow flies, respectively.

The presence of Kamchatkan obsidian in relatively large quantities outside of the Kamchatka Peninsula was previously unknown, and only a few artefacts from this region were identified in Chukotka (Grebennikov *et al*. 2018). By summing up the three sources, Itkavayam, KAM-8 and Payalpan, the total share of Kamchatkan obsidian in the region under consideration is equal to the Chukotkan source at Lake Krasnoe (Table 3). It seems that the Omolon River basin and neighbouring region was one of the ‘contact zones’ *sensu* Kuzmin (2014) where the distribution of obsidian from several sources overlap. This is an important new feature regarding the exploitation of archaeological obsidian sources in north-eastern Siberia.

As for the use of obsidian in different periods in the Omolon River basin and adjacent territory (Table 3), in the final Palaeolithic three sources were exploited. Although only one site was analysed so far. In the final Palaeolithic–Neolithic, a single source was used; but again the amount of data is limited. In the Mesolithic, obsidian was acquired from two sources; however, only one site was investigated. In the Mesolithic–Neolithic, three primary obsidian localities supplied obsidian, and the use of this raw material was more active than in previous times. The share of obsidian is the highest for the Neolithic when four major sources were exploited, and some unknown localities (which possibly represent separate sources) were also exploited.

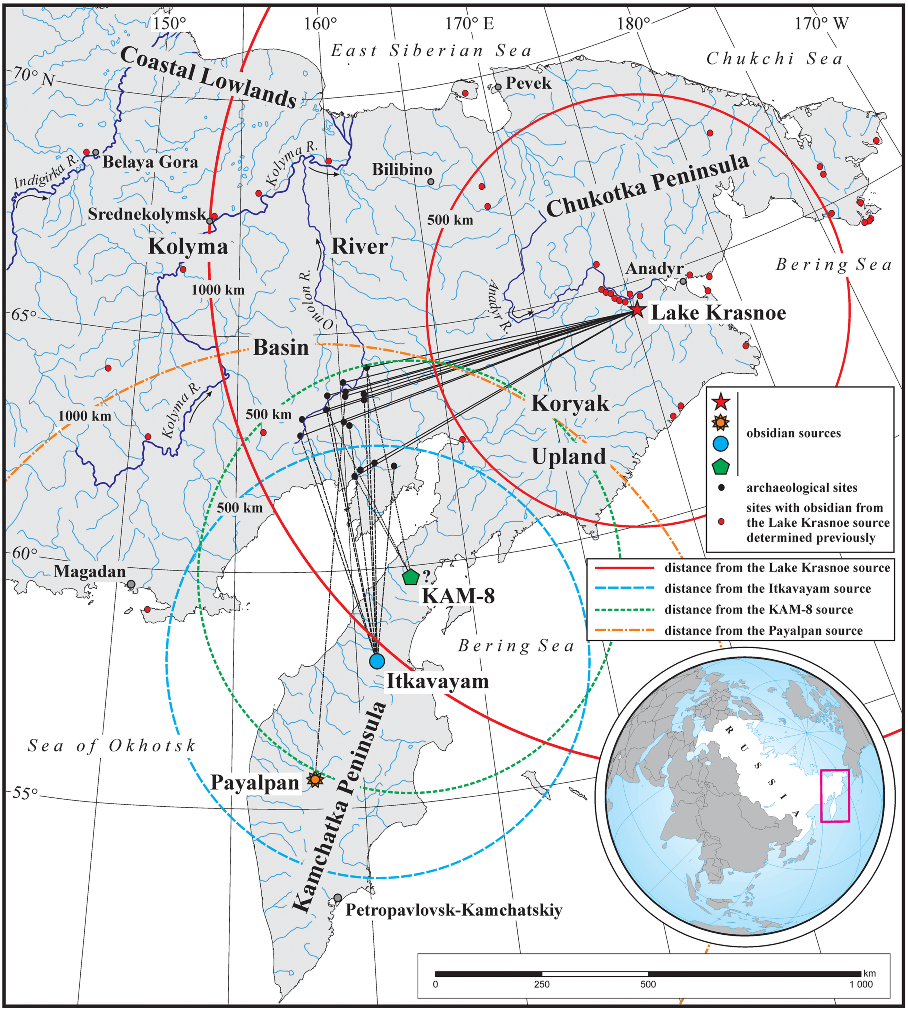


Figure 4 *Spread of obsidian from primary sources in north-eastern Siberia to archaeological sites in the Omolon River basin and neighbouring region. [Colour figure can be viewed at wileyonlinelibrary.com]*

The issue of unknown sources in the Neolithic obsidian assemblages (four sites) (Table 1 and Fig. 3) remains not yet fully understood. On the one hand, these artefacts could be outliers, but, on the other, one should consider that the Kamchatka Peninsula has at least 30 obsidian sources, including several in the northern part relatively close to the Omolon River (Grebennikov *et al*. 2010, 90), and only 16 of them have been sampled and studied geochemically (Grebennikov *et al*. 2014; Grebennikov and Kuzmin 2017). It is therefore possible that some of these groups represent sources that were rarely used by prehistoric humans in the Omolon River basin and around it. This, however, remains speculative until more data are available.

The mechanism of acquisition and transportation of obsidian from remote sources to the Omolon River basin and neighbouring area deserves special attention. Previously, the down-the-line mode of exchange *sensu* Renfrew (1975) was suggested based on data from the Kolyma River basin (Kuzmin *et al*. 2018) and High Arctic (Pitulko *et al*. 2019). According to these studies, obsidian was brought as cores (Kolyma River sites) and blades (Zhokhov site, New Siberian Islands). Although information about the *chaîne opératoire* for the Omolon River basin is limited, some suggestions can be made about the modes of transportation of obsidian from sources to utilization sites.

In the region under this study, 19 artefacts with remains of pebble cortex and the rough surface of original raw material blocks were found. Seven of them (six with a pebble cortex and one with a rough surface) were analysed (Fig. 2: 11). Five artefacts come from the Lake Krasnoe source and two from KAM-8 and Itkavayam locales (see Table S1 in the additional supporting information). This shows the movement of partly worked raw nodules that were used at occupation sites, mainly from Lake Krasnoe where the primary source is the concentration of obsidian pebbles and small boulders on the beach (Grebennikov *et al*. 2018).

A more comprehensive discussion of the mechanisms for the transportation and exchange of obsidian in the Omolon River basin is impossible not only due to the nature of the materials themselves, but also because of 'white spots' between the region under study and the sources, and the lack of published quantitative data for the Chukotkan and Kamchatkan sites with obsidian artefacts which were studied previously (Grebennikov *et al*. 2010, 2014, 2018; Grebennikov and Kuzmin 2017; Kuzmin *et al*. 2008; Popov *et al*. 2017). Therefore, sites in the Omolon River basin with obsidian from the Itkavayam source (Kamchatka) mark the last third (distances from the source is 500–700 km), and from the Krasnoe Lake (Chukotka) only the last quarter (distances from the source is 650–850 km) of the corresponding radii (Fig. 4).

Nevertheless, some observations can be made about the circulation of obsidian in the Omolon River basin and adjacent areas based on our quantitative data. At the same time, attention should be focused on the presence of specific indicators, and not on quantitative ratios. In the obsidian artefact collections there are two categories of *chaîne opératoire*: (1) prismatic knapping (including the one based on wedge-shaped microcores) and (2) production of bifacial tools not directly associated with prismatic blades. Neither of these categories is presented in our materials in full.

The elements of prismatic knapping give an idea of the knapping sequence, presented in the form of the following stages: selection of raw material → sampling and/or initial preparation → pre-forming (fashioning of core preform) → knapping (including the cyclic one). The continuation of this sequence is associated with the fashioning and use of bladelets and some flakes. It is impossible for us to study the selection of raw material directly at the sources. The supply to the Omolon River basin of non-worked pebbles and angular pieces was possible, but there is no evidence for that. The initial preparation of raw material (whole artefacts and diagnostic flakes/spalls) is also unknown. The longest regional *chaîne opératoire* can be reasonably reconstructed from the stage of pre-forming.

The pre-forming for the production of bladelets and microblades is represented by flakes at the sites of Bolshoi Elgakhchan 2 (244 pieces) and Grisha 1 (294 pieces, as well as six irregular bladelets and one diagnostic flake of fashioning the platform of prismatic core), among which there are rare specimens with secondary fashioning. The degree of reduction of raw material to some extent depends on the shape of the ellipse-like and angular pieces; therefore, the cortex could be preserved on core preforms. This is testified by a fragmented bladelet from the Kubaka-P site (Fig. 2: 11); two bladelet fragments with rough surface from the sites of Nizhniy Koargychan 1 and Bolshoi Elgakhchan 2; and a fragment of blade spall with remains of pebble cortex from the Lena 2 site. The knapping, carried out directly at the sites in order to obtain blade and microblades~~,~~ is evident from a number of artefacts. These are one wedge-shaped microcore and two platform rejuvenation spalls at the Bolshoi Elgakhchan 2 site; core trimming flakes for a platform of prismatic microcores at the sites of Lena 2 (three pieces), Beglaya 1 (three pieces), and Parenskoye Ozero 1 (one piece); distal massive fragments of plunging blades which took off the bases of prismatic microcores at the sites of Lena 2 (two pieces) and Lena 3 (one piece). The fact that in the Omolon River basin such splitting was carried out ‘from the beginning’ (i.e. starts from the pre-core), in addition to the above-mentioned bladelets with any cortex remnants, is also testified (although indirectly) by artefacts with negatives of core preforms on dorsal side (Fig. 2: 6, 8, 11, 16).

The production of bifaces (mainly projectile points) is represented only by the final forms. In addition to two medium-sized (up to 60 mm long) specimens, these are small fragments (including those with burin re-formalization) that retained only individual elements of the original configuration without the possibility of using it in the previous function. Spalls, presumably derived from making or readjusting the points, are also known, but they are generally small and do not represent all the stages in the production of the final forms. It can be assumed that flakes and small spalls, including blade-like ones, served as blanks.

Taking into account Renfrew’s down-the-line concept (e.g., Renfrew 1975), it is possible to suggest that direct acquisition of obsidian by inhabitants of the area under study beyond the ‘supply zone’ of about 300 km in diameter from the source was unlikely. The transport of obsidian raw material to the Omolon River basin was most probably carried out in the form of pre-processed blanks. For the final Palaeolithic, the supply of large bifaces can also be assumed. Further circulation of obsidian in the region was conducted not only as final products but also as preforms and cores, with their knapping directly at habitation sites if necessary. It is plausible to assume that the obsidian exchange was carried out through the network of prehistoric ‘hubs’ as it was earlier suggested for the Zhokhov site in the High Arctic (Pitulko *et al*. 2019). Nevertheless, more work needs to be done in order to obtain a better understanding of this process.

## CONCLUSIONS

The exploitation of obsidian as raw material in the Omolon River basin and neighbouring territory began in the final Palaeolithic, about 11 000–9500 yr BP, and continued throughout prehistory. Obsidian was used primarily to make blades and microblades, and their further utilization. The exchange networks existed in this remote—even by modern standards—region for millennia, with distances from primary obsidian sources to utilization sites of about 300–700 km in a straight line, and sometimes up to 900 km. For the first time, the extensive use of obsidian from several Kamchatkan sources outside of the Kamchatka Peninsula is established.

The transportation of obsidian was most probably conducted via the chain of intermediaries rather than by direct procurement from the sources. The incorporation of the Omolon River basin and adjacent areas into a vast prehistoric exchange network centred around the Lake Krasnoe source on Chukotka, which covers about 2 000 000 km$^2$, is additional evidence of a well-developed subsistence strategy with long-distance contacts and primitive exchange/trade of lithic raw material. Now the Omolon River basin and neighbouring region can be properly included into the wide system of obsidian acquisition that existed in north-eastern Siberia since the final Palaeolithic–Mesolithic.

## ACKNOWLEDGEMENTS

The authors are grateful to K. V. Shtern for assistance with the preparation of artefact drawings. The research by Y. V. Kuzmin and A. V. Grebennikov was supported by the State Assignment of the Sobolev Institute of Geology and Mineralogy, Siberian Branch of the Russian Academy of

Sciences, with funding provided by the Ministry of Science and Higher Education of the Russian Federation. The Archaeometry Laboratory at MURR is supported in part by a grant from the US National Science Foundation (grant number NSF-1912776). Comments by two anonymous reviewers were very helpful and improved an earlier version of this paper, for which the authors are very pleased.

## *PEER REVIEW*

The peer review history for this article is available at https://publons.com/publon/10.1111/arcm.12675.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

**Table S1.** Artefacts and their geochemical composition.