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Moving sources: A preliminary study of volcanic glass artifact distributions in northeast China using PXRF

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ABSTRACT

Recent studies have highlighted the long-distance transport of obsidian from the Paektusan (Tianchi or Baitoushan in Chinese) volcano on the border between China and North Korea to eastern Russia and Korea, but little is known about the role of the local population in the production and movement or exchange of this important raw material. This paper addresses this data lacuna by presenting sourcing results of 440 artifacts from 18 Late Paleolithic sites located in northeast China. A portable XRF enabled rapid non-destructive characterization of samples. The results show that although Paektusan obsidian was widely transported throughout northeast Asia, material from at least three other sources was also used. In particular, we highlight the significance of basaltic glass artifacts with the same geochemistry as sources found in the Primorye region of Far East Russia in sites from northeast China. This result indicates a two-way movement of volcanic glass artifacts between Primorye and the northeast of China rather than a unidirectional long-distance exchange system originating from Paektusan Volcano.

1. Introduction

Volcanic glass artifacts occur in many archaeological sites throughout Far East Russia, the Korean Peninsula and in the Changbaishan region of northeast China (Fig. 1). A variety of geochemical techniques (e.g. NAA, EDXRF, PIXE-PIGME) have linked the elemental composition of artifacts from Primorye in the Far East of Russia (e.g. Doelman et al., 2008; Popov et al., 2005, 2008; Kuzmin et al., 1999, 2000; Kuzmin and Popov, 2000, 2002a) and South Korea (Popov et al., 2005; Kim et al., 2007) to Paektusan Volcano, an important source of volcanic glass located on the border of North Korea and China (Fig. 1). In the surrounding Changbaishan region, near Paektusan (Tianchi or Baitoushan in Chinese) Volcano, large numbers of volcanic glass artifacts recovered by Chinese archaeologists from many Upper Palaeolithic through to the early Iron Age sites are now held at Jilin University. To date only a small number of artifacts have been geochemically analyzed using PIXE-PIGME (Chen et al., 2009). The limited amount of geochemical analysis of volcanic glass artifacts in northeast China has left a significant gap in our understanding of their procurement, manufacture and distribution in northeast Asia.

Three mechanisms have been proposed to account for the very long-distance movement of obsidian in eastern Asia: (1) highly mobile hunter/gatherers acquiring stone directly from the source, (2) networks of trade/exchange between groups of hunter/gatherers, and (3) the continuous colonization and occupation of new regions (e.g. Phillips and Speakman, 2009; Doelman et al., 2004, 2008). The vast distances (up to 1000 km) that volcanic glass artifacts were transported from Paektusan Volcano potentially indicates an early exchange system, as purported by Kuzmin et al. (2002a,b), but to fully understand the nature of social interaction, it is necessary to study obsidian discard near the source in China. An international collaborative project between Australian and Chinese archaeologists has begun this task by investigating the prehistoric distribution of volcanic glass sources in northeast China. The initial aim of this project is to establish the number of sources used and their distribution in northeast China. At this stage of the research we cannot fully address the mechanisms behind the long-distance

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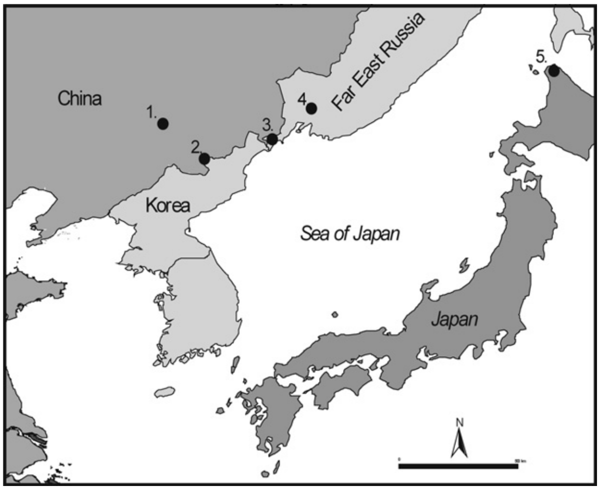

Fig. 1. The location of the study area showing the sources of volcanic glass. 1. Jilin Jiutai 2. Paektusan Volcano, 3. Gladkaya River Sources, 4. Shoktovo Plateau (basaltic glass). 5. Shirataki, Hokkaido.

movement of obsidian. A more detailed analysis of the typological and technological characteristics of the artifacts is needed to achieve this goal. Here we can only make tentative observations on the distribution of volcanic glass movement in the region.

To test the possibility that Russian basaltic glass was imported into China and to gain a better understanding of potential exchange networks, a much larger sample was required. A decision was made to focus on the Late Paleolithic period, for which there are excellent comparative studies elsewhere in Southeast Asia and abundant material was available for study at Jilin University. To ensure that an adequate sample size was obtained, the study utilized a portable XRF (Bruker AXS Tracer-III-V PXRF), also known as a handheld X-ray Fluorescence Spectrometer (XRF). This equipment enabled non-destructive, rapid and accurate characterization with no need to remove samples from the laboratory at Jilin University. A total of 440 artifacts from sites 18 dating to the Late Paleolithic were analyzed. In addition, geological data from various sources in Far East Russia allows us to trace artifacts back to well known sources in the wider region (Fig. 1; Doelman et al., 2008). The results provide new data highlighting the complexity of artifact movement in northeast China during the Late Paleolithic.

2. Archaeological background

All the artifacts in this study are from surface collections made at 18 Late Paleolithic sites. Most of these sites are distributed on the northern slopes of the Changbaishan Mountains which run along the border of China and North Korea (Fig. 1). The furthest from Paektusan Volcano is the Qinjia Dongshan site (QJDS) which is approximately 320 km away. Among these, 12 sites have been excavated. Although there are still no absolute dates available, the artifact typology and faunal assemblage indicate that they date to the Late Paleolithic (Chen and Wang, 2008; Chen et al., 2009, 2008a,b, 2006a,b,c; Chen and Zhang, 2004). Hopefully, future research will expand the study to include artifacts from stratified, well-dated contexts.

It was expected that the majority of the volcanic glass artifacts in these sites were derived from Paektusan Volcano. Previous research at sites located near volcanic glass sources in the central Primorye Region of Far East Russia has shown that artifacts from both local and distant (i.e. Paektusan Volcano) sources occur, the most from immediate sources (Doelman et al., 2008; Doelman, 2008). It is important to examine whether the same pattern emerges in northeast China as this can establish whether volcanic glass movement was unidirectional or a two-way movement across vast distances. As a result, this study allows us to further explore the mechanisms behind the movement of volcanic glass in the region.

3. Geological background

In northeast China there are three major volcanic zones: Songliao, Changbaishan and Daxing'anling. The Paektusan Volcano together with other three volcanoes: Wangtian'e, Longgang and Tumen belong to Changbaishan volcanic zone (Fan et al., 2007; Liu et al., 2002a,b; Li, 2007). Obsidian is only known to occur from the Paektusan volcano based on current geoarchaeological study. This volcano was formed through three stages of volcanism: (1) shield-forming, (2) cone-forming and (3) modern-day ignimbrite sheet (Wei et al., 2006). Today Paektusan Volcano is a large active stratovolcano of predominately pantellerite–trachyte (from the cone-building stage) formed over 3 Ma with a height of 2744 masl and a diameter of 10 km (Popov et al., 2005: 803). Volcanic glass was formed during the cone-building stage from ~1.59 Ma when the composition of the volcano changed from basaltic to trachyte. A series of catastrophic eruptions have typified its history, the last occurring more than 1000 years ago which formed the overlying, Stage 3 air-fall deposits of ignimbrite (Popov et al., 2005: 804; Ruoxin et al., 1998: 384). Paektusan Volcano lies on an extensive basaltic shield (Stage 1) formed from multiple eruptions.

Although numerous basaltic eruptions (c.f. Li, 2007) have taken place throughout northeast China no sources of basaltic volcanic glass have be described in the region. A significant gap in our understanding of the regional geology is the extension of the Shufan Basaltic Plateau into China from Primorye region of Far East Russia. In Primorye volcanic glass is found in the Basaltic Plateau. The plateau is sub-divided into the Shkotovo Plateau and the Shufan Plateau. This geochemical source was intensively exploited from the Upper Paleolithic through to the Bronze Age (Doelman et al., 2008; Kuzmin et al., 2002b). Potentially sources of volcanic glass occur in China with the same geochemistry as those in Russia.

4. Sources of volcano glass

Numerous studies have focused on the sourcing and movement of volcanic glass artifacts in northeast Asia, including Japan, Kuril Islands, Kamchatka, Sakhalin Island and Primorye (Russian Far East) (e.g. Doelman et al., 2008; Glascock et al., 2000, 2006; Kuzmin, 2006; Kuzmin et al., 1999, 2000, 2002a,b; Speakman et al., 2005; Phillips and Speakman, 2009). Consequently, the geochemistries of a significant number of volcanic glass sources in the wider region are well documented. In particular, thanks to the work done by previous scholars (e.g. Kuzmin et al., 2000; Popov et al., 2005), the geochemistry of the volcanic glass from Paektusan Volcano is well known. However, no geochemical data is available for other potential volcanic glass sources in northeast China.

Three distinct sub-groups of volcanic glass from Paektusan Volcano have been recognized: PNK 1, 2 and 3 (Popov et al., 2005, 2008; Kuzmin et al., 2002a,b). Only two of the three groups (PNK1 and PNK2) were used to make artifacts. PNK1 is a trachyrhyolitic glass classified as obsidian–perlite and perlite and is found along the southern side of the Paektusan summit in North Korea between the peaks of Khiando and Sanmuchjige, although the exact location is still unknown (Popov et al., 2005: 806). The second group (PNK2) is pantelleritic obsidian found near the summit of Paektusan Volcano (in China). The presence of phenocrysts makes this group of low flaking quality. PNK3 consists of alkali trachydacite obsidian from the slopes of the volcano also found in China. This volcanic glass is of very poor flaking quality (Popov et al., 2005: 806). PNK1 was considered the highest quality material and is more commonly found in archaeological sites than PNK2 (Kuzmin et al., 2002b; Popov et al., 2005; Kim et al., 2007: 126).

Although most artifacts have been characterized to PNK1, the actual outcrops that were quarried in the past are unknown. The border between China and North Korea follows the summit of the volcano. On the southwest slope of Paektusan Volcano in North Korea a layer of volcanic glass was noted (Michiya, 2000). The geological map that he derived from Paek et al. (1996) clearly indicates the location of this layer of volcanic glass (Fig. 3). Whether the two geological samples of PNK1 geochemically tested by Popov et al. (2005) are from the same layer, which extends into China, is unclear but highly likely. It is possible that quarrying has occurred along this layer both in China and in North Korea, but further fieldwork is required to locate these sites.

Geological samples collected by Chen near the crater of Paektusan Volcano were used in this study (Source Paektusan A1). The quality of these samples is similar to the source samples of PNK2 and PNK3 and described by Popov et al. (2005) as very poor and unsuitable for making stone tools. As yet no good quality samples of volcanic glass have been obtained from Paektusan Volcano for this study (e.g. PNK1). It is possible that a subsequent large-scale eruption (c. 1000 AD) destroyed or covered the earlier high quality volcanic glass outcrops in northeast China (Kim et al., 2007). Equally, outcrops of high quality volcanic glass may only occur in North Korea. A systematic geoarchaeological survey needs to be undertaken in the area.

The geochemistry of PNK1 was derived from source samples obtained by Kuzmin et al. (2002b) and compared to PIXE-PIGME analysis by Doelman et al. (2004). In addition, due to the difficulty of obtaining good quality source samples from Paektusan Volcano, 27 artifacts from the prehistoric site of Zaisanovka in the Primorye region of Far East Russia (PNK1 in Kuzmin et al., 2002b) were included as "Paektusan" source reference. Previous research using PIXE-PIGME found that these artifacts were from Paektusan Volcano (Doelman et al., 2004, 2008).

In the wider region other sources of basaltic glass and rhyolitic obsidian (Gladkaya) in the Primorye Region of Far East Russia were geochemically analyzed, firstly by Kuzmin et al. (1999, 2002b) using NAA and EDXRF and supported by further PIXE-PIGME analysis (Doelman et al., 2008) (Fig. 1). A total of 82 samples of basaltic glass (Russian Basaltic Glass) and 13 geological samples from primary outcrop and secondary sources along the Gladkaya River (Gladkaya Outcrop), already characterized using PIXE-PIGME, were included in the database for this study (Doelman et al., 2008). Two additional sources were also included: Japan-BL ($n = 6$), collected by Chinese archaeologists from the archaeological site of Shirataki in Hokkaido (Izuho and Sato, 2007) and geological samples ($n = 7$) from Jilin Jiutai (Jiutai), a volcanic region north of the Paektusan region in northeast China (Fig. 1).

5. Methodology

The use of a portable XRF has become increasingly well established as a non-destructive and quick method for geochemically identifying sources (e.g. Drake et al., 2009; Phillips and Speakman, 2009; Williams-Thorpe, 2003), A significant problem arises when comparing the results of PXRF with other methods. For example, a recent study highlighted an incompatible between the results derived from portable XRF and laboratory based XRF (Nazaroff et al. 2009). However, this study also showed that the results from the PXRF were internally consistent and therefore reliable in differentiating sources. A similar problem has occurred with PIXE-PIGME analysis. A comparative study of PXRF and PIXE-PIGME using ten artifacts from Paektusan Volcano and 10 of basaltic glass showed that while the means of three elements compared are different (Ti, Mn, Fe) and the standard deviations within each method is low (Table 1). This result indicates that each method is internally accurate. A further test of precision was undertaken for the PXRF. Each sample was read three times and little variation occurred in the results (Table 2).

For this study, the equipment used was a Bruker Tracer-III PXRF with a rhodium tube and a SiPIN detector with a resolution of ca. 170 eV FHWM for 5.9 keV X-rays (at 1000 counts per second) in an area of 7 mm^2. All analyses were conducted at 40 keV (15 mA) using a 0.076-mm filter constructed by 0.006″ Cu, 0.001″ Ti and then 0.012″ Al specifically designed for volcanic glass analysis with the X-ray path for a 180-s live-time count suggested by Bruker. The readings from the PXRF were directly transferred to a laptop showing the spectrum interface. Each sample was tested once. The following 14 elements were measured: Manganese (Mn), Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Gallium (Ga), Lead (Pb), Thorium (Th), Rubidium (Rb), Strontium (Sr), Yttrium (Y), Zirconium (Zr), and Niobium (Nb). A calibration file (KTIS1CalProcess.OCX, Verson:2.2.31) provided by Dr. Jeffrey R. Ferguson (University of Missouri) was used to adjust and convert the readings to parts-per-million (ppm). The spectrum readings were then transferred to an MS Excel spreadsheet and factor and principal component analyses were undertaken in SPSS 16. Separate analyses of source samples and artifacts were undertaken and then compared.

Artifacts were randomly selected from 18 sites for PXRF analysis in order to achieve a representative study population of the obsidian artifacts with less interference from researcher's preference (Table 3, Fig. 2). The proportion chosen varied depending on the size of the site with 100 percent samples for very small collections. Random sampling was used for large sites that have more than a thousand volcanic glass artifacts (e.g. Antu Shirengou (SRG) and Dadong (DD)), but for small assemblages (e.g. Dongtai, FH with less than ten) all artifacts were tested (Table 3). Some samples of special interest for local archaeological questions were also included.

6. Results

The plot of the first two principal components in Fig. 4 demonstrates that PXRF data can achieve a clear segregation between the sources included in the study. The distribution of basaltic glass samples is based on a reasonably large sample number ($n = 82$) and is a good indicator of the elemental variation. The elemental composition of the Gladkaya sources, in Far East Russia, is also well documented using the PXRF ($n = 6$). Samples A and Sample A1 from Paektusan Volcano are closely related (Fig. 4). However, Paektusan Volcano Sample A (PNK1) is based on only two geological samples. Similarly, Japan-BL and Jilin Jiutai have low sample numbers.

Table 1
The results comparison for three elements (Ti, Mn, Fe).

Source		PXRF		PIXE-PIGME	
		Basaltic	Paektusan	Basaltic	Paektusan
Ti	Mean	14 248.010	1415.458	8729.909	1054.242
	Stad. deviation	1129.757	318.046	911.342	387.787
Mn	Mean	10 020.870	2007.931	1287.182	397.727
	Stad. deviation	1648.461	135.614	83.389	70.880
Fe	Mean	236 001.700	30 475.740	80 498.820	15 021.550
	Stad. deviation	16 442.380	2864.680	2210.295	2119.651

Table 2
Comparison of three times reading from PXRF on single sample (001, 002, 003 next to the ID means three readings).

ID	Ti	Mn	Fe	Zn	Pb	Rb	Sr	Zr
WNB3028-001	1947.90	2029.00	32 535.40	401.30	151.60	146.00	84.80	105.00
WNB3028-002	1923.50	2216.70	34 199.20	425.80	155.90	150.60	85.20	107.40
WNB3028-003	1440.70	1988.90	31 208.10	393.60	152.10	146.80	84.90	106.00
WNB3587-001	14 682.90	10 798.20	241 069.90	503.10	171.40	103.10	158.10	86.40
WNB3587-002	14 913.10	10 997.50	241 229.10	511.80	168.70	104.60	157.80	84.70
WNB3587-003	14 335.10	10 448.40	236 886.70	499.70	167.30	102.50	156.00	85.50
WNB3607-001	1355.20	2082.00	31 376.20	384.10	153.00	148.70	84.00	105.20
WNB3607-002	1383.50	2069.30	31 385.30	383.30	145.10	146.10	83.30	104.80
WNB3607-003	1365.50	1948.10	31 166.60	383.20	142.50	145.40	84.30	104.80
WNB3608-001	16 935.90	12 212.40	274 320.00	617.00	187.60	115.10	181.60	92.90
WNB3608-002	14 218.00	8332.00	239 007.30	547.90	162.80	99.30	168.20	89.90
WNB3608-003	15 842.50	11 040.90	257 286.90	579.30	177.60	111.90	176.10	92.80
WNB3613-001	1777.80	2087.50	32 224.50	406.60	153.40	147.10	84.80	106.30
WNB3613-002	1931.00	2129.10	34 161.20	437.90	163.60	150.20	87.00	107.40
WNB3613-003	1646.50	2104.20	32 646.60	389.90	153.10	147.60	84.80	106.00
WNB3617-001	801.40	1613.60	22 579.90	522.90	144.70	204.20	76.00	79.30
WNB3617-002	838.60	1816.30	24 923.50	590.60	151.20	215.00	77.30	80.30
WNB3617-003	789.00	1786.10	24 839.00	538.10	145.90	213.00	76.00	79.90
WNB3618-001	1709.30	2116.30	33 417.90	459.10	154.20	154.40	80.40	105.40
WNB3618-002	1185.30	2037.50	30 111.50	435.30	154.40	150.00	79.60	105.10
WNB3618-003	1772.80	2101.00	33 402.90	465.90	153.90	153.80	80.10	104.90
WNB3619-001	1190.70	1995.20	30 461.30	393.30	148.70	149.60	79.70	103.20
WNB3619-002	1407.80	2090.00	30 877.70	387.60	151.50	154.30	79.10	104.10
WNB3619-003	1213.50	1894.90	28 517.10	373.90	143.80	145.20	77.20	100.30
WNB3621-001	14 595.40	10 945.50	245 810.20	519.50	169.20	105.70	160.50	87.70
WNB3621-002	13 230.20	7591.70	226 457.40	477.80	161.30	94.70	153.90	86.30
WNB3621-003	14 432.70	10 653.80	244 142.50	517.00	170.00	102.50	157.80	86.50
WNB3623-001	14 479.10	10 537.60	242 792.40	572.90	174.40	103.70	161.20	88.50
WNB3623-002	13 369.90	9556.80	228 044.50	545.30	166.30	100.80	156.90	87.10
WNB3623-003	13 812.80	11 144.90	231 325.00	541.20	167.50	101.30	159.20	87.30
WNB3624-001	13 625.80	7587.70	227 704.10	483.30	168.50	99.60	153.50	84.40
WNB3624-002	15 067.80	12719.40	247 603.90	519.10	173.00	105.40	158.90	86.20
WNB3624-003	13 992.70	9945.60	234 638.00	487.00	164.50	100.60	155.40	85.50
WNB3652-001	13 092.40	8819.70	219 083.70	467.70	159.50	97.70	152.60	84.80
WNB3652-002	14 243.50	11 610.20	235 100.20	490.10	165.90	102.80	157.90	86.10
WNB3652-003	10 802.90	5222.90	184 630.00	431.00	145.80	81.60	148.60	83.10
WNB3654-001	14 287.50	9809.90	242 333.20	490.40	174.00	104.20	162.30	88.70
WNB3654-002	15 252.40	10 908.40	252 762.70	520.10	172.70	109.70	166.50	88.30
WNB3654-003	14 690.30	10 327.70	246 476.20	495.10	174.10	101.80	160.40	87.30
WNB3656-001	1521.30	2014.60	30 157.40	377.20	146.90	138.30	85.60	102.10
WNB3656-002	1406.10	1876.50	28 013.00	362.40	141.80	135.10	83.40	101.90
WNB3656-003	1563.80	1903.30	30 702.70	372.40	145.80	137.80	84.30	102.20
WNB3657-001	14 366.60	9549.90	232 762.90	495.30	166.20	99.10	156.50	86.00
WNB3657-002	14 335.40	9190.00	230 111.80	489.40	162.20	101.00	153.00	84.20
WNB3657-003	15 042.00	11 955.60	246 390.30	513.90	175.20	106.10	161.40	87.20
WNB3659-001	14 845.00	9517.00	245 936.90	497.00	170.70	101.80	156.40	85.40
WNB3659-002	15 274.20	11 091.50	245 662.10	498.70	169.70	102.50	156.60	86.10
WNB3659-003	14 866.00	12 352.30	244 103.20	505.50	165.80	103.60	159.70	87.20
WNB3663-001	1275.60	2040.80	31 074.80	399.50	150.50	152.70	81.90	105.10
WNB3663-002	1095.80	1931.00	28 804.30	363.10	140.40	144.20	79.00	102.80
WNB3663-003	1419.20	2141.60	32 139.90	403.30	155.20	157.00	81.80	108.30
WNB3697-001	12 112.70	7241.30	202 726.80	531.50	159.20	91.70	151.30	85.40
WNB3697-002	13 956.70	11 495.30	232 734.90	510.90	170.00	103.00	159.30	85.80
WNB3697-003	12 646.50	9398.70	212 927.90	534.50	148.60	93.00	156.10	84.90
WNB3710-001	1515.40	2212.40	33 544.80	425.20	162.30	157.00	89.50	106.50
WNB3710-002	1356.80	1913.40	28 992.90	389.80	146.50	140.90	84.10	105.20
WNB3710-003	1383.50	2074.80	29 381.30	402.40	151.80	141.40	84.20	102.30
WNB3736-001	13 176.80	7880.60	216 031.90	457.60	155.90	92.70	156.20	85.20
WNB3736-002	14 048.90	9669.90	229 291.20	477.60	161.60	99.10	157.60	86.50
WNB3736-003	15 610.60	10 135.10	250 670.80	530.20	179.40	106.30	163.70	87.90

The principal component plot for the artifacts in Fig. 5 produced four main clusters labelled as Groups A, B, C and D (Fig. 5, Tables 4 and 5). These can be compared to the sources which are depicted as ellipses representing 95 percent confidence limits. Artifacts from Group A were assigned to Paektusan Volcano (PNK1). Group B artifacts have the same geochemistry as the basaltic glass sources from Primorye in Far East Russia. Artifacts in Group C are closely related to the source group from Gladkaya in Far East Russia and can be divided into two sub-groups; C1 and C2 (overlapping with the Gladkaya and Japan-BL sources) (Figs. 1 and 5). Lastly, artifacts in Group D are from an unknown source. Artifacts with an "x" symbol do not clearly fall into any existing groups ($n = 5$). No artifacts overlap with the Jilin Jiutai geological source (Fig. 5).

The results of the PXRF analysis clearly show that although most of the artifacts in the sample were from Paektusan Volcano ($n = 413$, 93.9%), artifacts derived from two sources in Primorye, Far East of Russia also occur in Late Palaeolithic sites in northeast China (Table 3). Basaltic glass artifacts ($n = 7$) were identified in five sites: AS, DD, HB, HL, SRG (Figs. 1 and 2). The Group C ($n = 12$) artifacts are found at four of the same sites as Group B (DD, HB, HL and SRG) and

Table 3
List of sites in the study and their location (refer Fig. 2).

Site name	Latitude-N	Longitude-E	Site ID
Beishan	43°8′3″	130°15′8″	HB
Dadong	42°22′21.60″	129°14′11.58″	DDC
Daxue	41°13′48.4″	126°18′18.4″	JG
Dongshan	44°31′47.85″	129°25′22.11″	QJDS
Dongtai	42°22′7.65″	127°16′42.50″	FH
Jinzigou	42°04′17″	128°54′31.6″	JZGC
Liudong	42°19′11″	129°6′23″	HL
Lixin	42°41′37.6″	128°11′15.3″	AL
Nanshan	44°22′41.2″	129°05′43.3″	YLNSC
Paotaishan	44°30′14.3″	129°15′25.6″	PTSC
Qingtou	42°48′51.9″	128°58′20.7″	HQC
Sandao	42°31′43.76″	128°27′34.32″	ASG
Shajingou	42°36′05″	128°16′2.9″	06ASC
Shaojiadian	42°27′05″	126°15′30″	HSP
Shirengou	42°11′20″	128°48′45″	HSP/SRG
Xigou	42°34′46.31″	128°58′13.85″	HXC
Xishan	42°33′	127°16′11″	FXP
Xishan, Jiuzhan	43°57′47.7″	126°21′	JZXS

at two additional sites HX and PTS. The two sites that have Group D artifacts, DD and SRG, also have Groups B and C. Of these DD is of particular interest because all four known groups, as well as unknown sources are represented. Five artifacts from two sites could not be assigned to a group (DD = 3, HD = 2).

7. Discussion

These results again highlight that Paektusan (PNK1, artifacts Group A) was a very important source of volcanic glass in the region. Artifacts of volcanic glass from this volcano have been transported considerable distances into Far East Russia and South Korea (Kuzmin, 2006; Kuzmin et al., 1999, 2000, 2002b; Doelman et al., 2008; Kim et al., 2007). Not surprisingly artifacts from Paektusan Volcano also dominant assemblages from northeast China. Interestingly, there is no clear relationship between distance from Paektusan volcano and the proportion of the assemblage that is derived from sources outside China.

An intensive geoarchaeological survey of primary sources (from outcrops) and secondary sources (water-rolled cobbles from waterways) of volcanic glass in northeast China is a priority for further research. For example, the location of a quarried source of high quality volcanic glass from Paektusan (PNK1) is still not known. In addition, unworked cobbles with a water-rolled cortex were found at the site of Dadong (DD) and suggest that secondary sources of PNK1 were also exploited. The waterways draining from Paektusan Volcano also need to be systematically surveyed to assess the distribution, size, quality and abundance of the available volcanic glass cobbles/pebbles.

Of significance is the presence in sites from northeast China of Group B basaltic glass artifacts identical in geochemistry to sources found in the basaltic plateau (sub-divided into the Shkotovo

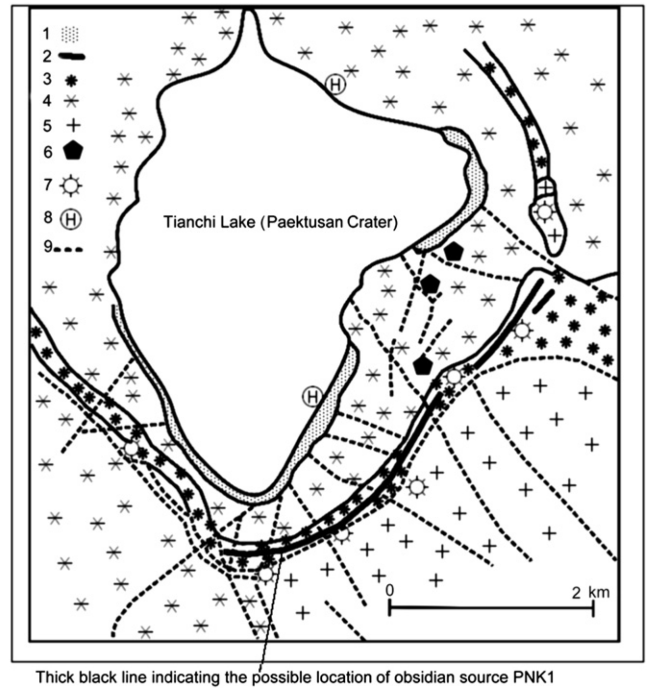

Fig. 3. The location of the volcanic glass outcrops on Paektusan Volcano (adapted from Michiya, 2000). 1 Pumice, 2 Obsidian, 3 Rhyolite and rhyolite–trachyte, 4 Trachytic aggromerate and tuffs, 5 Trachyte, trachydacite, 6 Tower, 7 Crater, 8 Hot spring, 9 Structural line.

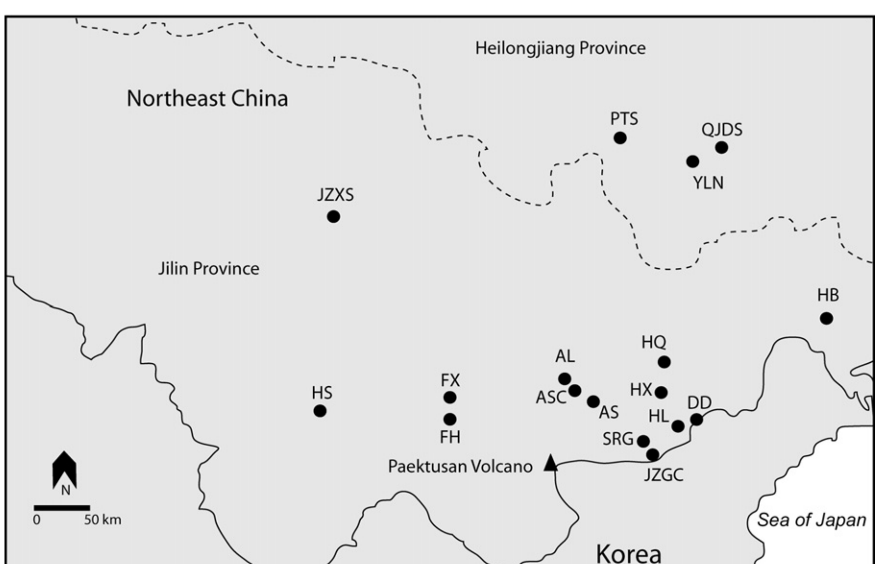

Fig. 2. The location of the sites in this study.

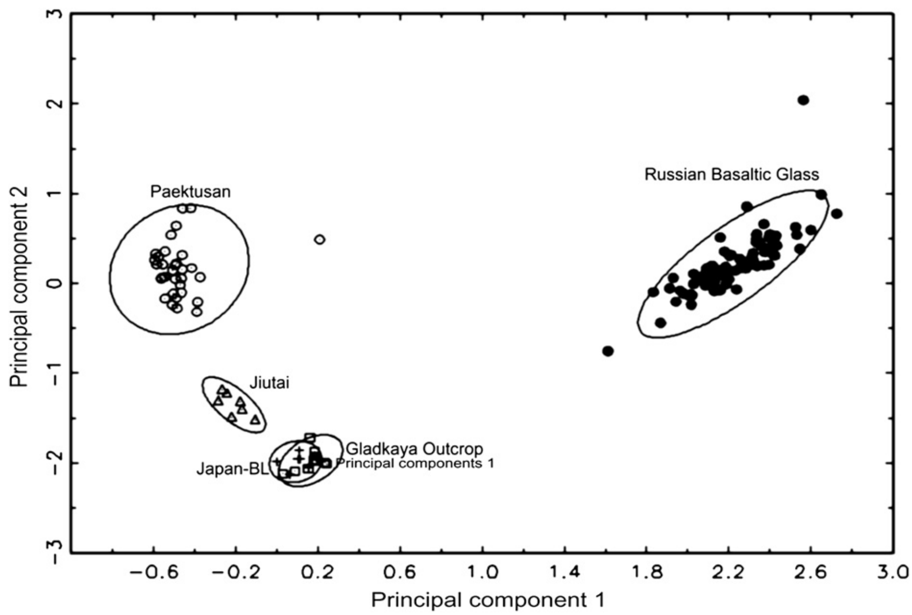

Fig. 4. Plot of the geochemistry of the geological sources against the first two principal components. The ellipses represent 95% confidence level.

Plateau and the Shufan Plateau) in the Primorye Region of Far East Russia. A geoarchaeological survey of the Shufan Plateau revealed that only poor quality volcanic glass, unsuitable for flaking, was available and so outcrops and waterways in the Shkotovo Plateau are the most likely sources of basaltic glass in the region (Doelman et al., 2008) (Fig. 1). However, the Shufan Plateau also extends into northeast China and it is possible that high quality sources occur here on the western slopes. A geoarchaeological survey of this region also needs to be undertaken. If the Shkotovo Plateau was the source of the basaltic glass in northeast China, then artifacts were moved at least 250 km and a maximum of 550 km.

Group C requires special attention in future research. The number of artifacts in this group is very small ($n = 12$), but it was found at six sites (SRG = 1, HX = 1, PTS = 1, HL = 2, HB = 3, DD = 4; Table 3). This group was further sub-divided into C1 and C2 (Fig. 5). Neither group overlaps with the Japan-BL or the Jiutai geological samples but they are closely related (Fig. 4). Most of these artifacts are green in reflected light ($n = 4$) but various other colours also occur in the group (e.g. black = 2, light grey = 3, red = 2, brown = 2). The six geological samples from Gladkaya in Primorye were compared to the Group C artifacts. These samples are also green under reflected light and fall into the subgroup of C2 (Fig. 5).

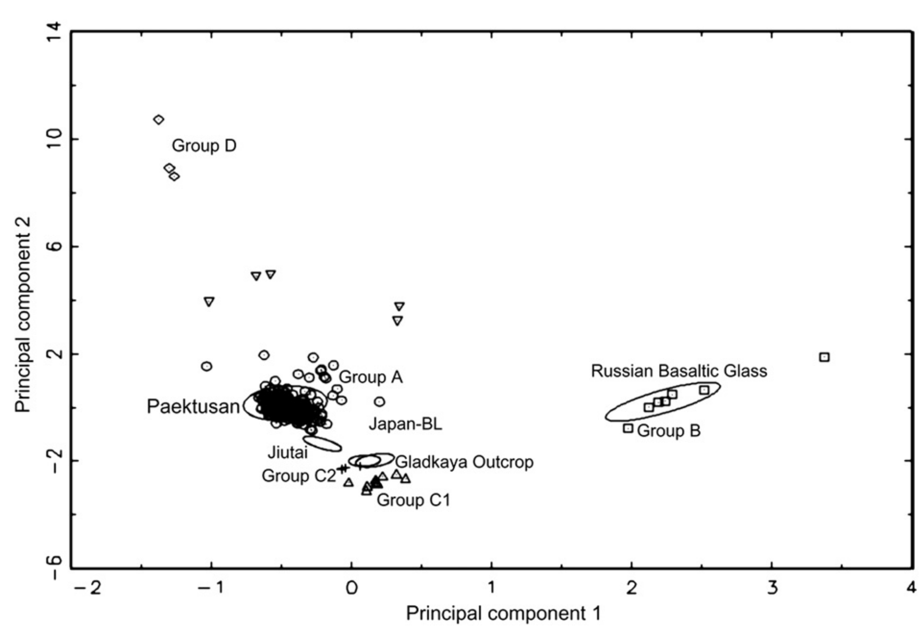

Fig. 5. Artifacts compared with geological sources. A plot of the geochemistry of the Late Paleolithic artefacts against the first two principal components. Circle = Group A, Square = Group B, Triangle = Group C1, Plus sign = Group C2, Diamond = Group D and Unclear = downward pointing triangle. The geological sources are depicted by 95% confidence ellipses.

Table 4
Means and standard deviations for the main elemental concentrations from volcanic glass analyzed in this study.

Element		A	B	C	D
K	Mean	66 472.75	46 509.88	68 460.16	63 803.80
	STD	1805.04	12 874.72	2069.62	1207.70
Al	Mean	61 341.59	56 551.19	62 187.31	56 672.27
	STD	473.12	1157.91	810.67	959.78
Na	Mean	31 178.89	36 257.02	30 699.68	36 168.02
	STD	622.04	775.79	323.95	1215.20
Fe	Mean	6184.87	34 462.62	5185.48	16 628.24
	STD	631.07	2468.50	2876.76	1488.82
Mn	Mean	308.17	1039.38	138.42	639.13
	STD	66.65	208.93	89.89	27.99
Zr	Mean	120.75	23.57	2.31	1485.01
	STD	29.62	30.93	37.69	125.55
Rb	Mean	108.69	15.71	31.14	202.69
	STD	9.91	3.31	18.36	15.91
Y	Mean	35.71	26.16	22.61	76.42
	STD	2.15	2.95	1.39	3.60
Sr	Mean	25.18	133.98	33.67	19.22
	STD	6.65	69.13	54.25	0.41
Th	Mean	11.10	5.89	2.09	23.02
	STD	1.06	0.79	0.90	1.04
Ga	Mean	10.88	10.00	8.04	22.55
	STD	0.52	0.82	0.67	1.58

Further testing of additional artifacts from the above sites is needed to increase the sample size and further refine the groups. An increased number of geological samples from the Jilin Jiutai source is also required to examine the range of elemental variation; and further systematic comparisons of Japanese sources is also desirable. It is possible that one of the sources of the artifacts in Group C, based on the geochemistry and green colour in reflected light ($n = 4$), is found in Gladkaya in southern Primorye, Far East Russia. However, colour is an unreliable indicator of source as many colours can occur at one outcrop.

The Group D artifacts ($n = 3$) are from two sites (SRG and DD). In reflected light they appear black and in transmitted light are light green. It is hoped that further research will clarify the location of this source in the future.

Artifacts made of basaltic glass (Group B in Fig. 3) from Primorye in Far East Russia occur in a number of sites ($n = 5$) found in the Changbaishan region of northeast China although only in small numbers. These results suggest that there was a two-way movement of volcanic glass between Primorye, namely the Shkotovo Plateau, in Far East Russia and the Changbaishan area of northeast China. Equally, artifacts from Group C fall into four of the same sites as the basaltic glass artifacts. These sites are all located to the east of Paektusan, between this volcano and the two sources in Russia (Fig. 1). It is possible that this pattern hints at an extensive network of interaction. However, larger sample numbers from more sites over a wider area are needed to verify this result.

Table 5
The distribution of the volcanic glass sources in sites from northeast China.

Site ID	A	B	C	D	Unknown
AL	10				
AS	55	2			
ASG	3				
DD	83	2	4	2	3
FH	4				
FX	4				
HB	29	1	3		2
HL	33	1	2		
HQ	49				
HS	18				
HX	53		1		
JG	4				
JZXS	1				
PTS	9		1		
QJDS	4				
SRG	48	1	1	1	
YLN	6				
Total	413 (93.9%)	7(1.6%)	12(2.7%)	3(0.7%)	5 (1.1%)

Volcanic glass artifacts were transported long distances (up to 1000 km), usually as highly curated tools or microblade cores (Doelman, 2008; Doelman et al., 2008) as early as c. 20 000 BP (Kim et al., 2007). Kuzmin et al. (2002b:514) have suggested that 'intensive long-distance exchange of obsidian' occurred. It is possible that an early low-level exchange system was in place aided by the high mobility of hunter/gatherers that quickly and efficiently moved vast distances throughout the landscape. It is also possible that continuous migration and colonization added to the distribution of artifacts. Whether or not volcanic glass was also obtained directly from the source is still open to debate. Indeed multiple mechanisms may have operated at different times in different places. A more detailed analysis of the typology and technology of the artifacts in these sites is needed to further address these questions.

All of the artifacts in this study are derived from surface collections made at Late Paleolithic sites. A future study using the PXRF based on a larger sample of artifacts from well-dated, spatially dispersed sites with good stratigraphic control would help increase understanding of the procurement, use and distribution of volcanic glass sources during the Late Paleolithic and through time. A focus on a single site with multiple stratigraphic layers covering a relative long period would specifically address the chronological issues.

In summary, this analysis has shown that artifacts from 18 Late Paleolithic sites in northeast China can be characterized to four geochemical groups: A, B, C1/C2, and D. Confident source identifications can be made for Group A (PNK1) and Group B (Russian basaltic glass) artifacts. Further testing of geological samples and artifacts are needed to refine Groups C and D. The results add significantly to our understanding of volcanic glass procurement and distribution in northeast China.

8. Conclusion

This study has made a useful contribution toward filling a significant gap in our understanding of volcanic glass acquisition and movement in northeast Asia. However, considerable research still needs to be undertaken to address unresolved issues. To further clarify how the use of sources changed over time, important future tasks include increasing the sample size of geological samples and artifacts, conducting a geoarchaeological survey of source areas, assessing the types of artifacts made and transported from the various sources, and further analyses of the spatial distribution of artifacts from the different sources.

The use of PXRF to source volcanic glass artifacts is a first in China. The results so far are promising. This technology allowed the non-destructive, quick and internally accurate geochemical identification of source samples and artifacts providing new insights into the acquisition and distribution of volcanic glass artifacts in northeast Asia. Although the sample size is still relatively small, it is hoped that future research will add to the growing database and resolve the issues surrounding, in particular, the sourcing of Group C and D artifacts. The results confirm the movement of basaltic glass artifacts into northeast Asia from Primorye, Far East Russia and hint at an increasing complexity in the movement of volcanic glass artifacts throughout northeast Asia during the Upper Paleolithic.

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