Source Selectivity: An Assessment of Volcanic Glass Sources in the Southern Primorye Region, Far East Russia

Trudy Doelman,[1,*] Robin Torrence,[2] Vladimir Popov,[3] Mihail Ionescu,[4] Nickolay Kluyev,[5] Igor Sleptsov,[5] Irina Pantyukhina,[5] Peter White,[1] and Mark Clements[6]

[1]*Department of Archaeology, University of Sydney, Sydney, NSW 2006, Australia*
[2]*Australian Museum, 6 College St., Sydney, NSW 2010, Australia*
[3]*Far East Geological Institute, 159 Prospect 100-letiya, 690022 Vladivostok, Russia*
[4]*Australian Nuclear Science and Technology Organisation, Sydney, NSW 2234, Australia*
[5]*Institute of History, Archaeology and Ethnography of the Peoples of the Far East, 89 Pushkinskaia St., 690950 Vladivostok, Russia*
[6]*National Centre for Epidemiology and Population Health, Australian National University, Canberra, ACT 0200, Australia*

Artifacts made from volcanic glass have been found in archaeological contexts dating from the Late Palaeolithic (ca. 20,000 yr B.P.) through to the end of the Bronze Age (ca. 2700 yr B.P.) in the southern Primorye region of Far East Russia. A geoarchaeological survey of volcanic glass outcrops assessed the various potential sources to determine their potential for sustained exploitation. A characterization study of source samples and artifacts from 27 spatially and temporally dispersed sites using a combination of PIXE-PIGME and relative density identified which sources had actually been exploited and a technological analysis of the assemblages described patterns of use. The combination of these three approaches shows the impact of a relatively stable geological environment on patterns of procurement and exchange. © 2008 Wiley Periodicals, Inc.

INTRODUCTION

Why people selected particular raw material sources for the production of flaked stone tools and avoided others can be a complex problem when there is a range of alternatives. Because these choices are often made from resources existing within a relatively stable geological environment, the ways sources have been used can provide important insights into changes through time and across space in the social contexts in which raw material selection was embedded. Acquisition of raw materials is based on the physical properties of the stone resources, but other requirements can be at

*Corresponding author; E-mail: trudy.doelman@arts.usyd.edu.au.

Geoarchaeology: An International Journal, Vol. 23, No. 2, 243–273 (2008)

Published online in Wiley Interscience (www.interscience.wiley.com). DOI:10.1002/gea.20216

least as, if not more, important: for example, tool types required; mobility patterns of the group (frequency of moves, seasonal pattern of movement, etc.); accessibility in terms of territoriality/ownership; and desire to establish social relationships through exchange. In this paper we use a combination of (1) geoarchaeological assessments of source potential, (2) characterization studies, and (3) technological analyses of assemblages to analyze changes in the use of raw material sources in the southern Primorye region of Far East Russia. We then use these results to consider the cultural factors that might have affected raw material choice.

The southern Primorye region of Far East Russia (Figure 1) provides an excellent case for studying raw material selection. First, the area encompasses much variation in the types of stone exploited for flaked stone artifact manufacture, as well as significant temporal and spatial changes in the way they were used. Second, it is possible to link artifacts directly to a number of volcanic glass sources through employing various characterization techniques. A number of previous characterization studies using INAA, EDXRF, and PIXE-PIGME have demonstrated that volcanic glass sources in Primorye can be successfully discriminated on the basis of their chemical composition. The geochemical signatures of 24 naturally occurring localities (outcrops), comprising 10 geological source regions of volcanic glass, have been characterized, and a large sample of artifacts have been matched with their individual sources (Shackley et al., 1996; Kuzmin et al., 1999; Kuzmin & Popov, 2000; Kuzmin et al., 2002; Doelman et al., 2004).

Third, exploitation of volcanic glass during ca. 20,000 years provides ample material for a comparative study of changes in use. Using studies of Late Palaeolithic, Late Neolithic, and Bronze Age assemblages, we can try to identify why particular sources were used extensively, whereas others were used only to a limited degree or not at all. Characterization studies of 110 artifacts from 33 widely distributed archaeological sites dated to the Late Paleolithic (ca. 20,000–10,000 yr B.P.), Neolithic (ca. 10,700–3500 yr B.P.), Early Iron Age (ca. 3000 yr B.P.), and Medieval periods (ca. 300 yr B.P.) have shown that two local sources, Gladkaya River-1 and the Basaltic Plateau, were exploited (Shackley et al., 1996; Kuzmin et al., 1999; Kuzmin & Popov, 2000; Kuzmin et al., 2002). However, it appears that the Gladkaya River-1 source was only used to a limited extent, and some sources of volcanic glass in the region, notably the Krabbe Peninsula, Gladkaya River-2, and Gladkaya River-3, were probably never used (Shackley et al., 1996; Kuzmin et al., 1999; Kuzmin & Popov, 2000; Kuzmin et al., 2002).

Fourth, in addition to the extensive use of local volcanic glass sources, people in this region also imported obsidian from Paektusan volcano in North Korea, which is located a significant distance away from Primorye (Figure 1) (Kuzmin et al., 2002:509; Doelman et al., 2004). We can therefore compare and contrast the use of local and imported types of volcanic glass. Given the properties of the local material, why was additional stone brought into the region? Perhaps the movement of raw material was a consequence of mobility patterns or was incorporated within a system of social exchange, as suggested by Kuzmin et al. (2002:514). Doelman et al. (2004:120–121) concluded that these competing hypotheses could not be satisfactorily tested until a detailed geoarchaeological study of the sources, combined with more systematic analyses of the archaeological assemblages, had been made. This paper is the

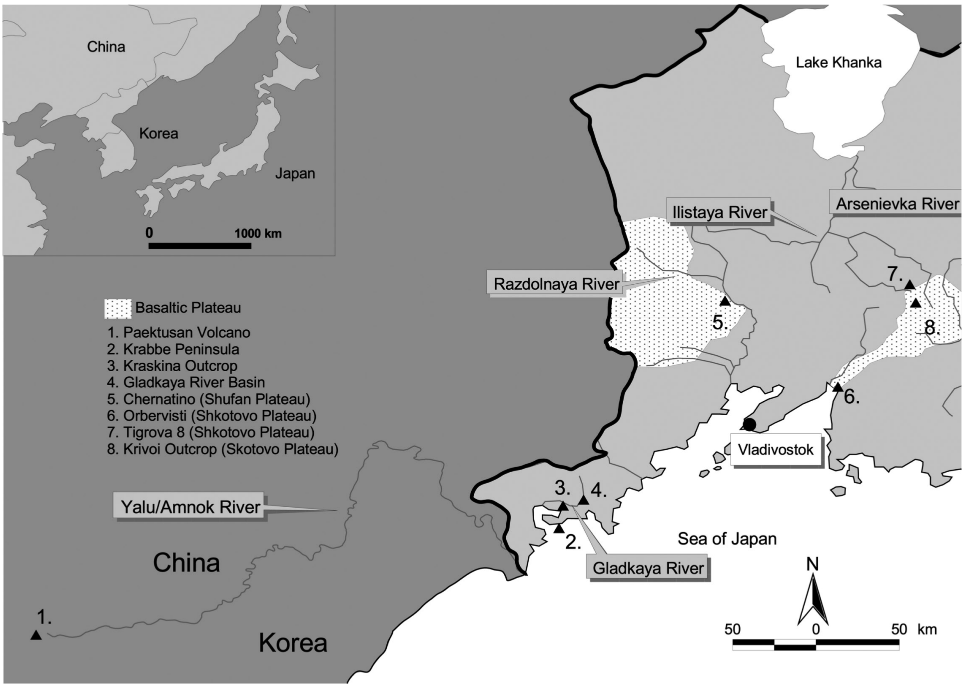

Figure 1. Location of surveyed volcanic glass sources in southern Primorye.

first step in providing the necessary data for understanding the social background for raw material selection and use in the Primorye region.

RESEARCH QUESTIONS

Previous research on volcanic glass use in the Primorye region has identified a number of specific questions that need to be answered in order to understand changes in the selection of volcanic glass sources through time. First, initial chemical studies of geological and archaeological samples of volcanic glass have demonstrated that basaltic glass from the Shufan and Shkotovo Plateaux (together known as the Basaltic Plateau) cannot be distinguished from each other with the various geochemical techniques employed (Kuzmin & Popov, 2000; Kuzmin et al., 2002; Doelman et al., 2004). These extensive plateaux, which together cover an area of roughly 7500 km^2, are separated by a distance of ca. 65 km (Figure 1). The distribution of source material over such a large area makes studies of exchange using the traditional methods of fall-off studies quite difficult (e.g., Torrence, 1986:10–23). If some of the outcrops could be eliminated as sources due to their physical properties, then studies based on spatial patterning of the material would be enhanced. For this reason, a geoarchaeological survey of the two plateaux aimed to assess their relative potential as archaeological sources of flaked stone raw material.

A second problem raised by previous research is why some potential stone sources appear to have been used only to a limited extent (Gladkaya River-1) and others not at all (Krabbe Peninsula, Gladkaya River-2, Gladkaya River-3). In these cases, it was important to identify whether the sources in question had been avoided due to their inferior physical characteristics. In studies elsewhere it has been found that some sources that do not appear in region-wide characterization studies were actually exploited to a limited degree and/or used very locally. It was only by searching for quarry and workshop sites that their past use was identified (e.g., Torrence et al., 1992). A survey at the Russian outcrops was therefore required to assess their potential for sustained exploitation and to search for archaeological evidence of their past use.

The third research question addressed by the geoarchaeological study was whether volcanic glass had been acquired from either or both primary (from an outcrop) and secondary (cobbles in streams/rivers or along beaches) sources derived from the same geological formation and whether these were used and distributed in the same way (Shackley, 1998, 2005; Doelman, Webb, & Domanski 2001). Spatially restricted outcrops are easier for social management and control, and more likely to be tied into exchange networks (e.g., Torrence et al., 1992:90–91).

GEOLOGICAL BACKGROUND

In order to answer these research questions, one needs to start with the basic geology of the volcanic glasses. As noted by Tykot (2003:63), studies of raw material use should be based on a solid understanding of their geological distribution and physical properties, and should take care to assess variability both between and within sources. Three types of volcanic glass are present within the southern Primorye region: (1) basaltic glass found in the Basaltic Plateau, (2) rhyolitic glass from the Gladkaya River Basin, and (3) perlites from the Krabbe Peninsula. The different volcanic glass types reflect not only their geological origin (e.g., basaltic or rhyolitic) but also variation in the water content: For example, perlites generally have more water (up to 6%) in comparison to obsidians ($<$1%) (Kuzmin et al., 2002:506).

Due to their high water content, perlites expand when heated and rarely break conchoidally (Harrison, 1947; Ross and Smith, 1955; Johnston, 1956; Znamensky, 1992). Although in principle one would not expect perlites to have been exploited in the past because of their poor conchoidal fracture, it is possible that there might be small pockets of flakeable rhyolitic glass associated with these flows. In addition, these sources, which have been included in the analyses of previous characterization studies (e.g., Kuzmin & Popov, 2000; Kuzmin et al., 2002), had not been previously assessed from an archaeological point of view. Rather than exclude them on principle, we decided to conduct a comprehensive survey of all types of volcanic glass in the region of southern Primorye.

The Basaltic Plateau was formed as part of the Amuro-Ussury rift system during the Late Tertiary (Neogene). It is subdivided into the Shkotovo and Shufan Plateaux, which are separated by the Razdolnaya River (Figure 1). Generally, basaltic glass is found as a rind around the bulbous bodies of pillow lavas (Figure 2). This type of volcanic glass is formed when a lava flow passively interacts with water, which forces the outer

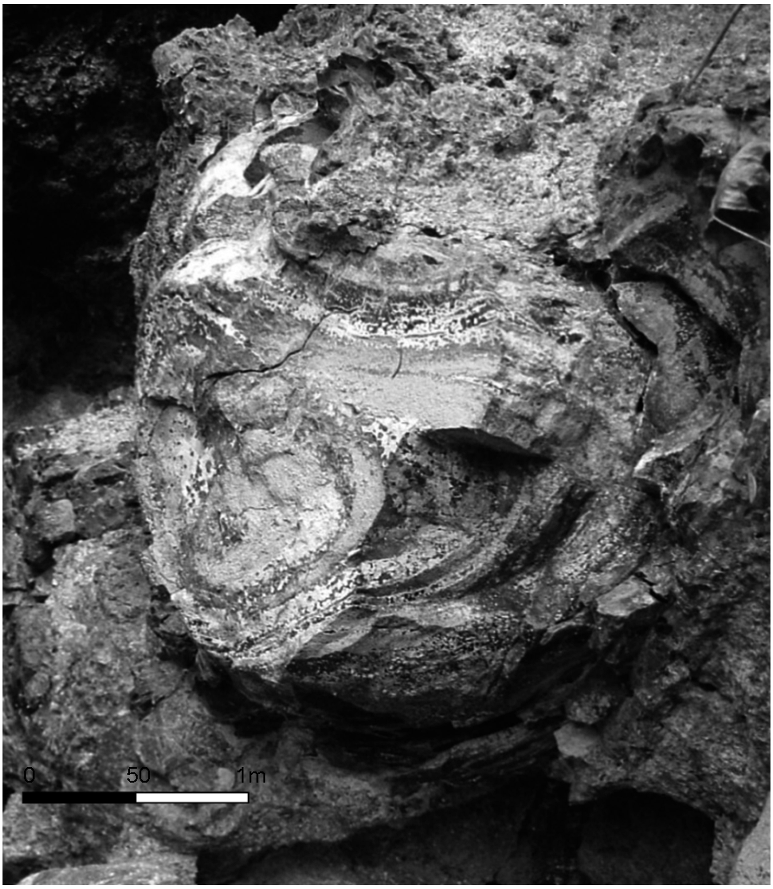

Figure 2. Krivoi outcrop (04/20), located on the Right Ilistaya River in the central region of the Shkotovo Plateau, showing the rinds of volcanic glass on the pillow lava.

layer to cool quickly (Jones & Nelson, 1970; Smith & Batiza, 1989; Batiza & With, 2000). The Shkotovo Plateau to the east of the Razdolnaya River covers an area of roughly 4536 km^2. The plateau stretches as a single, relatively narrow series of lava flows south from the central part of Primorye to Orbervisti on the coast (Figure 1). At its highest peak in Central Primorye, it reaches ca. 900 m asl. The Shufan Plateau is located on the west side of the Razdolnaya River. It extends 46 km north–south and 67 km east–west, with an area of 3082 km^2. The highest peak, located on the border of Russia and China, has an elevation of ca. 600 m asl. Numerous waterways drain these two plateaux and transport cobbles of volcanic glass, often long distances, downstream (Figure 1).

Rhyolitic glass is found in dikes exposed within stream beds (Olenyi Stream, Vinogradnaya River) or as flows outcropping along hill slopes (Vinogradnaya outcrop-1) within the Gladkaya River Basin (GRB) in southern Primorye. A second potential source of high-quality rhyolitic glass is available outside the region near the

Paektusan Volcano, located on the border of China and North Korea, 300–640 km to the southwest of the Primorye region. Paektusan (known to the Chinese as Baitoushan) is a large stratovolcano which stands 2700 m asl. (Lee, 1987). During a massive eruption around A.D. 1000, the crater collapsed, forming a large caldera (Chichagov et al., 1989; Horn & Schmincke, 2000). Obsidian is now only observed as a single bed around the crater wall, but in the past it is likely to have been readily available as extensive flows (Kuzmin & Popov, 2000:43). These flows may still be visible in North Korea, but due to the current political climate, access is not possible.

Finally, volcanic glass in the form of massive and extensive perlites was formed in association with Eocene-Oligocene rhyolites on the Krabbe Peninsula (Figure 1) (Kuzmin & Popov, 2000:39).

SURVEY METHODOLOGY

Our fieldwork focused on the assessment of four potential source areas in southern Primorye: Shufan and Shkotovo Plateaux, Gladkaya River Basin, and the Krabbe Peninsula (Figure 1). Following the success of previous work in the Mediterranean, Papua New Guinea, Australia, and North America (e.g., Tykot, 1998, 2001, 2003; Torrence, 1986; Torrence et al., 1992; Doelman, Webb, & Domanski, 2001; Doelman et al., 2004:114-5; Shackley, 1998, 2005; Bamforth, 1990, 1992), the survey assessed both primary and secondary sources in terms of physical properties that might have influenced the kinds and degree of prehistoric exploitation. Evaluations were made of the accessibility, abundance, and quality of each of the source areas and the raw material within them. Brief surveys were made to look for evidence of prehistoric use of specific localities. The following variables were recorded at each location: (1) physical context, such as the topography, type of exposure, and exposure size; (2) method and ease of extraction; (3) flaking properties; (4) color; (5) type of cortex; and (6) associated cultural material (Table I). Independent assessments of the source localities

Table I. Geological and archaeological characteristics recorded for primary and secondary sources.

Location	UMG coordinates
Material	perlite, rhyolite, basaltic glass
Exposure type	primary (outcrop), secondary (beach cobbles, stream cobbles)
Topography	cliff, hill slope, gully, beach, river/stream, road cutting
Outcrop extent	m^2
Color	light gray, dark gray, black, green, blue/gray
Cortex type	water-rolled, rough, shiny, contact
Context	massive, blocks in ash, dike, dome, cobbles
Phenocryst density	low, medium, high
Phenocryst size	small, medium, large
Fracture type and quality	poor chonchoidal, good chonchoidal, hackly
Maximum size	mm
Mean size	mm
Activities present	quarry, workshop, none
Ease of extraction	easy, moderate, hard

could then be compared with evidence from characterization studies of artifacts to establish the degree to which the physical characteristics of the raw material and sources played a role in how these raw materials were used and distributed in the past. This assessment is an essential first step in reconstructing the influence of social and ideological variables in stone tool procurement, use, and exchange.

1. Physical Context

The exposure type (e.g., dike, dome, massive layer), its position (e.g., cliff, hill slope, gully), and the size of the outcrop both in extent and thickness are key characteristics that influence the use of a stone resource. Ideally, exposures that are accessible, extensive, and thick would be most suitable for continued, low-cost quarrying (Torrence et al., 1992:85).

Another key aspect is the difference between primary and secondary sources. A primary context is defined as an *in situ* exposure or outcrop (e.g., Figure 2), whereas a secondary context is one in which material eroded from primary exposures has been transported downstream or reworked as beach deposits. Secondary sources are therefore characterized by reworked, rounded cobbles/pebbles (e.g., Figure 3). Outcrops of volcanic glass in the southern Primorye region are mainly associated with volcanic-tectonic depressions and calderas but can also be found within smaller structures such as extrusive domes, dikes, lava, or pyroclastic flows (Kuzmin & Popov, 2000:161). Because they offer very different opportunities for human use, the primary and secondary sources for each geological type of volcanic glass will be discussed individually.

2. Extraction

The ease of extraction may also influence decisions about the use of a particular source. Extraction was rated "easy," "moderate," or "hard," based on criteria proposed by Torrence et al. (1992: 85). In "easy" extraction, material is readily available in large blocks (>15 cm), thereby yielding low time and labor costs for high returns. Large blocks also allow more flexibility in the kinds of reduction strategies that can be employed. "Moderate" extraction usually demands digging to some depth to extract blocks of material. "Hard" extraction involves direct percussion of an *in situ* flow to remove blocks and may also require the removal of the surrounding substrate.

3. Flaking Properties

The geological formation of a volcanic glass affects its flaking properties. In addition to the chemical composition (especially water content), how quickly the glass cools and particularly the magmatic processes during ascent and eruption all influence the number and size of phenocrysts and hence the flaking quality; poor quality material has numerous, large phenocrysts (Noble, Smith, & Peck, 1967; Carmichael, Turner, & Verhoogen, 1974; Uhlmann, 1972). The degree of weathering and water-rolling can also affect quality because these can create internal flaws in the rock's structure. Furthermore,

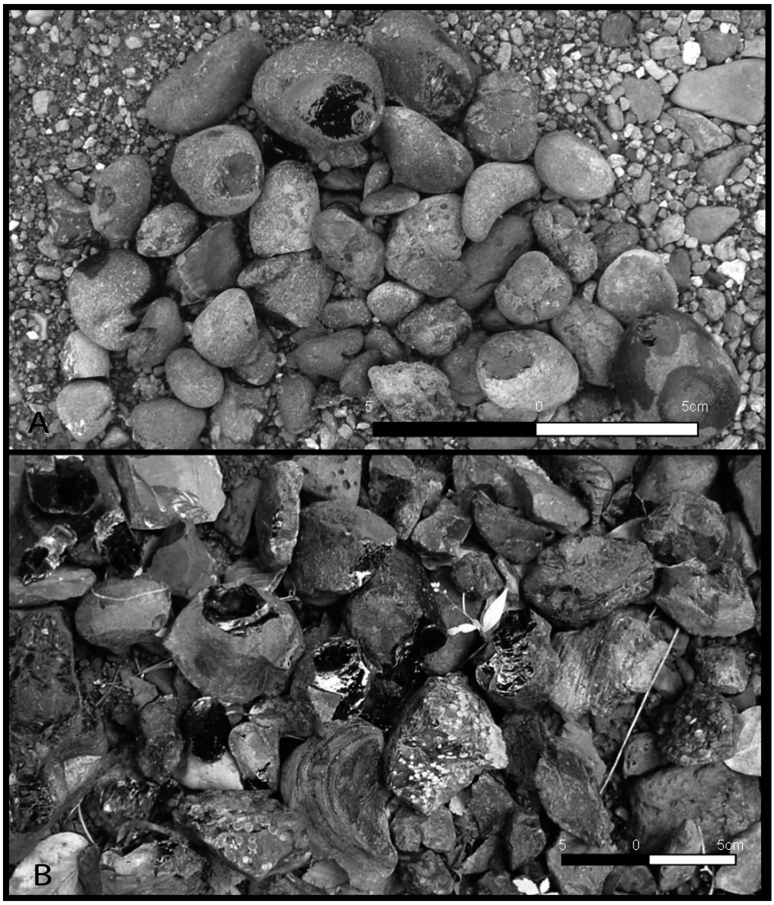

Figure 3. Examples of water-rolled volcanic glass cobbles found in the Shkotovo Plateau. Location A (04/18): cobbles with a highly rounded, pitted surface found 35 km from the Krivoi outcrop, Shkotovo Plateau. Location B (04/21): cobbles with a more angular, water-rolled cortex found in the Right Ilistaya River, 2 km from the Krivoi outcrop in Figure 2, Shkotovo Plateau.

although, rhyolitic and basaltic glass flake conchoidally, perlites generally break along discrete fracture planes, so they are usually unsuitable for flaking. The size of the pieces that can be obtained also puts limits on what can be produced. Size and shape of the available cobbles or blocks can restrict the potential for preparing certain types of cores and, consequently, the range of flake shapes that can be manufactured (Bamforth, 1992:132).

4. Color

Color is important because it can be used to discriminate among various volcanic glass types or exposures. Cultural groups often assign particular values to specific colors (e.g., Dillian, 2004; Santley & Pool, 1993). The rhyolitic sources in the Gladkaya

River Basin are notable in this regard because they are typically green and very translucent, unlike the opaque blue/gray/black basaltic glasses.

5. Cortex

Noting the nature of the cortex on artifacts is especially useful for distinguishing between primary and secondary sources. In this study cortex was divided into outcrop (from a primary source) or water-rolled (from a secondary source). Outcrop cortex was described as "rough," "flat/shiny," or "contact." Shiny or flat cortex sometimes has a dull, pitted surface depending on the degree of weathering (hydration). It is created during the weathering process when water seeps through natural cracks (formed during cooling) in flows and breaks apart the layers into blocks. Rough and contact cortex types are formed along a margin where the volcanic glass meets either another geological unit (rough cortex) or water (contact cortex). Rounded cobbles with water-rolled cortex (i.e., having a smooth to pitted surface) are found in rivers, stream beds, and along beaches. The surface varies from subrounded/slightly angular to highly rounded depending on the distance transported, the velocity and turbidity of the water, and the length of time in the water. Often nodules of better quality material survive longer within waterways and are transported further downstream than poorer types, which break down because of the presence of internal flaws and phenocrysts.

6. Associated Cultural Material

Finally, to determine whether the locality was actually used as a source in the past, the presence of extraction or stone knapping activities was recorded. Because flaking debris can be subject to a wide range of potential formation processes, the absence of activities is not necessarily a good indicator that the source was not exploited. The presence of flaking debris, however, is an excellent positive measure.

SOURCE DESCRIPTION

Four source areas were visited: the Krabbe Peninsula, Gladkaya River Basin, and the Shkotovo and Shufan Plateaux (Figure 1). Each source was given a unique identification number (e.g., 04/02). Based on a combination of all the variables, an overall evaluation of each source was made. It was logistically impossible to visit and record all the potential sources of volcanic glass, but we think that the recorded sample provides a good indication of the basic nature and range of variability of the available material in each area. Following Torrence et al. (1992:85), the potential of the source as a flaked stone resource was rated as "not viable," "low," "moderate," or "good" based on the amount of available material, the quality of stone, the size of blocks/cobbles, and the ease of extraction. A summary of the descriptions is provided in Appendices 1 and 2. At each location, hand specimens representing the variation in the physical attributes were collected and additional samples were taken for geochemical analysis and use-wear studies.

Primary Contexts

1. Krabbe Peninsula

The Krabbe Peninsula has an abundance of massive perlite flows that extend for hundreds of meters (04/03, 04/04, 04/05; Figure 1). Outcrops up to 3 m high occur on hilltops and along beaches. Despite the abundance of the material and ease of extraction, the material is very poor quality because it does not flake conchoidally but breaks along weathering planes. Nearby, another perlite source is present at Kraskina (04/06), where a 10 m wide dike extrudes from a cliff face. This volcanic glass is a black/gray color and its fracture ranges from poorly conchoidal to hackly. Although perlites are abundant in this region, none were suitable for use as a flaked stone resource. These outcrops were rated as not viable. Not surprisingly, evidence of prehistoric quarrying or knapping was absent.

2. Gladkaya River Basin

Vinogradnaya 2 (04/11) is a large dike located on a hilltop. The 7 m wide dike extends downslope for ca. 600 m. Most of the volcanic glass in this location is perlite, but one localized area ($90 \times 60\ cm^2$) of dark green, rhyolitic glass was found. This obsidian is very high quality, with only a few small phenocrysts. The cortex is flat, dull, and angular. The maximum size of blocks that could be extracted at the depth that we investigated (ca. 20 cm below current ground surface) was only 15 cm, but it is thought that larger blocks (up to 1 m in length) of good-quality material might occur at a greater depth (at ca. 1 m). It is difficult to establish whether the source was worked. Several shallow extraction pits were observed, but we suspect that these are recent in origin. Although the material is rated as high quality, the limited extent of the outcrop and the effort required to acquire large, solid blocks means the outcrop is ranked as having moderate potential as a flaked stone resource.

3. Shufan Plateau

At Chernatino (04/15) (Figure 1), volcanic glass is only present as a thin rind (<2 cm thick) on lava bombs and pillow lava and as thin horizontal layers in between the tephra sequence, within what are now very steep and sheer cliff walls. Some of the volcanic glass has been reworked and is now part of a hydroclastic flow. It was virtually impossible to remove sizable flakes because the layers are so thin and the material had poor flaking properties. The basaltic glass in this source was low in abundance, of poor quality, and extremely difficult to extract, making it highly unlikely that it was ever exploited for flaked stone production. The outcrops in this region were therefore judged as not viable.

4. Shkotovo Plateau

Three outcrops were visited in the Shkotovo Plateau during the course of the fieldwork: Orbervisti (04/01), the Krivoi outcrop (04/20), and Tigrova 8 (04/25). At Orbervisti (04/01), discontinuous bands of basaltic glass observed at the base of a cliff profile varied in thickness from 1–37 cm. In places, larger lenses of basaltic glass were present. Extraction of these lenses was not easy, but evidence for quarrying was found in terms of percussion scars on the surrounding substrate. The presence of flakes on a nearby hill demonstrates that the source had been exploited. The quality of the basaltic glass varied from a highly conchoidal, blue/gray material to a light gray or black type that had poor fracturing properties. The low abundance, difficulty of extraction, and the generally poor flaking characteristics mean this source is rated as having poor potential as a flaked stone resource.

Krivoi outcrop (04/20) is located on the Right Ilistaya River, in the central region of the Shkotovo Plateau at an elevation of 270 m asl. It was discovered in 2002 during the course of survey work (Sleptsov, 2003; Doelman et al., 2004:Table 1). Currently a 40 m long section is exposed in a cliff face. Lava bombs and pillow lava occasionally have a basaltic glass rind which is typically thin (5–10 cm). Basaltic glass could be extracted from the cliff face using percussion. Blocks have also eroded from the outcrop and formed a scree slope, making the volcanic glass easily available. The volcanic glass ranges in color from light gray to dark blue/gray and black. The cortex is mostly flat with occasional rough or contact forms. The occasional phenocrysts are large. In general, the flaking quality is medium, but there is also some good material. The basaltic glass is relatively abundant and easy to obtain. The potential of this outcrop was rated as good.

Tigrova 8 (04/25) is situated on a level terrace along the ridge line at c. 350 m asl. A 1 m^2 test excavation recovered over 500 volcanic glass artifacts (Sleptsov, 2003). Our survey identified large numbers of artifacts with cortex types normally found at outcrops (flat, contact, and rough) among the roots of two uprooted trees. The cortex and abundance of flaking debris suggest that a good or excellent quality outcrop is currently buried under recent colluvium at this location.

Secondary Contexts

As noted above, cobbles and pebbles of volcanic glass have been widely distributed from some primary sources via waterways. It is important to know the variation in the material quality and size of the available cobbles/pebbles as this influences how the secondary sources could have been used (cf. Doelman et al., 2004:114).

1. Krabbe Peninsula

Large cobbles of perlite (with a median length in the 5–10 cm category, largest 20 cm) were found along the beaches of the Krabbe Peninsula or at Kraskina beach. Although abundant, none were suitable for flaked stone production because of their poor fracture properties; most break with a hackly fracture. As with the outcrops in the Krabbe Peninsula, the secondary sources can also be discounted as a suitable source for archaeological stone.

2. Gladkaya River Basin

Within the Gladkaya River Basin small highly rounded pebbles have eroded from outcrops and can be found in the Vinogradnaya River. At the two localities studied, the largest pebble of good-quality material (with few phenocyrsts) observed was only 3 cm in length and the mean size was less than 2 cm, even though the eroding dike is less than 2 km away. The very small size of these pebbles would have severely restricted the potential of these localities as a source of material for flaked stone manufacture. Even in the context of a bipolar technology, the resulting flakes would be extremely small and not usable as blanks for the majority of tools used in prehistory in this region. The small size of the cobbles therefore makes it unlikely that these secondary sources were used to any extent in the past.

3. Shufan Plateau

Tributaries of the Razdolnaya River, which drains the Shufan Plateau, contain cobbles and pebbles of basaltic glass (Figure 1), but the localities visited were ranked as non-viable sources. For example, at location 04/16, a river gravel deposit along the Razdolnaya River, which is only about 500 m from the outcrop, only blocks of basalt with very thin layers of volcanic glass were found. These layers were less than 2 cm thick, showed evidence of crushing, and were almost completely broken down. No usable material was found in the river. It seems very unlikely that the basaltic glass from this region was used systematically in the past for stone tool manufacture.

4. Shkotovo Plateau

In contrast to the Shufan Plateau, cobbles of basaltic glass are quite common in many streams and rivers within the Shkotovo Plateau to the east. To record the full range of variation in the available raw material, the sample size of surveyed localities reported previously (Doelman et al., 2004) was significantly increased. Cobbles of basaltic glass originating from outcrops in the Shkotovo Plateau are present in the Ilistaya, Partizanskaya, and Arsenievka Rivers and their tributaries (Figure 1). Similarly, numerous cobbles of basaltic glass were also observed along the beach at Orbervisti near the base of the outcrop previously described.

Cobbles/pebbles from several locations were recorded along the Ilistaya River (Figure 3) and its tributaries and within gravels of the Arsenievka River, both of which drain the Shkotovo Plateau. It must be noted that there are no volcanic glass cobbles in the main Ilistaya River upstream from where it is joined by the Right Ilistaya River. Likewise, there are no volcanic glass cobbles in the Left Ilistaya River, but they are present in the headwaters of the Right Ilistaya before it joins the Ilistaya River. We suspect additional primary outcrops will be found in this region following additional systematic exploration.

Surveys along the rivers and streams indicate that the size of the basaltic glass cobbles decreases significantly with increasing distance from the outcrops (e.g., Doelman et al., 2004:114–115). The highest location assessed (04/21) was along the Right Ilistaya River at an elevation of c. 250 m asl. Here the cobbles were large (above 10 cm with the largest in the 15–20 cm range) and angular. The flaking quality varied, with some containing high numbers of large phenocrysts, and the color ranged from blue/gray to black. Overall, this was ranked as having good potential as a source. Another location further downstream along the Suhoi Stream (04/22) is now a dry creek bed but was previously a tributary of the Right Ilistaya River. Here the material quality and color (blue/gray and black) also varied, but the mean size of the cobbles was smaller than at 04/21 (median in the 0–10 cm size group with the largest in the 10–15 cm range). The pieces were still angular with a smoother cortex. Despite the smaller size, the abundance of cobbles composed of good-quality raw material ranks this source as having good potential.

At about 20 km from the 04/20 outcrop, the cobbles ranged from 5–8 cm in length, indicating that they did not have to travel very far downstream before their volume had significantly decreased (Doelman et al., 2004). Further downriver along the Ilistaya River, roughly 30–35 km from the 04/20 outcrop at an elevation of 150 m asl, two locations (04/18, 04/19) were assessed. Very few basaltic glass cobbles were found, possibly because these are popular spots for private collectors. The largest pebble we noted was only 7 cm in diameter with the majority ranging between 2–4 cm, and the majority have a very battered cortex (Figure 3). Pebbles of blue/gray and black material were observed, some of very high quality, but due to their small size, they could only be flaked using a bipolar technique. Based on these results, river sources at a distance of 30 km from the outcrops have limited potential as a stone resource due to the small size of the cobbles and the substantially lower densities of material. Defining the potential utility of sources in this way helps restrict the region within which basaltic glass could have originated.

Turning to the largest river draining the Shkotovo Plateau, the Arsenievka River, at approximately 53 km from the 04/20 outcrop at 150 m asl, only a few small pebbles (<5 cm) of basaltic glass were observed. Basaltic glass was generally found preserved as a thin rind on basalt cobbles, suggesting that they had been derived from a nearby outcrop, rather than from 04/20. Survey work is planned to further investigate the river gravels and outcrops of this region.

SOURCE ASSESSMENT

Following the detailed assessments of the various localities, we can now use what we know about the constraints of the geological formation processes and subsequent erosion and alteration of the rhyolitic, perlitic, and basaltic glass outcrops to pose a number of hypotheses about how the volcanic glass might have been procured and worked in the region.

1. Although abundant, the extremely poor quality of both primary and secondary sources of perlite in the broader Krabbe Peninsula region explains why this source has not been found in archaeological sites despite being easily accessible and abundant.
2. There are two reasons we predict that the Gladkaya River Basin sources were only used to a limited extent for flaked stone production. First, excavation is required to obtain good-quality volcanic glass. Second, only pebbles which cannot produce flakes large enough for viable stone tools can be obtained from gravels within the Vinogradnaya River even within 2 km of the outcrop.
3. The Shufan Plateau can be discounted as a source of basaltic glass for the production of flaked stone tools due to the absence of high-quality raw material

Table II. Number of basaltic glass and Gladkaya River Basin artifacts with cortex that can be assigned to primary and secondary contexts.

	Primary context	Secondary context
Basaltic Glass		
Late Paleolithic	619	422
Late Neolithic	1	1
Bronze Age	19	18
GRB		
Late Neolithic		6
Bronze Age	4	

of a suitable size and shape. Stone from either the primary outcrops or secondary gravels within the riverbed is non-viable. This result significantly narrows the potential source area for basaltic glass and means that studies of spatial patterning to understand how it may have been distributed in the past are now feasible.

4. On cost-effective terms alone, the outcrops would not need to be exploited because large cobbles of medium—good-quality material can be easily extracted from stream beds in the Shkotovo Plateau. However, abundant stone working debitage from the primary source of basaltic glass at Locality 04/25 demonstrates that outcrops were also exploited. In addition, the presence of rough, contact, or flat cortex on artifacts recovered from a wide range of archaeological sites substantiates the use of outcrops (Table II). Ample, high-quality material is certainly available at the Krivoi outcrop (04/20), although the resource is only accessible in a limited area, in comparison to the widespread distribution of the secondary deposits. In contrast, the low abundance and difficulty of extracting material from the Orbervisti outcrop make this a much less attractive source. We therefore predict that the bulk of the basaltic glass used on archaeological sites was derived from both primary and secondary sources in the central part of the Shkotovo Plateau.
5. The quality of the material found in the secondary sources is highly variable. Our observations suggest that a considerable amount of testing needs to be undertaken to identify suitable raw material. Consequently, if a nearby high-quality outcrop with ample material was present, then this source is more likely to have been targeted than secondary material within the steam bed.
6. Based on the presence of water-rolled cortex in flaked stone assemblages (Table II), secondary sources in the Shkotovo Plateau were used. However, the distance downstream from an outcrop dramatically influences the size of the available cobbles/pebbles (Doelman et al., 2004). Large cobbles of good-quality raw material were only observed in the upper reaches of the Ilistaya River. It was noted that near the outcrops, high in the Shkotovo Plateau, cobbles up to 25 cm in diameter are present in the stream bed. In contrast, at 30–35 km downstream from the outcrops in gravels within the Ilistaya River, the largest available pebble was only 8 cm in length. A similar scenario occurs in the Arsenievka River, which also drains the Shkotovo Plateau. At ca. 50 km from

the headwaters of the Arsenievka River, the pebbles are smaller than 5 cm in diameter. Our survey and assessment of primary and secondary sources has therefore narrowed the spatial distribution of useable basaltic glass from the whole of the Basaltic Plateaux region to a distance of 30 km (possibly less) along the beds of a few rivers.

GEOCHEMICAL STUDIES

Having used a geoarchaeological analysis of the primary and secondary sources of volcanic glass in Primorye to assess their potential for least-cost exploitation, we now turn to a characterization study of volcanic glass artifacts. The results of this study provide a good test of whether the physical properties alone can be used to predict the nature of past use.

Geochemical techniques have been widely used in many parts of the world to link volcanic glass artifacts with their geological origin. Using a combination of techniques, pioneering geochemical analysis of geological sources of volcanic glass reported by Kuzmin and Popov (2000) identified ten distinct chemical sub-groups from four geological formations local to the Primorye region: (1) Gladkaya River-1, 2, and 3; (2) Basaltic Plateau; (3) Krabbe Peninsula; and the (4) Sikhote-Alin volcanic belt (Sadovy, Chernaya Rechka, and Samarage). They also analyzed samples from two locations found on the distant Paektusan Volcano (Paektusan 1 and 2). They concluded that because the geochemical analyses did not match any artifacts with glasses from the Sikhote-Alin volcanic belt, the Krabbe Peninsula, Paektusan-2, or the Gladkaya River-2 and 3 chemical groups, these geological formations were not used in the past (Kuzmin and Popov, 2000; Kuzmin et al., 2002:509–510). These results have been confirmed and broadened by subsequent PIXE-PIGME analyses of 39 geological and 76 archaeological samples (Doelman et al., 2004).

In order to ensure that a comprehensive analysis had been made of intra-source variability, additional geological samples were collected from primary and secondary deposits within five local source areas (Figure 1). Two samples from the distant Paektusan obsidian obtained from Korean scientists were also analyzed. The established technique PIXE-PIGME and a simpler, less well known method based on relative density were used to characterize the geological deposits and artifact assemblages.

PIXE-PIGME Analysis

PIXE-PIGME has been successfully used to characterize volcanic glass artifacts (e.g., Summerhayes et al., 1998; Araho, Torrence, & White, 2002; Torrence, 2004). The current analyses were undertaken at the Australian Nuclear Science and Technology Organisation (ANSTO), Sydney. PIXE-PIGME analysis is a non-destructive technique that measures a range of elements (Summerhayes et al., 1998:134). In PIXE (Proton Induced X-ray Emission) analysis samples are irradiated by medium-energy (a few MeV) protons produced by an accelerator. Following the interaction between protons and the electronic shells of atoms present in the sample, characteristic X-rays are emitted. These X-rays can be measured by solid state detectors, usually of silicon (Si).

A "pinhole" filter is used to limit the intensity of the major elements, making it easier to detect trace elements and discriminate the sources to a finer degree. In PIGME (Proton Induced Gamma-ray Emission) analysis the medium-energy protons interact with the nucleus of the elements producing a nuclear reaction which may be accompanied by the emission of characteristic γ-rays. The γ-rays can be detected by solid state germanium (Ge) detectors. The signal produced by the detectors is then processed by a standard electronic system (detector, preamplifier, pulse generator, amplifier, and a multi-channel analyzer) designed to count the characteristic X-ray and γ-ray quanta emitted by each element, which is proportional to the abundance of that element in the sample. The PIGME technique is effective for light elements, such as fluorine (F), whereas the PIXE technique is best at detecting elements heavier than fluorine. Six elements were used to produce five ratios showing the differing concentrations of Al/Na, Mn/Fe, Fe/Na, K/Fe, and Ca/Fe. Ratios are commonly used in statistical cluster analysis if they represent independent variables (Torrence et al., 1992:92).

During the PIXE-PIGME analysis a number of samples charged, resulting in an increased background level that made the analytic process less accurate. The charging, which is indicative of an increased surface resistance, was suppressed by coating the samples with a layer of sputtered carbon, approximately 100 nm thick. An increased surface resistance may be associated with a particular bulk composition which is low in heavy metals such as iron (Fe), cobalt (Co), and nickel (Ni). In our samples we found no correlation between the bulk composition and the charging effect. Another possible cause for a low surface resistivity may be a depletion of heavy metal elements in the outer layers of the samples, caused by the interaction with the soil in which the artifacts were buried.

A sample of 121 artifacts and source samples were analyzed, 12 of which were repeats from Doelman et al. (2004) to ensure consistency between runs. The concentrations of the elements used to discriminate between sources are presented in Table III. The results compare favorably with Instrumental Neutron Activation Analysis (INAA) undertaken previously by Kuzmin et al. (1999; 2002; cf. Kuzman and Popov, 2000:62–70; Doelman et al., 2004:Table 3).

Multivariate statistical techniques assessed whether the geochemical data were clustered based on their principal components, and multinomial and linear discriminant classification were used to associate unclassified observations (artifacts) with previously identified geological subgroups. Visual inspection of the plot of the first two principal components for the PIXE-PIGME data (Figure 4) confirms there is excellent separation among the samples from the Basaltic Plateau, Paektusan Volcano, Kraskina outcrop (although only one geological sample), and the Krabbe Peninsula. Furthermore, the results substantiate previous studies by Kuzmin et al. (2002) and Doelman et al. (2004) that show that the perlitic sources of the Krabbe Peninsula and Kraskina were not used in the past, as no artifacts were present within these clusters. They also support our predictions based on a geoarchaeological assessment of the potential of the geological deposits for sustained exploitation as flaked stone raw material.

Concerning the Gladkaya River Basin, all the geological samples we collected from the Vinogradnaya-1 outcrop and the Vinogradnaya River are clustered into one

Table III. Element concentrations (mean and standard deviations) measured by PIXE-PIGME. F and Mn are measured in parts per million (ppm). Na, Al, K, Ca, and Fe are in percentages.

		F		Na		Al		K		Ca		Mn		Fe	
Source	N	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Basaltic	147	236	14	2.37	0.65	8.12	18.3	0.61	0.52	6.33	1.55	1371	543	8.09	1.92
Krabbe	9	149	32	2.51	0.27	6.44	0.63	3.59	1.29	0.75	0.22	235	29	1.20	0.26
Kraskina	1	43		1.32		5.27		4.42		0.66		55		0.46	
Paektusan	96	1855	416	2.72	0.27	6.43	0.65	4.28	0.96	0.64	1.20	402	180	1.55	1.28
GRB-1	16	332	26	2.41	0.13	5.76	0.19	3.90	0.50	0.34	0.04	260	23	0.64	0.04
GRB-2	12	342	7	2.00	0.06	5.72	0.15	5.18	0.45	0.33	0.03	269	24	0.65	0.08

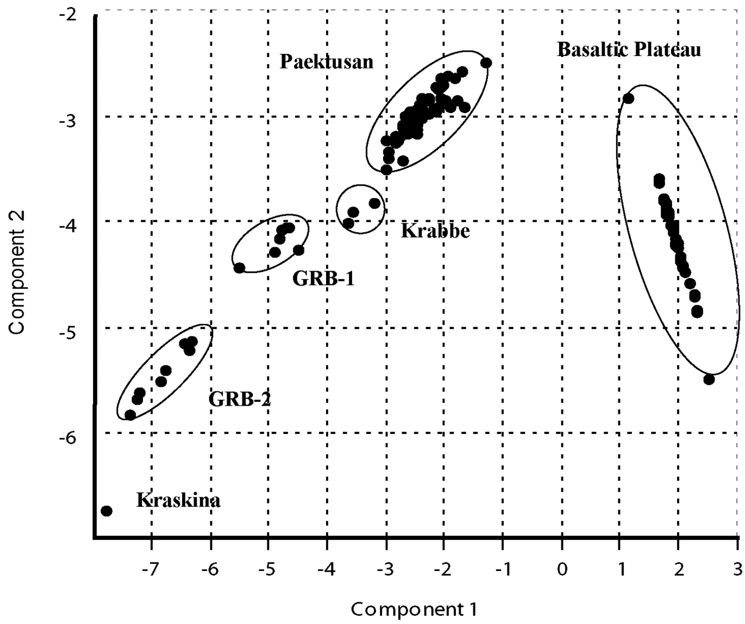

Figure 4. Bivariate plot of the first two principal components (ratios of elements Al/Na, Fe/Na, Mn/Fe, K/Fe, Ca/Fe) showing the different source groupings of volcanic glasses in southern Primorye.

chemical group (GRB-1), whereas the artifacts occur in a different group that was geochemically distinct (GRB-2). The artifacts are all derived from the site of Sinie Skaly (Figure 5). They are rhyolitic in origin and have the distinctive green color typical of the Gladkaya River sources. Based on the geochemical composition of one artifact from Sinie Skaly, Popov and Shackley (1997:83) and Kuzmin and Popov (2000:85) also concluded it was probably from the Gladkaya River sources.

Cross-validation of classification using both multinomial and linear discriminant analyses of the log-ratios were able to correctly classify known source material. Moreover, classification of unidentified artifactual material was consistent with our clustering of the known Basaltic Plateau and Paektusan Volcano samples. Two discrepancies occurred in the results, which were easily resolved as both samples were green and could not be confused with volcanic glass from Paektusan. The results indicate that the GRB-1 and GRB-2 groups are very similar in geochemical composition and for our purposes will be considered as a single GRB source area. Further exploration is needed to identify the exact location of the GRB-2 source used at Sinie Skaly. Given the chemical similarity among the GRB sources, it seems likely there is an undiscovered outcrop in the Gladkaya River basin. However, as noted by Kuzmin and Popov (2000:40), there is another volcanic glass source near the Chinese border in the Rjazanovka River valley which should also be explored in future work, when the political situation allows.

In summary, the PIXE-PIGME study demonstrates that physical characteristics of volcanic glass sources played a major part in the selection of raw material. The sources which were rated as non-viable were not used. Only the best-quality primary and

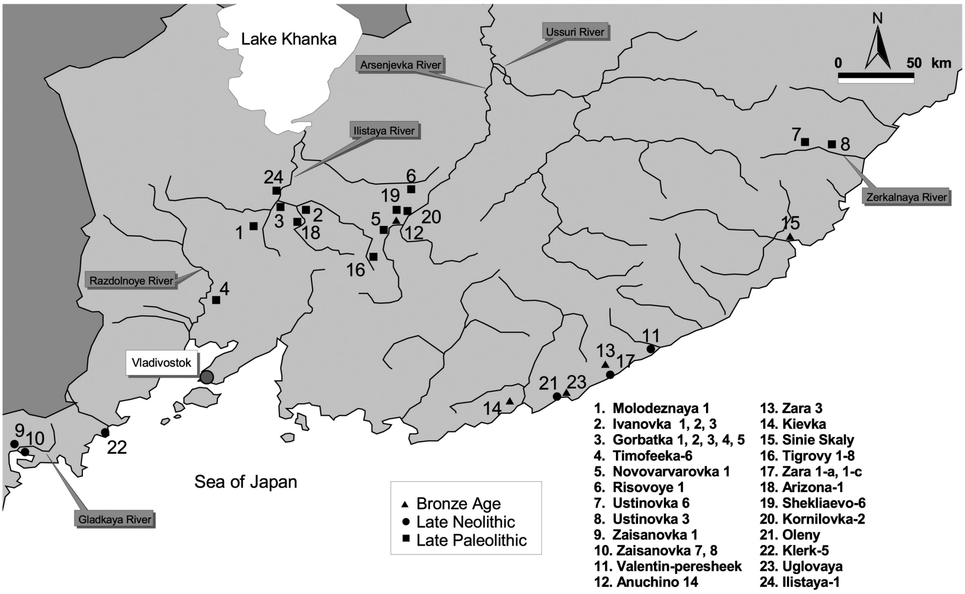

Figure 5. Location of archaeological sites included in the characterization study of volcanic glasses.

secondary basaltic glass sources were regularly exploited. Although our studies using PIXE-PIGME analysis provide excellent characterization, the sample size of artifacts, considerably restricted by cost, was not large enough for a meaningful interpretation of temporal changes in spatial distribution (Doelman et al., 2004).

Density Analysis

In order to increase the sample size of the characterized material, color was used to identify material from the GRB area and the technique of relative density was used to differentiate between volcanic glass from Paektusan and the Basaltic plateau. Characterization studies in the Pacific have successfully discriminated between major source regions of obsidian based on their specific gravity (e.g., Ambrose, 1994; Green, 1987; Torrence and Victor, 1995; White and Harris, 1997). Fortunately, the two main volcanic glass sources used in the southern Primorye region, basaltic glass and Paektusan obsidian, have significantly different chemical compositions, especially in terms of their iron content (Table III) (cf. Doelman et al., 2004:Table 3; Kuzmin et al., 2002:Table 2) and consequently very different specific gravities. Characterization of artifacts by differences in relative density was achieved using a simple method which was later corroborated with more sophisticated measurements.

The first approach followed a protocol similar to Green (1987). A solution of sodium polytungstate was made to a specific gravity of 2.45. This value was selected to best differentiate between published values for basaltic glass and obsidian (Webster, 1983:443). Samples already sourced using PIXE-PIGME were tested. Artifacts made from rhyolitic glass (Paektusan) float, whereas those from basaltic glass sink. This relatively simple test allowed significant numbers of artifacts stored at the Institute of History, Archaeology and Ethnography of the Peoples of the Far East in Vladivostok to be assigned to one of these two sources (Table IV).

Further tests of specific gravity using a different methodology were used to establish the range of variation in the samples from each source area with greater precision. Following the approach first described by Ambrose (1994; Torrence and Victor, 1995:123), a solution of perfluoro-1-methyl-decalin (PFMD) was placed in a beaker with enough liquid to cover a suspended glass cradle. The scale was tared and the artifact was carefully placed in the cradle, making sure that it was completely covered by the PFMD solution and neither the artifact nor the cradle were touching the sides of the beaker. Once the scale stabilized, a reading was taken to three decimal places. The temperature of the solution was also recorded and the formula in Table V (Ambrose, 1994; Torrence and Victor, 1995:123) was applied to calculate the relative densities.

A clear separation in the specific gravities of volcanic glasses from the Basaltic Plateau ($n = 16$) and Paektusan volcano ($n = 14$) was demonstrated. When compared, the results of the Green method (1987) and PIXE-PIGME analysis on 90 artifacts yielded only 1 discrepancy (Table VI). A single sample classified as rhyolitic obsidian

Table IV. Relative density results of artifacts ($n = 2372$).

	Late Paleolithic		Late Neolithic		Bronze Age	
Source	*N*	%	*N*	%	*N*	%
Basaltic Plateau	1718	90.9	11	3.5	117	70.9
Paektusan	157	8.3	297	93.4	23	13.9
Gladkaya River Basin (GRB)			10	3.1	23	13.9
Unknown	14	0.7			2	1.2
	1889		318		165	

*GRB sources were primarily determined by green color.

Table V. Formula for the relative density of obsidian artifacts and source samples (derived from Ambrose, 1994; Harri,s 1994:43; Torrence and Victor, 1995:123).

$$d = \frac{ma. (T\text{-}965.99/\text{-}480.88)}{(ma\text{-}ml)}$$

d = relative density; ma = weight in air;
ml = weight in PFMD; T = temperature

Table VI. Comparison of PIXE-PIGME and relative density analyses.

Source	PIXE-PIGME	Density analysis (after Green, 1987)
Basaltic	30	29
Paektusan	47	48
GRB	13	13
Total	90	90

from Paektusan Volcano using the Green (1987) method was shown by PIXE-PIGME to be basaltic in origin. The failure of relative density to discriminate this artifact is possibly due to the presence of cortex on the artifact, because this has been shown to skew the results (cf. Torrence and Victor, 1995:128–130).

SOURCE USE

Using the combined techniques of PIXE-PIGME, density, and color, 2372 artifacts were characterized from sites located throughout southern Primorye (Table VII). These sites include 27 Late Palaeolithic, eight Late Neolithic, and four Bronze Age assemblages (Figure 5). We note here that site chronologies are largely based on typological markers and that the chronological designation was provided by the archaeologist who excavated the particular assemblage. All the artifacts were also submitted to a basic technological analysis which included a study of metrical attributes. Pulling together the results of the geoarchaeological survey, the geochemical analyses, and the technological, typological, and metrical variables of individual artifacts, we can begin to reconstruct changes through time in how stone was obtained, used, and discarded.

Table VII. Sites and samples used in the technological analysis.

Site	*N*		*N*
Late Paleolithic			
Arizona-1	6	Risovaya-1	107
Gorbatka-1	2	Shekliaevo-6	136
Gorbatka-2	31	Tigrova-1	6
Gorbatka-3	40	Tigrova-2	286
Gorbatka-4	3	Tigrova-3	13
Gorbatka-5	16	Tigrova-4	3
Ilistaya-1	6	Tigrova-5	140
Ivanovka-1	10	Tigrova-6	44
Ivanovka-2	1	Tigrova-7	68
Ivanovka-3	36	Tigrova-8	40
Kievka	14	Timofeeka-6	2
Kornilovka-2	16	Ustinovka-3	1
Molodeznaya-1	669	Ustininoka-6	2
Novovarvarovka-1	191	**Sub-total**	**1889**
Late Neolithic		**Bronze Age**	
Kierk-5	3	Anuchino-14	79
Olenya	1	Sinie Skaly	70
Uglovaya	3	Zara-1a	9
Valentin-Peresheek	6	Zara-3	7
Zaisanovka-1	222	**Sub-total**	**165**
Zaisanovka -7	2	**Total**	**2372**
Zaisanovka -8	73		
Zara-1c	8		
Sub-total	**318**		

Late Palaeolithic period (ca. 20,000–10,000 yr B.P.)

During the Late Paleolithic period a relatively small but significant amount of Paektusan obsidian was imported into the Basaltic Plateau region (cf. Kuzmin et al., 2002). To better understand resource acquisition and movement (i.e., by social exchange, through mobility patterns, or migration), it is important to establish the form in which the material was transported. Artifacts that relate to systematic blade production were monitored because this technology is widespread at this time (Table VIII). The blade cores are similar to boat/wedge-shaped examples found in Japan, known as the Horoko Type (Kajiwara and Yokoyama, 2003:20–23). Of the 154 artifacts sourced to Paektusan, a significant number (70; 46.1%) were generated during the process of blade manufacture, including crested blades, ridge-straightening flakes, and platform rejuvenation flakes (Table VIII). It therefore seems likely that Paektusan blade cores were transported, curated, and continually reworked. This behavior would be expected within a highly mobile settlement system. In contrast, only 15.6% of the 269 basaltic glass artifacts were related to blade manufacture. The question then arises whether the Paektusan material was specifically procured because it was well suited to microblade core production.

A second major difference in the use of raw material is that a high proportion of the artifacts from Paektusan Volcano were retouched (49.4%, $n = 76$) in comparison to those from the Basaltic plateau (9.8%, $n = 169$) (Table IX). Most of the retouched artifacts from Paektusan Volcano were invasively flaked points and bifaces, with significantly fewer scrapers than in the retouched assemblages made from basaltic glass ($X^2 = 31.667$, $df = 2$, $p < 0.0001$). These results suggest that obsidian from Paektusan Volcano arrived in the Primorye Region mainly as prepared blade cores and "formal" retouched tool types.

Whether the treatment of Paektusan obsidian is related to exchange or mobility is not yet clear because the number and spatial distribution of the sites studied is not adequate for a study of fall-off in shape and size with distance from the source (cf. Renfrew, 1975). The majority of the assemblages we have studied are situated close to the basaltic glass sources, so it is not surprising that the local resource is represented by a wider range of activities and types of reduction sequences, including early stages of production and less curated forms of retouched items (i.e., scrapers), than those represented in the Paektusan assemblages.

No artifacts in our sample were derived from the GRB sources during this period, but Kuzmin et al. (2002:508) have identified a GRB artifact from the Late Palaeolithic site of Razdolnoye. Because this site is situated closer to the GRB than to the basaltic glass sources, it may represent casual use of easily accessible material.

Late Neolithic period (ca. 5700–3500 yr B.P.)

No early Neolithic assemblages were included in the study. All the Late Neolithic sites in this analysis belong to the Zaisanovka Culture and are coastal. Because they are situated in a different area than our Palaeolithic sample, a study of change through time is somewhat restricted. It has been proposed that these sites have close ties with other Late Neolithic cultures in Korea and China (Cassidy and Kononenko, 2001;

Table VIII. Artifacts related to blade technology made from the different volcanic glass sources.

	Basaltic Plateau		Paektusan		GRB
Blade related artifacts	*N*	%	*N*	%	
Late Paleolithic					
Assemblage total	1721	100	154	100	
Blade	89	5.2	47	30.5	
Blade-like	110	6.4	10	6.5	
Crested blade	5	0.3	1	0.6	
Ridge straightening	11	0.6	4	2.6	
Blade cores					
Bullet	3	0.2	2	1.3	
Microblade	40	2.3	7	4.5	
Tabular	5	0.3			
Unidirectional	1	0.1			
Prismatic	1	0.1			
Sub-prismatic	4	0.2			
Subtotal	**269**	**15.6**	**71**	**46.1**	
Late Neolithic					
Assemblage total	11	100	297	100	
Blade			10	3.4	
Blade-like	1	9.1	26	8.8	
Crested blade			2	0.7	
Ridge straightening			3	1.0	
Blade cores					
Microblade	2	18.2	1	0.3	
Subtotal	**3**	**27.3**	**42**	**14.1**	
Bronze Age					
Assemblage total	117	100	24	100	
Blade	3	2.6			
Blade-like	6	5.1	3	12.5	2
Crested blade					
Ridge straightening					
Blade core					
Bullet			1	4.2	
Microblade	1	0.9			
Prismatic	1	0.9			
Subtotal	**11**	**9.4**	**4**	**16.7**	**2**

Kuzmin et al., 2002:513). This argument is supported by the high numbers of artifacts (93.4%, n = 297) from Paektusan Volcano found in the sites and the extremely limited use of basaltic glass (ca. 60–70 km away) (Table IV), suggesting a lack of either travel to and/or contact with the inland. Similarly, the GRB sources appear not to have been exploited to any significant degree at this time (3.1% of characterized artifacts; Table IV).

It is possible that the Yalu (Amnok) River forms an inland route that was easily and quickly navigated by the peoples of the Zaisanovka Culture. The river stretches

Table IX. Retouched tool types.

	Basaltic glass		Paektusan		GRB	
	N	%	*N*	%	*N*	%
Late Paleolithic						
Retouched point	19	11.2	30	39.5		
Scraper	122	72.2	30	39.5		
Biface	14	8.3	11	14.5		
Drill	4	2.4	2	2.6		
Notch	3	1.8	2	2.6		
Burin	7	4.1	1	1.3		
Total	169	9.8	76	49.3		
Late Neolithic						
Retouched point			21	40.4	2	100
Scraper			18	34.6		
Biface			10	19.2		
Drill			1	1.9		
Notch			2	3.8		
Total			52	17.5		
Bronze Age						
Retouched point	9	14.1	5	100		
Scraper	39	60.9			4	100
Biface	11	17.2				
Drill	4	6.3				
Notch	1	1.6				
Burin	9	14.1				
Total	73	62.4	5	20.8	4	17.4

790 km from the Bay of Korea to the Baitou mountain range where Paektusan Volcano is found (Figure 1) and potentially allowed for the seasonal migration and the relatively easy transport of obsidian from Paektusan. It is likely that there was a system of exchange that enabled the obsidian to be acquired and transported down the river to the sea, where it was then moved along the coast. Kuzmin et al. (2002:507–508, Table 1, Figure 1) also show that most of the sites related to the Zaisanovka culture utilized Paektusan obsidian (n = 9, 66.7%).

A reasonable proportion of the artifacts from Paektusan Volcano were retouched as points or bifaces (Table IX); however, the proportion of the assemblage made up of imported retouched material (17.5%, n = 52) is much lower than in the Late Palaeolithic (49.3%, n = 76). Because it seems unlikely that these were made "on-site due to the relative absence of debitage directly related to systematic core reduction, these may represent a continuation in the transport of curated items. Very little of the obsidian was used in systematic core reduction (14.1%, n = 42; Table VIII). Instead, most cores were reduced expediently. A ratio of cores to unmodified complete flakes indicates that in the Late Neolithic period more Paektusan flakes were struck from each core (1:7) in comparison to those in the Late Palaeolithic period (1:5). The aim of Late Neolithic core reduction was simply to produce large flakes. Their expedient approach to raw material use indicates that consumers were not so concerned about conserving raw material as they had been during the Late Palaeolithic, either because they had ready access to large amounts of material, possibly via coastal/inland trade, and/or, equally likely, because their more sedentary lifestyle was more conducive to scheduled procurement trips coupled with stockpiling of supplies (cf. Torrence, 1992, 2001:86).

Bronze Age (ca. 4000–2700 yr B.P.)

Volcanic glass artifacts are relatively rare at the Bronze Age sites we studied, especially when compared to the previous period (Table IV), but our sample of sites is located further from all the sources than in previous periods (Figure 5). The occurrence of artifacts made from volcanic glass from the GRB-2 chemical group is all the more important because on the basis of the presence of cortex, the Bronze Age samples are derived from primary contexts, whereas in the previous period only stream cobbles had been used (Table II). An emphasis on outcrop sources rather than dispersed secondary material is more likely to be associated with exchange, because the resources are more easily identified with specific "owners." In contrast, there is no change through time in the almost equal use of both primary and secondary sources of basaltic glass (Table II).

Very little systematic core reduction occurs in the Bronze Age, with only 16.6% ($n = 4$) of the artifacts from Paektusan Volcano resulting from blade manufacture and 9.4% ($n = 11$) from the Basaltic Plateau (Table VIII). The primary difference between these and earlier assemblages is the increase in the proportion of scrapers, possibly reflecting economic changes (Table IX).

SYNTHESIS AND CONCLUSIONS

Our research on volcanic glass in the Primorye region of Far East Russia has brought together a number of approaches to understand the ways societies procured, transported, and worked volcanic glass. The systematic investigation of the primary and secondary sources of volcanic glass achieved a number of useful results. First, the potential source area of basaltic glass was significantly narrowed to the central region of the Shkotovo Plateau. Second, the study demonstrated that quarrying and not just collection of cobbles from secondary sources had a significant role to play in how volcanic glass was acquired and used. Third, we now have a clear picture of why the perlites from the Krabbe Peninsula and the rhyolitic glass from the Vinogradnaya sources (GRB-1) were never used. These findings demonstrate the importance of a geoarchaeological survey for providing a sound geological context that enables an assessment of source potential that can be compared to how the raw material was actually used.

This research also demonstrates the high potential of relative density studies in conjunction with PIXE-PIGME to characterize large samples of artifacts. Because tests of relative density can cheaply, easily, quickly, and effectively separate rhyolitic and basaltic volcanic glass, complete assemblages can be sorted into meaningful groups. It seems likely that this technique could be extremely useful for characterizing volcanic glass in other parts of the world, as is the case for the Pacific region (e.g., Green, 1987; White and Harris, 1997).

Finally, our study of geological sources and archaeological material from southern Primorye has revealed interesting chronological changes in the relative use of distant and local sources and in the types of the artifacts made from these sources. In particular, our investigation identifies which sources were exploited, what artifacts were manufactured, and the spatial distributions of volcanic glass artifacts from the different sources. Additional studies are required to widen the spatial and temporal coverage. In particular, the Early Neolithic was not included in this study. Once the sample size has been expanded sufficiently, it should be possible to determine the nature of the mechanisms (e.g., mobility, migration, or exchange) that were responsible for changes in source use and in the types and spatial patterning of volcanic glass artifacts within the southern Primorye region.

This research was supported by an Australian Research Council Discovery grant to Torrence, Kononenko, and Doelman and AINSE grants to Torrence and Doelman. At ANSTO we received assistance from Ed Stelcer, Olga Hawas, and Rainer Siegele. An international team of archaeologists and geologists aided in the collection of geological samples for this study in October 2001: Y. Yoshitani (Tottori University), T. Tomodo (Hokkaido), and J. Cassidy (University of California at Santa Barbara). Much help and support was provided by Nina Kononenko, Mi-Yong Hong, and Ian Graham. Ian Graham, Gayle Webb, and Ross Pogson (Geosciences, Australian Museum) gave advice about specific gravity. We also thank Yuri Vostretsov (Institute of History, Archaeology and Ethnography of the Peoples of the Far East, Russian Academy of Science) for access to the Zaisanovka assemblages.

REFERENCES

Ambrose, W.R. (1994). Relative density measurement. Unpublished manuscript, Research School of Pacific Studies, Australian National University, Canberra.

Araho, N., Torrence, R., & White, P. (2002). Valuable and useful: Mid-Holocene stemmed obsidian artifacts from West New Britain, Papua New Guinea. Proceedings of the Prehistoric Society, 68, 61–81.

Bamforth, D.B. (1990). Settlement, raw material and lithic procurement in the central Mojave Desert. Journal of Anthropological Archaeology, 9, 70–104.

Bamforth, D.B. (1992). Quarries in context: A regional perspective on lithic procurement. In J.E. Arnold (Ed.), Stone tool procurement, production and distribution in California prehistory (pp. 131–150). Los Angeles: Institute of Archaeology, University of California.

Batiza, R., & With, J.D.L. (2000). Submarine lavas and hyaloclastite. In H. Sigurdsson (Ed.), Encyclopedia of volcanoes (pp. 361–381). San Diego: Academic Press.

Carmichael, I.S.E., Turner, F.J., & Verhoogen, J. (1974). Igneous petrology. New York: McGraw-Hill.

Cassidy, J.G., & Kononenko, N.A. (2001). A reconstruction of the paleocoastal landscape of the Primorye Region (Russian Far East). In A.P. Derevianko (Ed.), Russia and China at the far eastern boundary (pp. 25–35). Blagoveshensk: Amur State University.

Chichagov, V.P., Muk, R.K., Cherkinsky, A.E., & Chichagova, O.A. (1989). Radiocarbon age of trees buried by tephra from the Paektusan Volcano in the north of Korea. Reports of the Russian Academy of Sciences, 306, 169–172 (in Russian).

Dillian, C. (2004). Sourcing belief: Using obsidian sourcing to understand prehistoric ideology in Northeastern California, USA. Mediterranean Archaeology and Archaeometry, 4, 33–52.

Doelman, T., Webb, J., & Domanski, M. (2001). Source to discard: Patterns of lithic raw material procurement and use in Sturt National Park, northwestern New South Wales. Archaeology in Oceania, 36, 15–33.

Doelman, T., Kononenko, N., Popov, V., Summerhayes, G., Torrence, R., Bonetti, A., Guglielmetti, A., Manzoni, A., & Oddone, M. (2004). Acquisition and movement of volcanic glass in the Primorye Region of Far Eastern Russia. Russia and the Pacific, 46, 112–125.

Green, R. (1987). Obsidian results from the Lapita sites of Reef/Santa Cruz Islands. In W. Ambrose & J.M.J. Mummery (Eds.), Archaeometry: Further Australasian studies (pp. 239–249). Canberra: Department of Prehistory, Research School of Pacific Studies, Australian National University.

Harrison, A.J. (1947). Water content and infra-red transmission of simple glasses. American Ceramic Society Journal, 30, 362–366.

Horn, S., & Schmincke, H.U. (2000). Volatile emission during the eruption of Baitoushan Volcano (China/North Korea) ca. 969 AD. Bulletin of Volcanology, 61, 537–555.

Johnston, S.W. (1956). Perlite. Engineering and Mining Journal, 154, 108–109.

Jones, J.G., & Nelson, P.H.H. (1970). The flow of basalt lava from air into water—Its structural expression and stratigraphic significance. Geology Magazine, 107, 13–19.

Kajiwara, H., & Yokoyama, Y. (2003). The significance of the Japanese-Russian joint archaeological expeditions at the sites of Ustinovka complex, Primorye Region. In A. Derevianko & N. Kononenko (Eds.), Foraging populations of the Sea of Japan during the Late Pleistocene–Early Holocene (pp. 140–146). Novosibirsk: Izdatelbstvo Institute of Archaeology and Ethnography.

Kuzmin, Y.V., & Popov, V.K. (2000). Volcanic glasses of the Russian Far East: Geological and archaeological aspects. Vladivostok: Dalnevostochny Geologichesky Institut DVO RAN (in Russian).

Kuzmin, Y.V., Popov, V.K., Glascock, M.D., & Shackley, M.S. (2002). Sources of archaeological volcanic glass in the Primorye (maritime) province, Russian Far East. Archaeometry, 44, 505–515.

Kuzmin, Y.V., Tabarev, A.V, Popov, V.K., Glascock, M.D., & Shackley, M.S. (1999). Geochemical source analysis of archaeological obsidian in Primorye (Russian Far East). Current Research in the Pleistocene, 16, 97–99.

Lee, D. (Ed.). (1987). Geology of Korea. Kyohak-SA: Geological Society of Korea.

Noble, D.C., Smith, V.C., & Peck, L.C. (1967). Loss of halogens from crystallized and glassy silica volcanic rocks. Geochimica et Cosmochimica Acta, 31, 215–224.

Popov, V.K., & Shackley, M.S. (1997). Obsidian of Primorye: First results of archaeological-geological correlation. Vestnik DVO RAN, 8, 77–85 (in Russian).

Renfrew, C. (1975). Trade as action at a distance. In J. Sabloff & C. Lamberg-Karlovsky (Eds.), Ancient civilization and trade (pp. 3–60). Albuquerque: University of New Mexico Press.

Ross, C.S., & Smith, R.L. (1955). Water and other volatiles in volcanic glasses. American Mineralogy, 40, 1071–1089.

Santley, R., &. Pool, C. (1993). Prehispanic exchange relationships among central Mexico, the Valley of Oaxaca, and the Gulf Coast of Mexico. In J. Ericson and T. Baugh (Eds.), The American Southwest and Mesoamerica: Systems of prehistoric exchange (pp. 179–212). New York: Plenum.

Shackley, M.S. (1998). Intra-source variability and secondary depositional processes: Lessons from the American Southwest. In M.S. Shackley (Ed.), Advances in archaeological volcanic glass studies (pp. 83–102). New York: Plenum Press.

Shackley, M.S. (2005). Obsidian: Geology and archaeology in the North American Southwest. Tucson: University of Arizona Press.

Shackley, M.S., Glascock, M.D., Kuzmin, Y.V., & Tabarev, A.V. (1996). Geochemical characterization of archaeological obsidian from the Russian Far East: A pilot study. International Association of Obsidian Studies Bulletin, 17, 16–19.

Sleptsov, I. (2003). Survey of the Tigrova Valley. Vladivostok. Unpublished report, Vladivostok, Institute of History, Archaeology and Ethnography (in Russian).

Smith, T.L., & Batiza, R. (1989). New field and laboratory evidence for the origin of hyaloclastite flows on seamount summits. Bulletin of Volcanology, 51, 96–114.

Summerhayes, G.R., Bird, R., Fullagar, R., Gosden, C., Specht, J., & Torrence, R. (1998). Application of PIXE-PIGME to archaeological analysis of changing patterns of obsidian use in West New Britain, Papua New Guinea. In S. Shackley (Ed.), Advances in archaeological volcanic glass studies (pp. 129–158). New York: Plenum Press.

Torrence, R. (1986). Production and exchange of stone tools: Prehistoric obsidian in the Aegean. Cambridge: Cambridge University Press.

Torrence, R. (1992). What is Lapita about obsidian: A view from the Talasea sources. In J.-C. Galipaud (Ed.), Poterie Lapita et peuplement (pp. 111–126). Noumea: ORSTOM.
Torrence, R. (2001). Hunter-gatherer technology. In C. Panter-Brick, R. Layton, & P. Rowley-Conwy (Eds.), Hunter-gatherers: An interdisciplinary perspective (pp. 73–98). Cambridge: CUP.
Torrence, R. (2004). Now you see it. Now you don't. Changing patterns of obsidian distribution in Papua New Guinea. In J. Cherry, C. Scarre, & S. Shennan (Eds.), Explaining social change: Studies in honour of Colin Renfrew (pp. 115–125). Cambridge: McDonald Institute of Archaeology.
Torrence, R., Specht, J., Fullagar, R., & Bird, R. (1992). From Pleistocene to present: Obsidian sources in West New Britain, Papua New Guinea. Records of the Australian Museum, Supplement, 15, 83–98.
Torrence, R., & Victor, K.L. (1995). The relativity of density. Archaeology in Oceania, 30, 121–31.
Tykot, R.H. (1998). Mediterranean islands and multiple flows: The sources and exploitation of Sardinian obsidian, In S. Shackley (Ed.), Advances in archaeological volcanic glass studies (pp. 67–82). New York: Plenum Press.
Tykot, R.H. (2001). Chemical fingerprinting and source tracing of obsidian: The central Mediterranean trade in black gold. Accounts of Chemical Research, 35, 618–627.
Tykot, R.H. (2003). Determining the source of lithic artifacts and reconstructing trade in the ancient world. In P.N. Kardulias & R.W. Yerkes (Eds.), Written in stone: The multiple dimensions of lithic analysis (pp. 59–85). Lanham, MD: Lexington Books.
Uhlmann, D.R. (1972). A kinetic treatment of glass formation. Journal of Noncrystalline Solids, 7, 337–348.
Webster, R. (1983). Gems. Their sources, descriptions and identification. London, Butterworths.
White, J.P., & Harris, M.N. (1997). Changing sources: Early Lapita period obsidian in the Bismarck Archipelago. Archaeology in Oceania, 32, 97–107.
Znamensky, V.S. (1992). Perlite formation. Moscow: Nauka (in Russian).

Received 18 February 2007
Accepted for publication 15 August 2007
Scientific editing by Paul Goldberg

Appendix 1. Characteristics of volcanic glass sources.

Location	ID	Material	Topography	Geological context	Color	Abundance	Extraction type	Extraction ease	Activities
Orbervisti	04/01a	basaltic	beach	secondary	light–dark gray	low	hand	easy	nearby
	04/01b	basaltic	beach	secondary	light–dark gray	low	hand	easy	nearby
	04/02	basaltic	cliff	bands	light–dark gray/black	low	percussion	hard	nearby
Krabbe Peninsula	04/03	perlite	hilltop/ slope	massive flow	black	high	percussion	medium	none
	04/04a	perlite	beach	massive flow	black	high	percussion	medium	none
	04/04b	perlite	beach	secondary	black	high	hand	easy	none
	04/05a	perlite	beach	massive flow	black	high	hand/ percussion	medium	none
	04/05b	perlite	beach	secondary	black	high	hand	easy	none
Kraskina	04/06	perlite	beach	dike	green/gray	medium	percussion	hard	none
	04/07	perlite	beach	secondary	green/gray	medium	hand	easy	none
Gladkaya River Basin									
Vinogradnaya Outcrop 2	04/11	perlite/ rhyolite	hilltop/ slope	massive flow	dark green/gray/black	medium	digging	medium-hard	none/ doubtful
Vinogradnaya	04/13	perlite	stream	secondary	green	low	hand	easy	none
River	04/14	perlite	stream	secondary	green	low	hand	easy	none
Shufan Plateau									
Chertnatino	04/15	basaltic	cliff	bands	black	low	percussion	hard	none
Razdolnaya River	04/16	basaltic	river	secondary	black	v. low	hand	easy	none
Shkotovo Plateau									
Ilistaya River	04/18	basaltic	river	secondary	light gray/black/ dark gray	medium-high	hand	easy	none
Ilistaya River	04/19	basaltic	river	secondary	light gray/black/ dark gray	medium-high	hand	easy	none

(*Continued*)

Appendix 1 *(Continued)*

Location	ID	Material	Topography	Geological context	Color	Abundance	Extraction type	Extraction ease	Activities
Krivoi Outcrop	04/20	basaltic	cliff	bands/pillow	light gray/black/ dark gray	medium	hand, percussion	easy–moderate	none
Right Ilistaya River	04/21	basaltic	stream	secondary	light gray/black/ dark gray	medium	hand	easy	nearby
Suhoi Stream, Ilistaya River	04/22	basaltic	stream	secondary	dark blue/gray/ black	low–medium	hand	easy	nearby
Tigrova 3	04/24	basaltic	eroded hill slope/ terrace	secondary/ redeposited blocks	black	low–medium	hand	easy	nearby
Tigrova 8	04/25	basaltic	ridge	unknown	black	high	digging/ surface	easy–medium	present (workshop)
Arsenievka River	04/26	basaltic	stream	secondary	black	low–medium	hand	easy	none

Appendix 2. Characteristics of volcanic glass at source localities.

Id	Fracture	Maximum size cm	Mean size cm	Cortex type	Phenocryst density	Phenocryst size	Quality
04/01a	conchoidial	10	5–10	water-rolled	mixed	varied	medium
04/01b	conchoidial	10	5–10	water-rolled	mixed	varied	medium
04/02	poor conchoidal	50	0–5	rough	none	none	poor–medium
04/03	hackly	42	20–50	shiny	none	none	poor
04/04a	hackly	50	20–50	shiny	none	none	poor
04/04b	hackly	20	5–10	water-rolled	none	none	poor
04/05a	hackly	20	20–50	shiny	none	none	poor
04/05b	hackly	20	20–50	water-rolled	none	none	poor
04/06	hackly	10	2–10	water-rolled	none	none	poor
04/07	conchoidal-hackly	20	5–10	water-rolled	none	none	poor–medium
04/11	conchoidal-hackly	10	0–5	flat/dull	medium	small	poor–good
04/13	conchoidial	3	0–2	water-rolled	none-high	none-large	poor–medium
04/14	conchoidial	3	0–2	water-rolled	none	none	good
04/15	poor conchoidial	5	0–5	rough/flat/contact	mixed	varied–large	poor
04/16	poor conchoidial	2	0–2	water-rolled	mixed	varied–large	poor
04/18	conchoidial	4	2–4	water-rolled	mixed	varied	good
04/19	conchoidial	6	2–4	water-rolled	mixed	varied	good
04/20	conchoidial	10	5–10	rough/flat/contact	medium	large	medium
04/21	poor conchoidal-conchoidal	10	5–10	water-rolled	mixed	varied	poor–good
04/22	poor conchoidal-conchoidal	15	10–15	water-rolled	mixed	varied	poor–good
04/24	conchoidial	15	5–10	contact	mixed	varied	medium
04/25	conchoidial	20	5–10	rough/flat/contact	none	none	good
04/26	conchoidial	8	5–10	water-rolled	mixed	varied	poor–medium