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Rhyolite characterization and distribution in central Alaska

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ABSTRACT

Fine grained volcanic rocks are common in lithic assemblages of interior Alaska and are amenable to geochemical characterization using a variety of analytical techniques. Our study focuses on rhyolite with the intent of identifying and delineating geochemical groups that may correlate to specific geological source areas. PXRF technology was used to analyze 676 rhyolite artifacts from 123 sites in interior Alaska. Our preliminary results recognize ten distinct geochemical groups that appear to correlate with distinct geological sources. While geological origins of eight of the ten groups identified remain unknown, two geological sources have been pinpointed, one (represented by Group H) is located in the central Alaska Range and the second (Group G) is in the Talkeetna Mountains. The provisional framework of geochemical variation among tool quality rhyolite sources in this region is an important first step toward a more robust understanding of prehistoric landuse in interior Alaska.

1. Introduction

Interior Alaska has long been considered the "Gateway to the Americas" with a long record of human occupation that is documented in the archaeological record to have begun at least 14,000 years ago (Holmes 2001) (Fig. 1). This long and continuous occupation offers archaeologists a prime opportunity to address changes in tool-stone procurement, tool manufacture, and mobility strategies among prehistoric foraging groups. One way to address these questions is to use data from lithic source provenance analyses. Such analyses are an important tool for examining prehistoric behaviors associated with raw material procurement, mobility, and for reconstructing landuse strategies. In Alaska, such studies are in their infancy and have largely been confined to obsidian (cf. Cook, 1995; Reuther et al., 2011), yet other kinds of fine-grained volcanic rocks are even more common in lithic assemblages of interior Alaska and are well suited to geochemical characterization using a variety of techniques. Our study focused on rhyolite, a fine grained volcanic material, with the intent of identifying and delineating geochemical groups and proposing a provisional framework for describing the identified groups, while attempting to "pinpoint" the source origin of the material. It is clear rhyolite was used prehistorically, but to what extent and was there preference given to different types rhyolite for the manufacturing of different tools? Here we present results of an initial attempt to describe geochemical variation among rhyolite artifacts from interior Alaska with the intent of identifying and delineating geochemically similar sets of artifacts, and linking these geochemical groups to geological sources of rhyolite. In addition, we seek to address the relationship between tool stone elemental analysis and lithic technological organization of these rhyolitic artifacts in central Alaska.

Portable X-ray Fluorescence (pXRF) technology was used to analyze 676 rhyolite artifacts from 123 sites in interior Alaska (Fig. 1). Many of the artifacts analyzed in this study derived from stratified or dated contexts that range in age from the late Pleistocene through the late Prehistoric period (ca. 200 BP). In addition, we have established a growing body of geological source samples in an attempt to link geochemical groups known from archaeological context to the geologic origin of primary and secondary sources of lithic raw materials, a first in Alaska and Beringia.

2. Pre-contact use of rhyolite

Rhyolite is a felsic igneous rock that forms when magma of granitic composition erupts at the Earth's surface or intrudes the crust at shallow depths. Owing to the rapid cooling of the lava flow, only small crystals (mostly of microscopic size) are able to develop. The conditions of its formation make rhyolite a felsic rock, and

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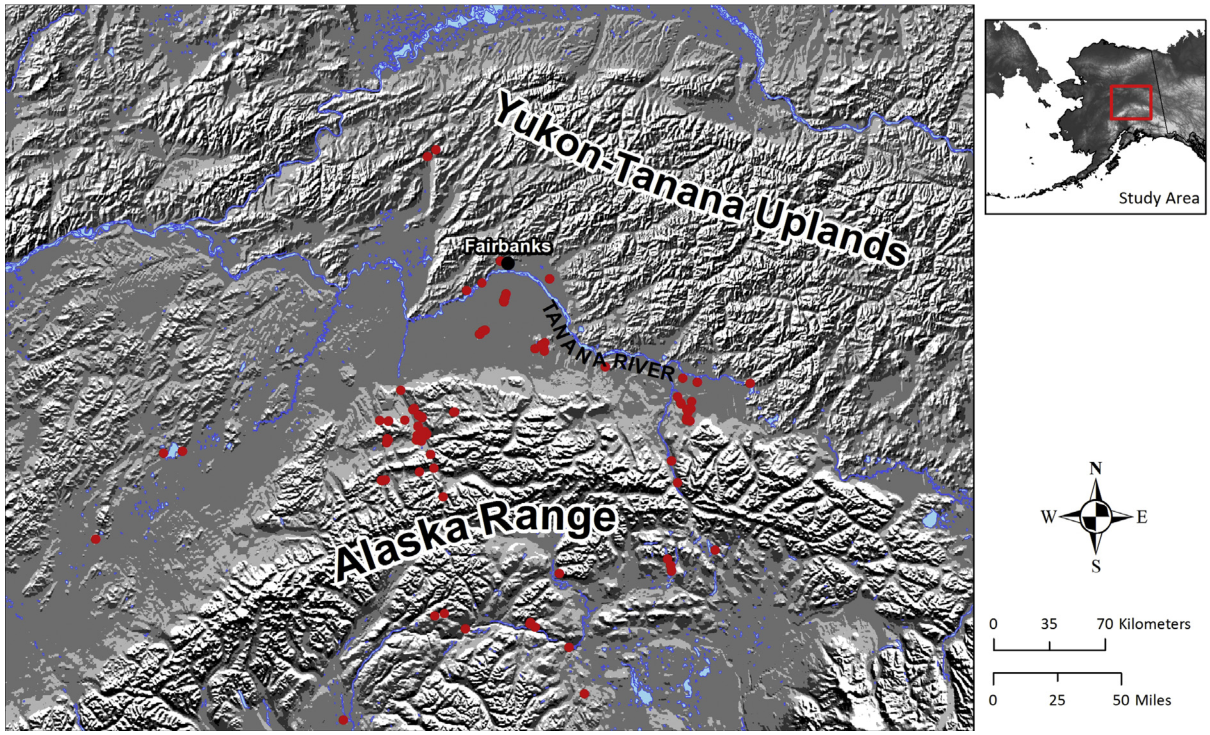

Fig. 1. Interior Alaska, the focus area of this research with analyzed sites containing rhyolite.

contain a similar chemical makeup to that of obsidian (Le Maitre et al., 1989). Rhyolite usually contains more than 70% silica (SiO_2). This high silica content gives the rock its generally light color (usually light gray, pink or rose in color), and relative low density. It also contributes to the properties that made rhyolite a useful raw material for flaked stone tool production.

Rhyolite is a common rock type in interior Alaska and was one of the most commonly used lithic raw materials in central Alaskan prehistory. Rhyolitic calderas known from east central Alaska (near Tok, Alaska) were studied by Bacon et al. (1990) and date to the mid-Cretaceous. The central Alaska Range (around Healy, Alaska) has been subject to a greater number of geological studies, due to easy access of roads and other infrastructure (e.g. train). Most important of these are studies conducted by Gilbert et al. (1976) and Nye (1978) both of which spent considerable time mapping and describing the Teklanika formation which contains many felsic (of rhyolitic and andecitic) volcanic flows and have been dated to the Paleocene (~57 Ma.). Additional metarhyolitic formations were documented in 1998 by T. Bundtzen (unpublished data 1998 cf. Wilson et al., 1998) in the Mount McKinley quadrangle and dated to ~370 Ma. However, rhyolite and other rhyolitic calderas in western interior Alaska have not been widely studied and most importantly rhyolite of knappable, or stone-tool quality rhyolite is largely unknown. Geological mapping in the region, on the whole, is not detailed and many unmapped rhyolite deposits likely exist. Prior to this study not a single specific rhyolite quarry or primary procurement location with evidence from prehistoric human use had been documented in central Alaska. However, in respect to the previous statement, no one has ever looked for rhyolite sources in an archaeological context.

3. Methods

A total of 676 unaltered artifacts consisting of debitage and tools from 123 sites were sampled largely from collections housed at the University of Alaska Museum of the North, as well as from a few active field research projects being conducted in the Tanana River basin and in southcentral Alaska. Site assemblages derive from archaeological sites throughout interior Alaska. We emphasized analysis of collections from well-dated, stratified deposits whenever possible, but also included collections from surface contexts with little or no chronological control in order to expand our geographic coverage and sample size. The number of rhyolite artifacts from each assemblage varied depending on the number of artifacts within each site assemblage. We targeted a sample of 30 artifacts from each site component when sufficient samples were available and in many cases we examined additional artifacts. Thirty artifacts were sampled from each site, and more whenever possible. Sample selection largely consisted of conducting pXRF on every artifact within a given collection. However, this was dependent upon two factors; size and thickness of the artifact. Artifacts at least 1 cm in maximum dimension were selected to ensure consistent coverage of the pXRF detector and samples at least 3 mm in thickness ensured consistent absorption of the X-Ray spectrum (see Hughes, 1998; 2010) and provided reliable results. We used maximum dimension and average weight measurements as a way to identify distance of the geological source locations to the point of discard (i.e. the site where the artifact was found). This was done primarily on the basis that heavier and larger artifacts would possibly indicate the source was nearby. Conversely, smaller, lighter artifacts may indicate the source was farther away. The data representing each group was not kept consistent in order to evaluate each identified group on their own merit.

3.1. pXRF analyses

Archaeological specimens were analyzed as whole rock samples, with non-destructive X-ray fluorescence (XRF) analyses conducted on each sample using a portable Bruker Tracer III-V portable XRF analyzer equipped 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. Our methods followed those described by Phillips and Speakman (2009). All of our analyses were conducted at 40 keV, 15 μA, using a 0.076-mm copper filter and 0.0305 aluminum filter in the X-ray path and were conducted for a 200 s live-time count. Similar with other sourcing studies (e.g. obsidian), ten elements were measured: Potassium (K), Manganese (Mn), Iron (Fe), Gallium (Ga), Thorium (Th), Rubidium (Rb), Strontium (Sr), Yttrium (Y), Zirconium (Zr), and Niobium (Nb). Peak intensities for these elements were calculated as ratios to the Compton peak of rhodium, and converted to elemental concentrations using a linear regressions derived from the analysis of 15 well-characterized whole rock or pressed powder samples, including international rock standards (Table 1), that have been analyzed by NAA and/or XRF. Additionally, 31 analyses conducted over five years with our instrument with the same internal standard, a piece of rhyolitic obsidian from Oregon, has been used as a protocol to detect instrument drift (finding none), but it also serves as a way to assess precision (see Supplementary data). For the key, Mid Z trace elements (Rb, Sr, Y, Zr, Nb), the standard deviations from the mean value ranges from 2 to 3%. The one exception is Sr, which, because of its low concentration, varies from the mean value by 27%, but has a standard deviation of 0.72 ppm and in repeated measures remains consistently between 1 and 5 ppm.

An additional minor concern to this study was whether or not weathering could affect the geochemical analysis of an artifact. Lundblad et al. (2008, 2011) found that the Mid Z trace elements (Rb, Sr, Y, Zr, Nb), the same trace elements measured and used to define our clusters in this study, are resistant to alterations from weathering. Despite this, we avoided heavily weathered artifacts judged by surface color relative to exposed, unaltered interiors of the artifacts and clean and/or "fresh" surfaces were chosen whenever possible.

3.2. Group assignment methods

Geochemical groups were initially identified by aid of trivariate plots, scatterplots (Fig. 2) and histograms of key elements measured by pXRF. Once basic characteristics of these groups were observed our study followed similar multivariate analysis approach as described by Glascock et al. (1998). Principal component analysis was used to test the validity of these groups. Final geochemical groupings were defined on the basis of discriminate and principal component analyses. In performing our final statistics, we used the following trace elements to delineate clusters (Rb, Sr, Y, Zr, and Nb). Two components yielded Eigenvalues greater than one: Component 1 (Group A) = 2.790; Component 2 (Group B) = 1.138. These two distinct groups are demonstrated in the Principal Component Score Plot (Fig. 3). The remaining groups were defined with the same methods with Groups A and B artifacts removed to reduce skewing results. Table 2 lists all of the groups with their average and standard deviation values for the five trace elements measured.

4. Geochemical descriptions and distributions

4.1. Group A

Rhyolite assigned to Groups A (n = 337) range in color from light gray (N7) to pale purple (5P 6/2) to yellowish/pale orange (in web version) (10YR 6/6; 10YR 8/2), with many artifacts exhibiting a slight luster to them (Fig. 4). Artifacts assigned to this distinct rhyolitic group were found in archaeological contexts that range in age from the late Pleistocene to late Prehistoric (last 200 years). Sites containing this type of rhyolite span much of interior Alaska and cover an area of approximately 92,000 km^2. Group A rhyolite is the largest distributed group analyzed thus far and almost half of the rhyolite artifacts analyzed in this study were assigned to Group A.

This material is fine-grained, homogeneous, glassy in appearance and is excellent quality for flintknapping. Out of our sample size, it was frequently used in the manufacture of microblades (n = 55; 16%) (Table 3), demonstrating this material was high quality enough for the manufacturing of microblade technology. Bifacial material is also well represented within Group A rhyolite (n = 52; 15%).

The precise geological source for this group is currently unknown, however the densest concentration of sites with abundant Group A rhyolite occur in the Nenana River valley, interior Alaska, suggesting the source location likely in the central Alaska Range. Maximum dimension (mm) and weight (g) of artifacts further supports this (Figs. 5 and 6). Geochemical variation exists within Group A. Principle component and multi-variant analyses of only Group A artifacts have shown two marginally different groups. However, there is no difference in the distribution or color of artifacts and when these same analyses are run for the complete sample this variation is not strong enough. Identification of the source outcrops and analysis of source samples are needed to explain the cause of this variation.

4.2. Group B

Groups B (n = 170) rhyolite is predominantly beige to white in color with artifacts exhibiting shades of pale purple (5P 6/2) to varying shades of yellowish brown (10YR 5/4) and gray (N7; 5YR) (Fig. 4). Similar to Group A, Group B rhyolite was used from the late Pleistocene through the late Prehistoric and is spatially distributed throughout interior Alaska and in most instances co-occurs with other groups of rhyolite.

Group B is the second most common form of rhyolite identified in this study and represents a quarter of the rhyolite artifacts

Table 1
Measured and recommended trace element concentration values for rhyolite rock standards.

Sample	Mn	Fe	Rb	Sr	Y	Zr	Nb
SRM-278 NIST recommended	520	13,600	127	63.5	NR	NR	NR
SRM-278 (Shackley, 2005)	372 ± 17	15,229 ± 399	129 ± 2	68 ± 2	42 ± 2	290 ± 3	17 ± 2
SRM-278 (Glascock, 1991)	428 ± 8	9932 ± 210	128 ± 4	61 ± 15	NR	208 ± 20	NR
SRM-278 (Jochum et al., 2005)	324.5–401	11,710–14,900	105–137	30.2–67	35–41	211–287	21.4–22
SRM-278 this study	402	13,591	117	56	37	263	12
RGM-1 USGS recommended	280 ± 30	12,700 ± 500	150 ± 8	110 ± 10	25	220 ± 20	8.9 ± 0.6
RGM-1 (Glascock, 1991)	323 ± 7	863 ± 210	145 ± 3	120 ± 10	NR	150 ± 7	NR
RGM-1 (Shackley, 2005)	259 ± 19	13,991 ± 143	152 ± 3	108 ± 2	24 ± 1	226 ± 4	10 ± 1
RGM-1 (Jochum et al., 2005)	282	12,800	142–165	96.15–116	21.5–25.6	173–258	8.37–13
RGM-1 this study	273	11,028	131	92	22	205	8

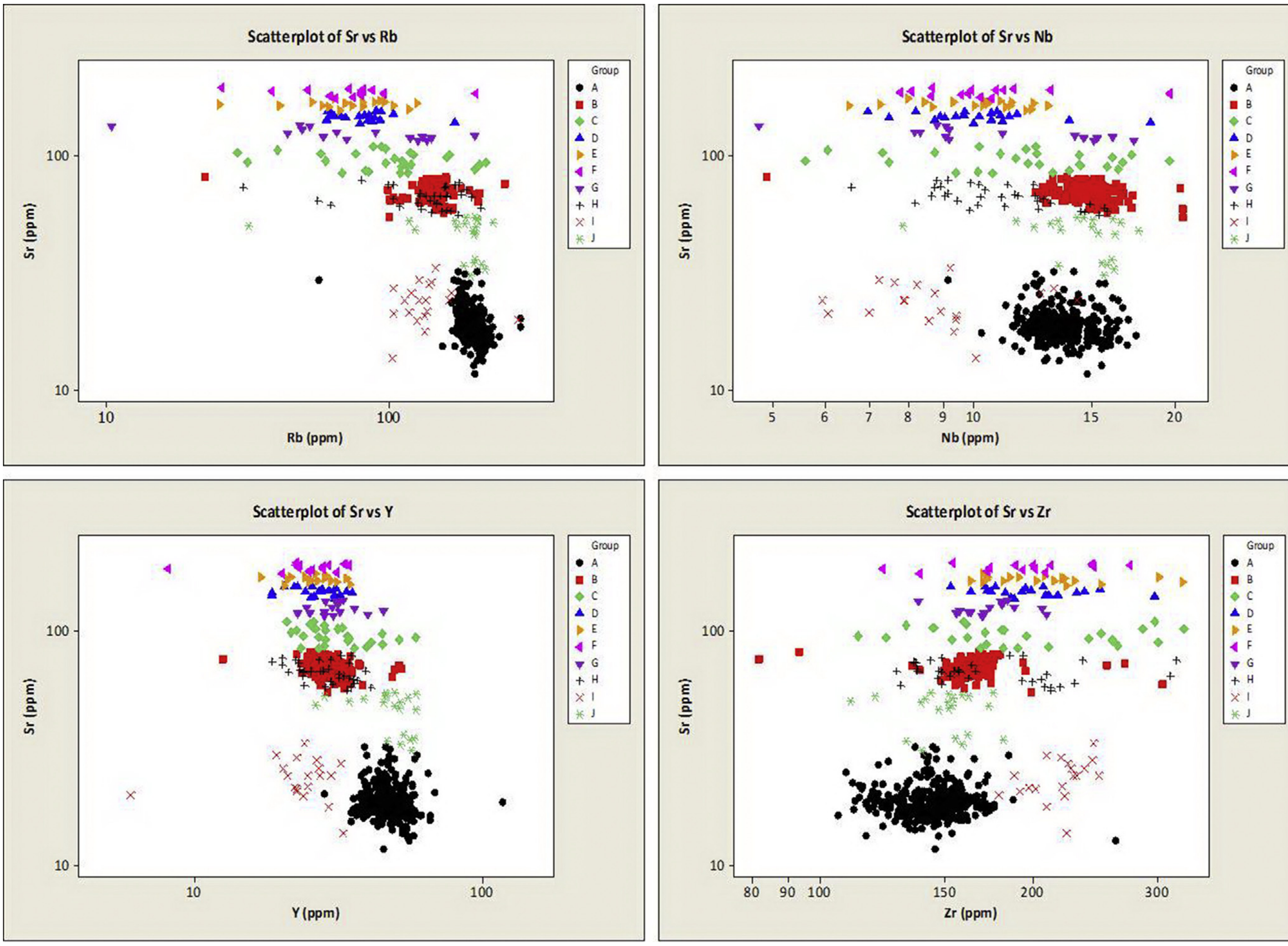

Fig. 2. Scatterplots of trace elements measured in parts per million (ppm).

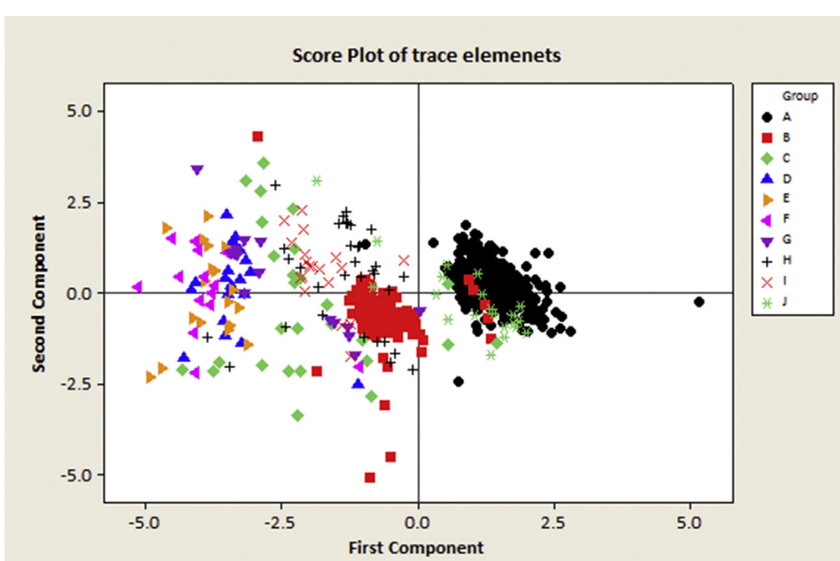

Fig. 3. Principle component score plot of trace elements and of the first two groups.

Table 2
Trace elements in Parts per Million (PPM) of each source group.

Source group	Rb	Sr	Y	Zr	Nb
A	197 ± 16	19 ± 3	48 ± 7	145 ± 16	14 ± 1
B	140 ± 37	70 ± 5	29 ± 6	162 ± 21	15 ± 2
C	107 ± 50	95 ± 8	32 ± 9	201 ± 60	12 ± 4
D	83 ± 25	147 ± 5	26 ± 5	202 ± 34	10 ± 2
E	78 ± 26	165 ± 4	27 ± 4	210 ± 46	10 ± 2
F	79 ± 41	186 ± 6	25 ± 6	194 ± 42	11 ± 3
G	89 ± 49	124 ± 7	31 ± 6	174 ± 18	11 ± 4
H	140 ± 37	66 ± 6	29 ± 6	183 ± 51	12 ± 3
I	138 ± 40	24 ± 5	24 ± 6	217 ± 20	9 ± 2
J	176 ± 55	46 ± 8	47 ± 10	146 ± 28	14 ± 3

analyzed. Unifacial (n = 28; 17%) and bifacial (n = 19; 12%) tools were the most common tools analyzed. Microblade technology (n = 11; 7%) is not as common as with Groups A and I rhyolite (Table 3). This may be limited to sample size or due to the material itself, in that it was not conducive to manufacturing microblades. Group B rhyolite is less brittle and slightly coarser grained than Group A rhyolite. Group B rhyolite can still fracture in a controlled planned manner.

The precise location of the geological source for Group B is currently unknown. Based on maximum dimension and weight of artifacts the source may be located in the central Alaska Range (Figs. 7 and 8).

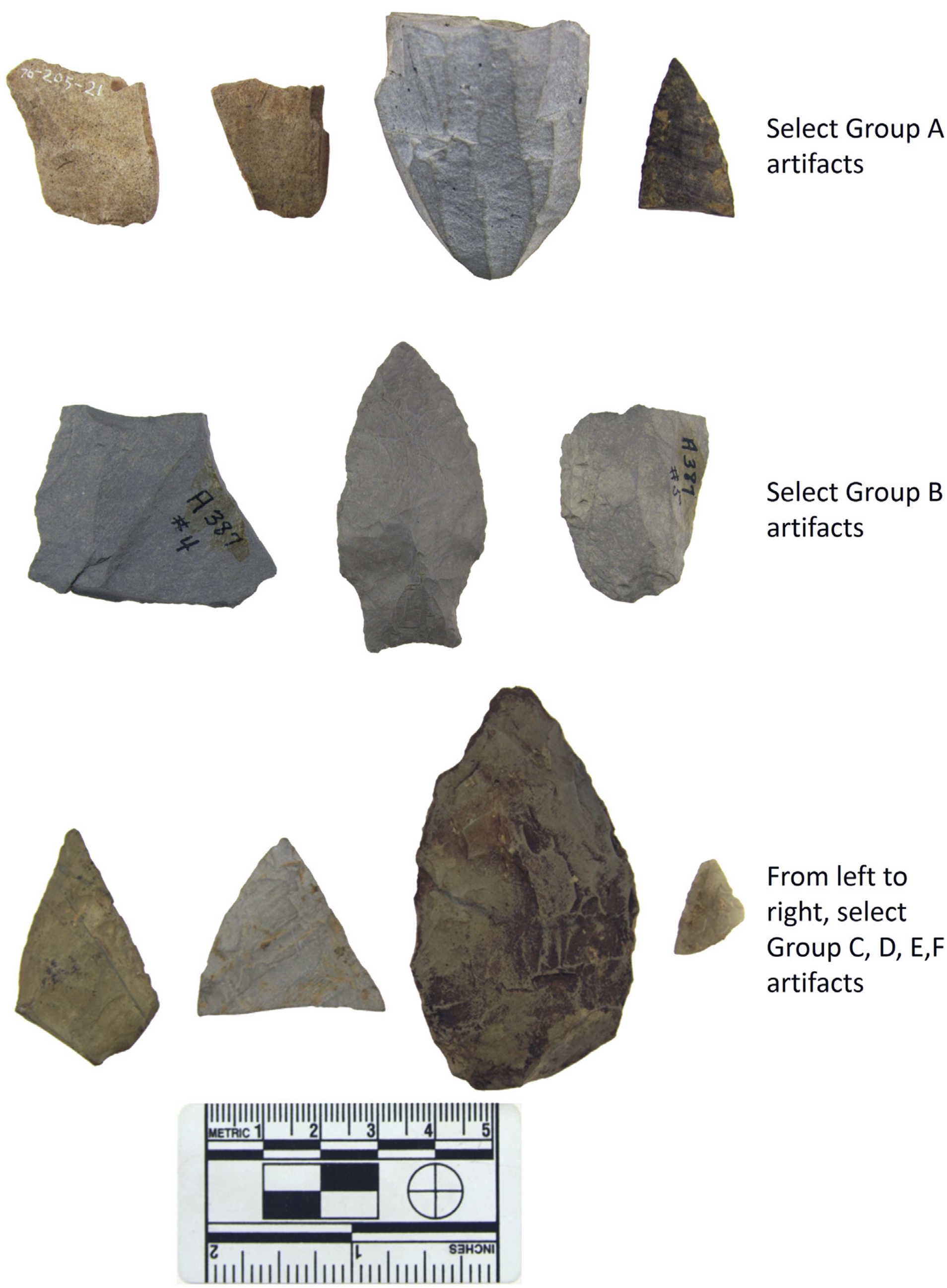

Fig. 4. Select rhyolite artifacts from some of the groups identified in this study.

Table 3
Technological similarities and differences among each rhyolite group.

Group	Cortical spall	Interior flake	Unifacial tool	Bifacial tool	Microblade technology	Other	Total
A	22 (7%)	149 (44%)	57 (17%)	52 (15%)	55 (16%)	2 (1%)	337
B	20 (12%)	90 (52%)	28 (17%)	19 (12%)	11 (7%)	2 (1%)	170
C	0 (0%)	18 (67%)	4 (15%)	4 (15%)	1 (3%)	0 (0%)	27
D	0 (0%)	12 (60%)	4 (20%)	2 (10%)	2 (10%)	0 (0%)	20
E	0 (0%)	11 (59%)	4 (24%)	1 (5%)	2 (12%)	0 (0%)	18
F	1 (7%)	4 (29%)	4 (29%)	3 (21%)	2 (14%)	0 (0%)	14
G	1 (6%)	11 (75%)	1 (6%)	0 (0%)	2 (13%)	0 (0%)	15
H	3 (9%)	18 (50%)	9 (26%)	5 (15%)	0 (0%)	0 (0%)	35
I	0 (0%)	12 (63%)	3 (16%)	0 (0%)	4 (21%)	0 (0%)	19
J	1 (5%)	9 (45%)	2 (9%)	7 (32%)	1 (5%)	0 (0%)	21

4.3. Group C

Twenty-seven artifacts thus far have been assigned to Group C. The color of this rhyolite is light (10YR 7/4) and pale yellowish brown (10YR 6/2) gray to yellowish gray (10YR 8/2) and pale yellowish brown (10YR 7/4) (Fig. 4). Group C rhyolite appears from the late Pleistocene through late Prehistoric and is present both north and south of the Alaska Range. The material is similar to that of Groups A and B, in that the material is brittle and a wide array of tools can be produced on the material.

The highest concentration of sites with Group C rhyolite is in the Nenana River valley, however the largest and heaviest artifacts are found to the west of the Nenana River at Lake Minchumina (Figs. 9 and 10) and in the upper Kuskokwim region. This suggests the geological source of Group C material may be in the Kuskokwim Mountains (west central interior Alaska).

4.4. Group D, Group E, and Group F

At this time the following three groups appear to be geochemically distinct however each group is not well defined, which is why the three of them are presented as one section. Additional samplings are needed to fully understand these groups. Group D (n = 20), E (n = 18), F (n = 14), are very pale orange (10YR 8/2) to pale yellowish brown (10YR 6/2) in color, with some artifacts also being pale olive green (5GY 3/2) and few of the artifacts analyzed are also light brown (5YR 6/4) (Fig. 4). All of these groups were not widely used prehistorically until the middle Holocene, possibly suggesting the source(s) were not easily accessible until then.

Sample sizes for all of these groups are limited making it difficult to fully gauge the technological organization of these groups. At this time, it can be observed that these group materials fractured in a way that allowed for both the manufacture of bifacial and microblade technology (Table 3).

Geological sources for Groups D, E, and F are currently unknown. Based on weight and maximum dimension of artifacts these sources might be located in either Talkeetna Mountains or in the Alaska Range (Fig. 11, and 12).

4.5. Group G

Group G (n = 15) rhyolite is predominately greyish olive green (5GY 3/2) and is seen in the archaeological record from the middle Holocene through the late Prehistoric period. The distribution of

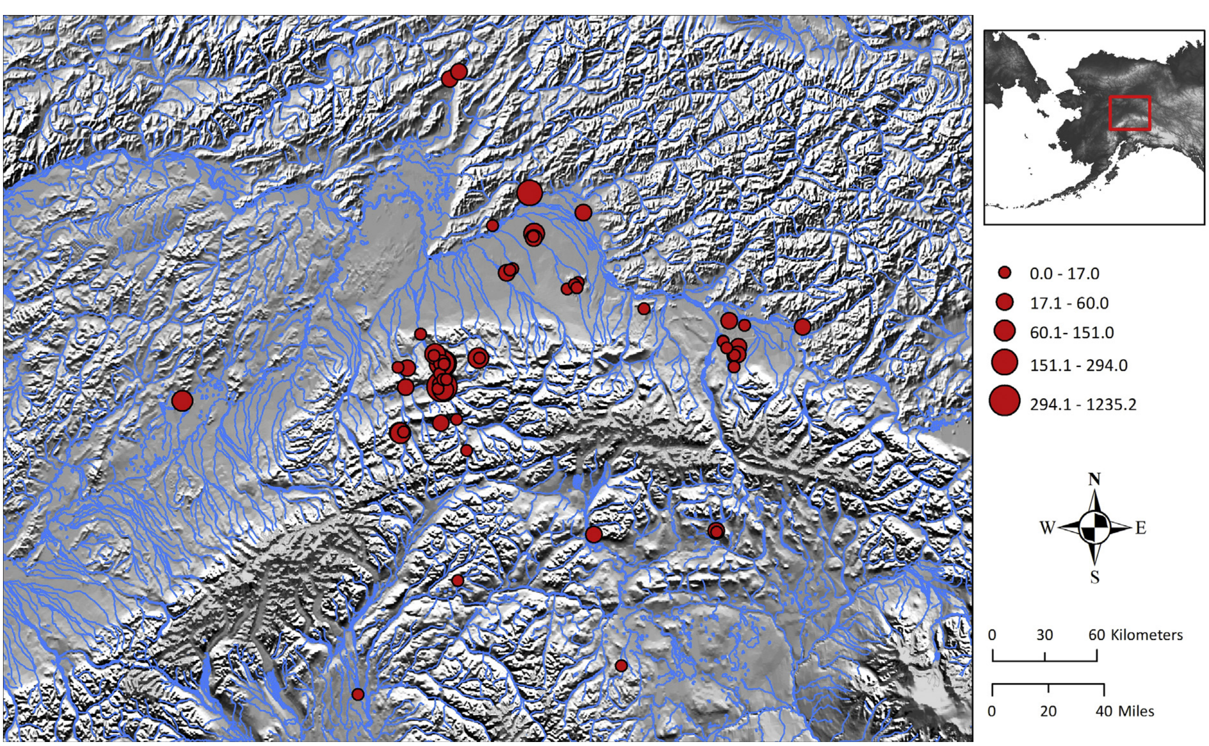

Fig. 5. Average maximum dimmension (mm) of artifacts measured from Group A.

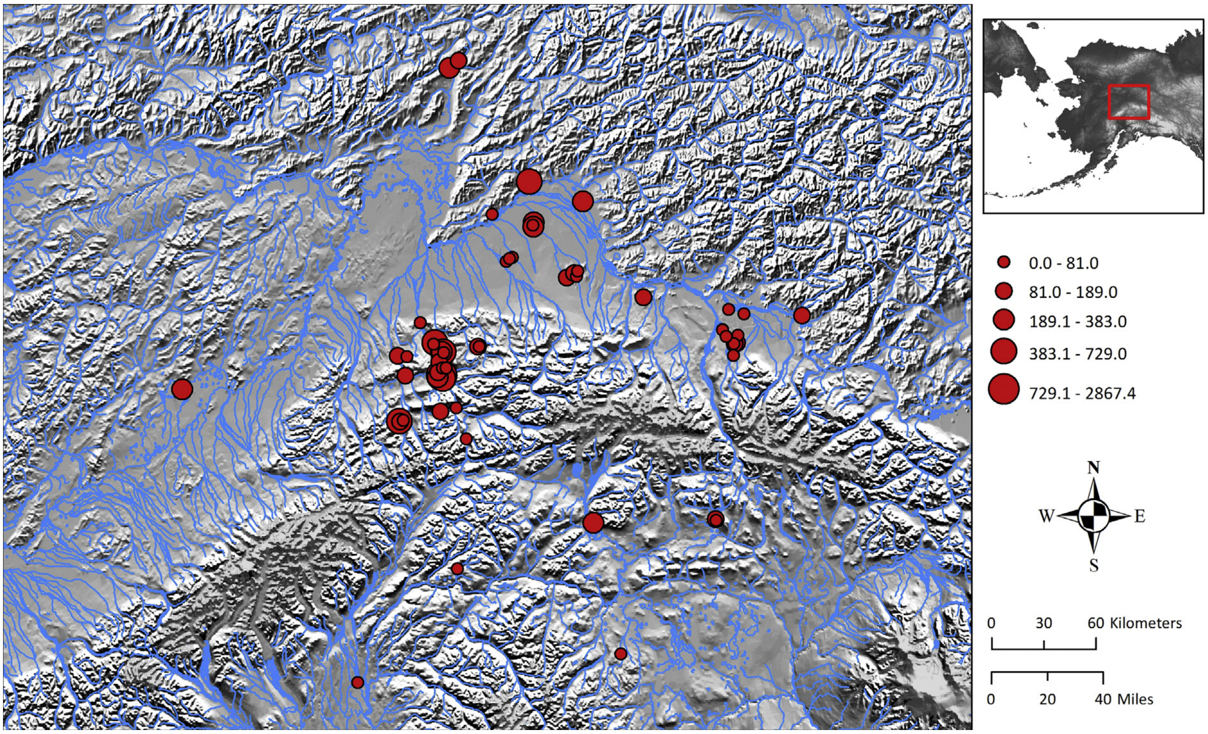

Fig. 6. Average weight (g) of artifacts from Group A.

Group G rhyolite is largely random. It is seen in the Talkeetna Mountains (Jay Creek Mineral Lick), southcentral Alaska (Trapper Creek Overlook), the Tangle Lakes area (Phipps), and at several site north of the Alaska Range (Panguingue Creek, Blair Lakes #2 and HEA-00008). Almost all of the artifacts assigned to this group are interior flakes (lacking any cortex) (n = 11) (Table 3). A microblade core from the Phipps site has been assigned to this group, suggesting this rhyolite was conducive for the manufacture of

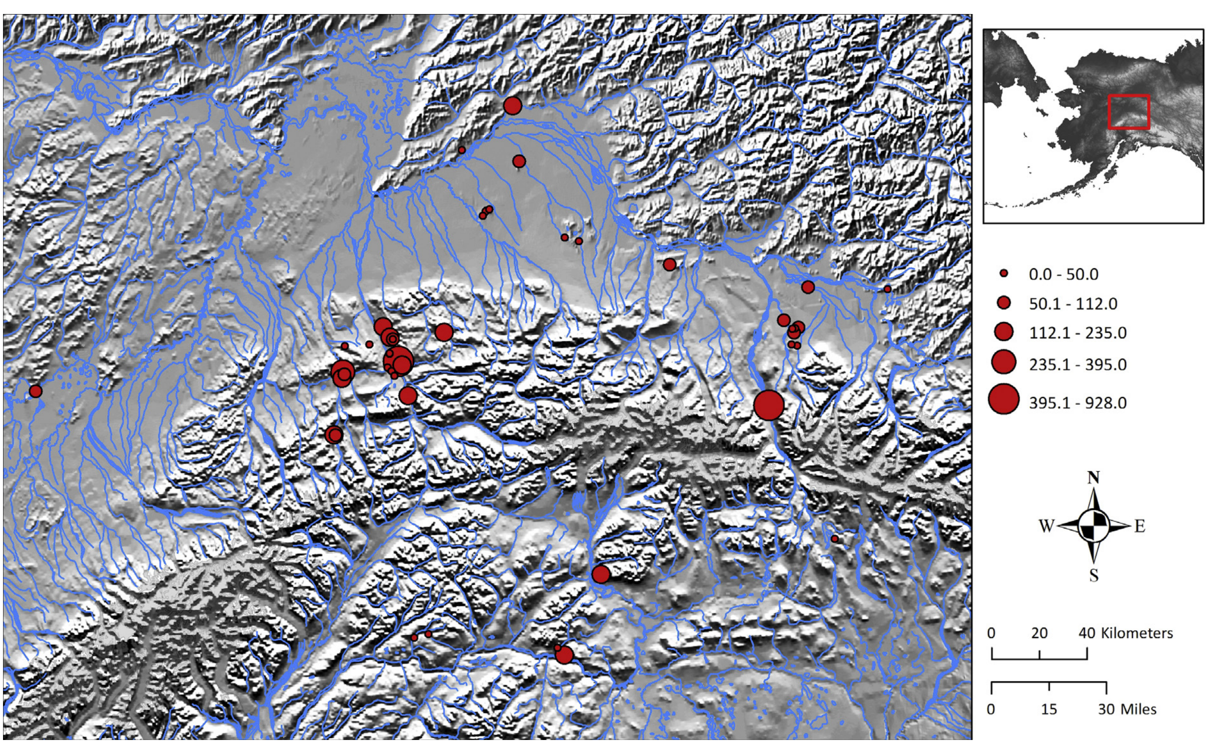

Fig. 7. Average maximum dimmension (mm) of artifacts measured from Group B.

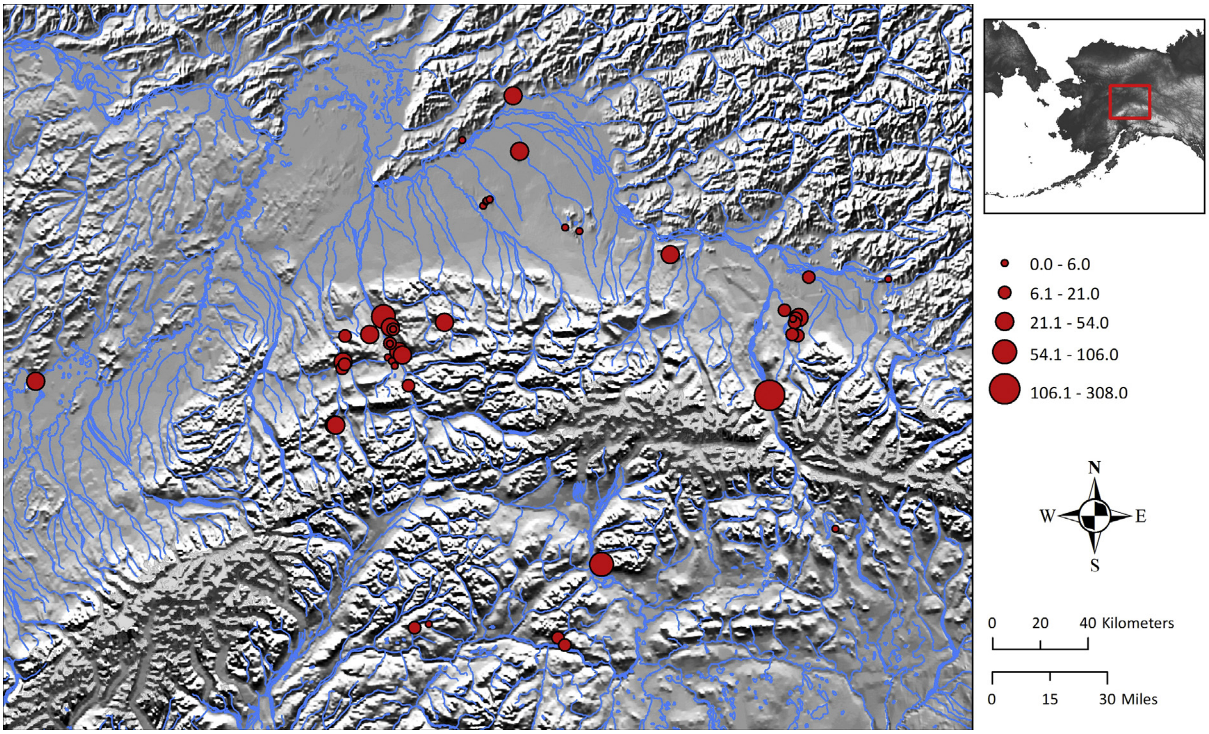

Fig. 8. Average weight (g) of artifacts from Group B.

microblades and microblade technology. Figs. 13 and 14 show the distribution of Group G rhyolite based on maximum dimensions and weight of artifacts analyzed thus far.

The geologic source for Group G rhyolite is located at the headwaters of the Talkeetna River in the Talkeetna Mountains. The source was documented in 2001 by J. Schmidt of the US Geological Survey. Currently, samples from Schmidt (2001) (c.f. USGS, 2014) match geochemically to artifacts from our study. Additional sampling from this location is needed to further characterize this source.

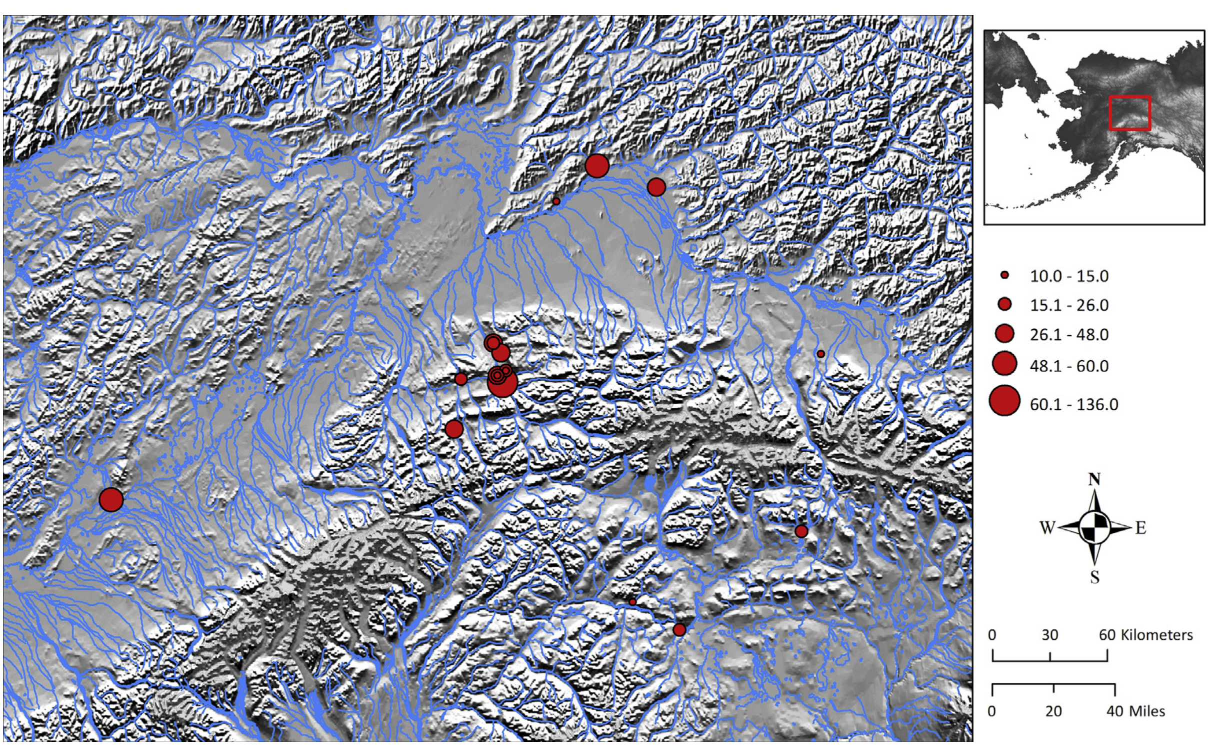

Fig. 9. Average maximum dimmension (mm) of artifacts measured from Group C.

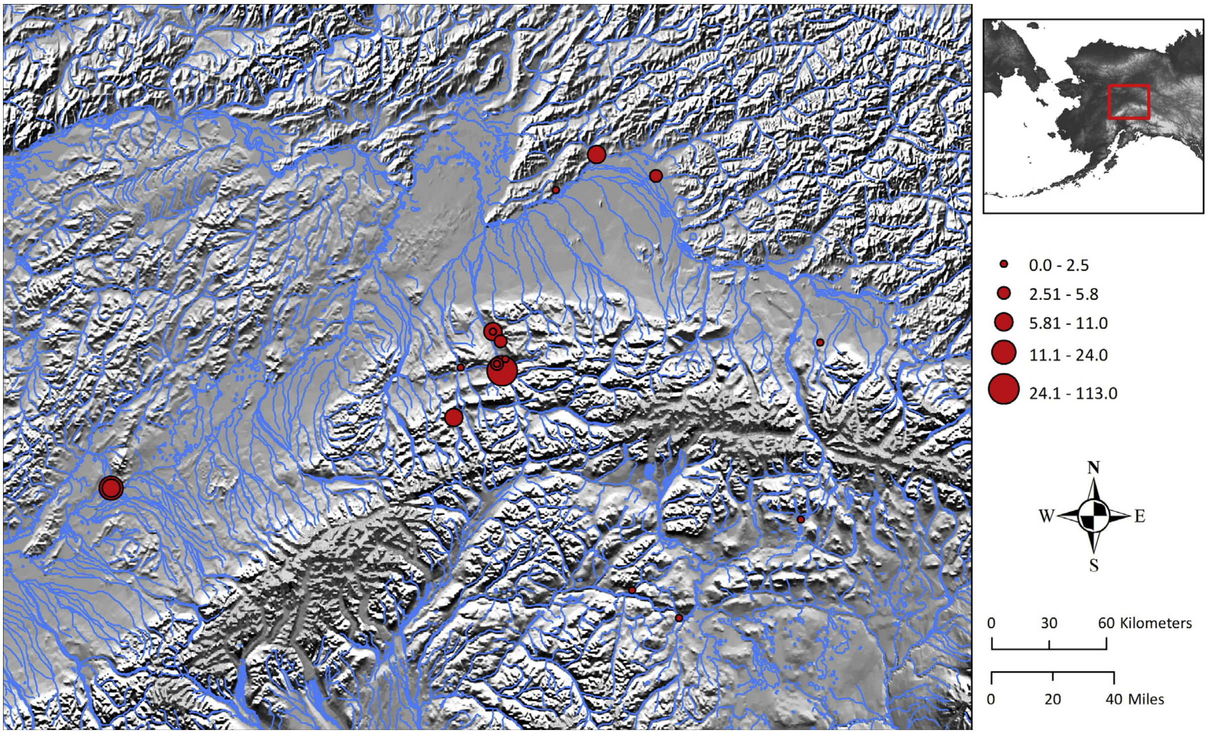

Fig. 10. Average weight (g) of artifacts from Group C.

4.6. Group H

Rhyolite assigned to Group H (n = 35) tend to be varying shades of light to medium gray (N8, N6, N5) to olive and yellowish gray (5Y 5/2, 5Y 8/1) in color with some artifacts also a pale purple (5P 6/2). Group H rhyolite is found in archaeological contexts that range in age from the late Pleistocene through the late Holocene. Although the flintnapping quality of this rhyolite is decent we have found no examples of its use for the production of microblades in our sample (Table 3). Formal tools consist of bifaces, projectile points, and

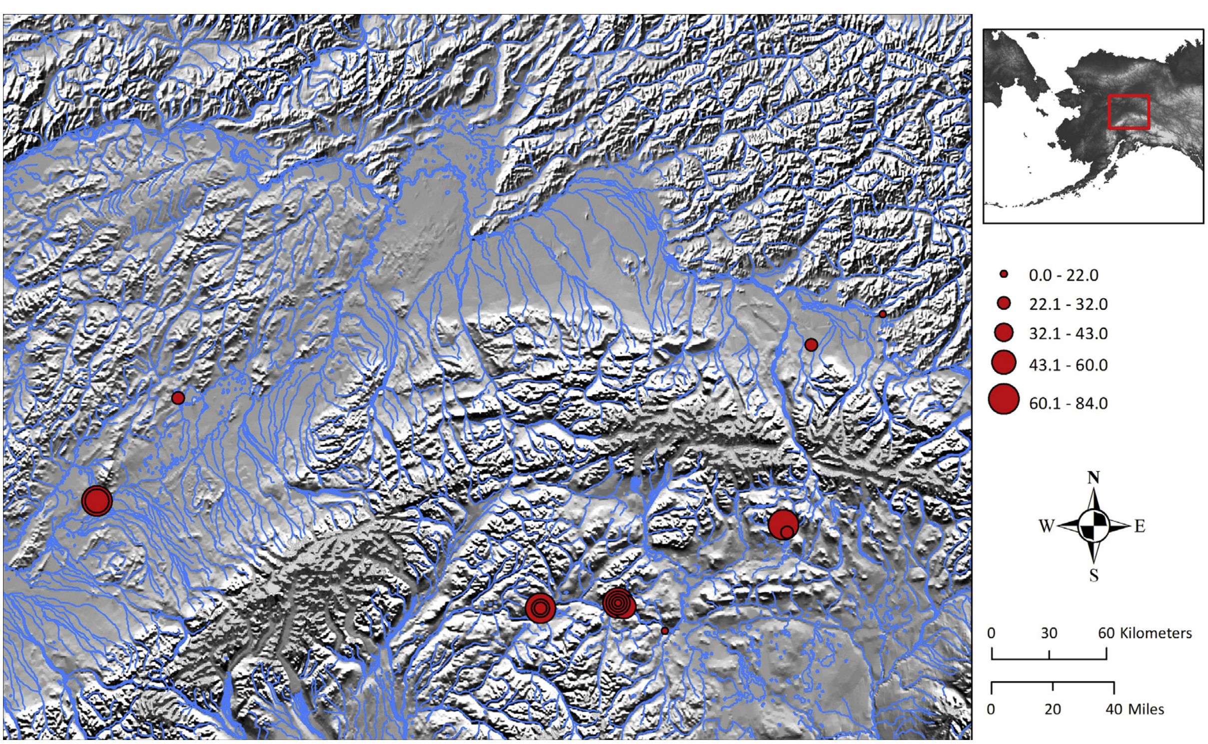

Fig. 11. Average maximum dimmension (mm) of artifacts measured from Group DEF.

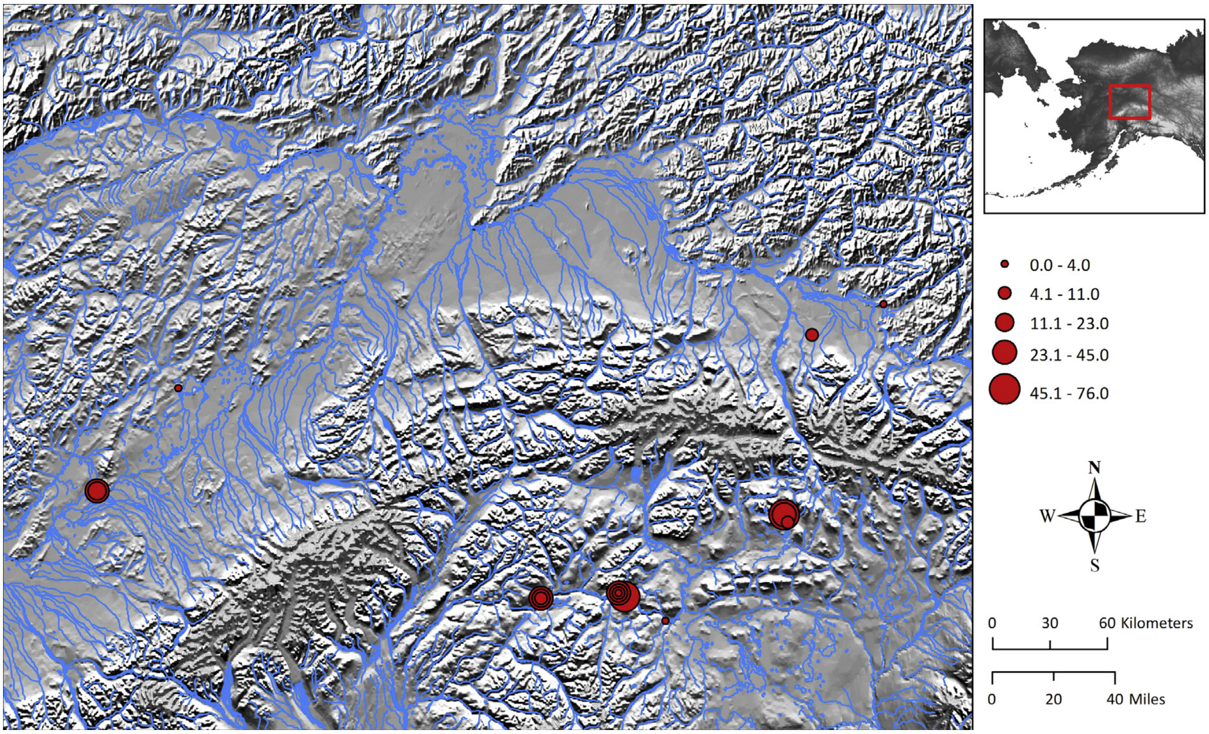

Fig. 12. Average weight (g) of artifacts from Group DEF.

retouched flakes. Figs. 15 and 16 show the distribution of Group H rhyolite based on maximum dimensions and weight of artifacts analyzed thus far.

The geological source of this rhyolite was identified in 2013 with the analysis of source samples from the location. It is located in the upper Teklanika River valley on an un-named tributary near Calico Creek located in the Teklanika River valley, central Alaska. Additional sampling from this location is needed to fully characterize and document any possible geochemical variations within this source.

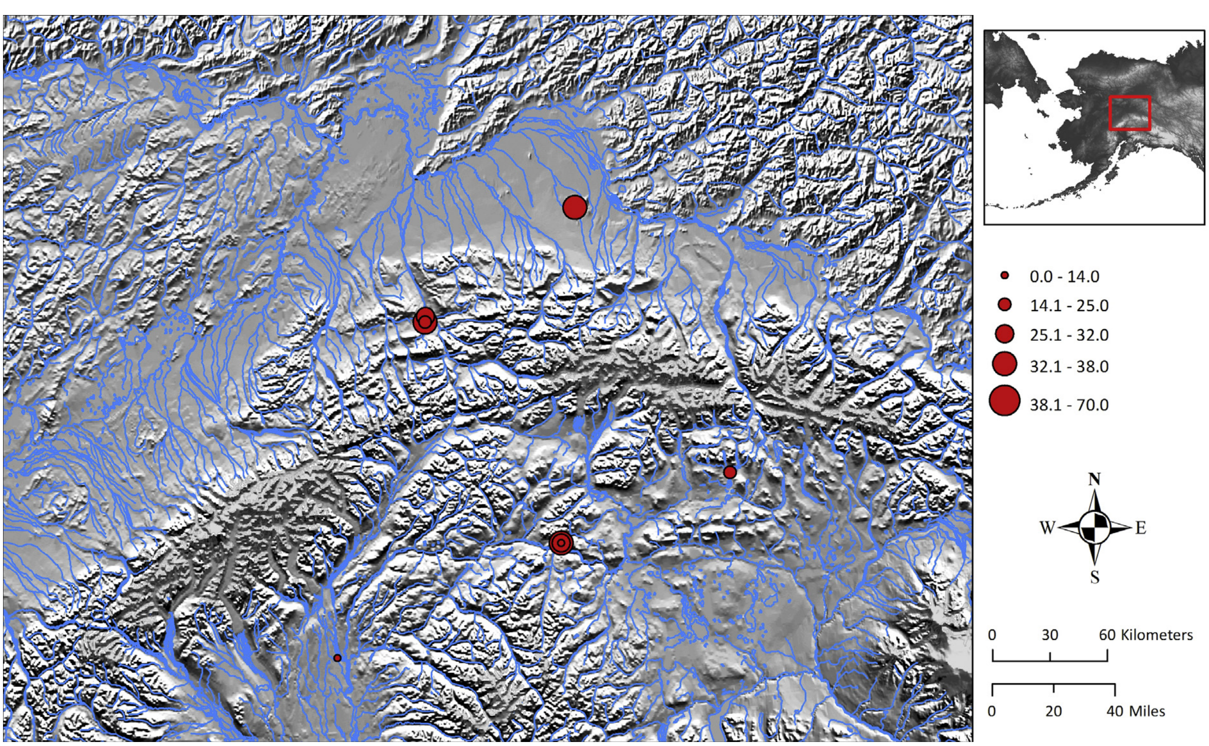

Fig. 13. Average maximum dimmension (mm) of artifacts measured from Group G.

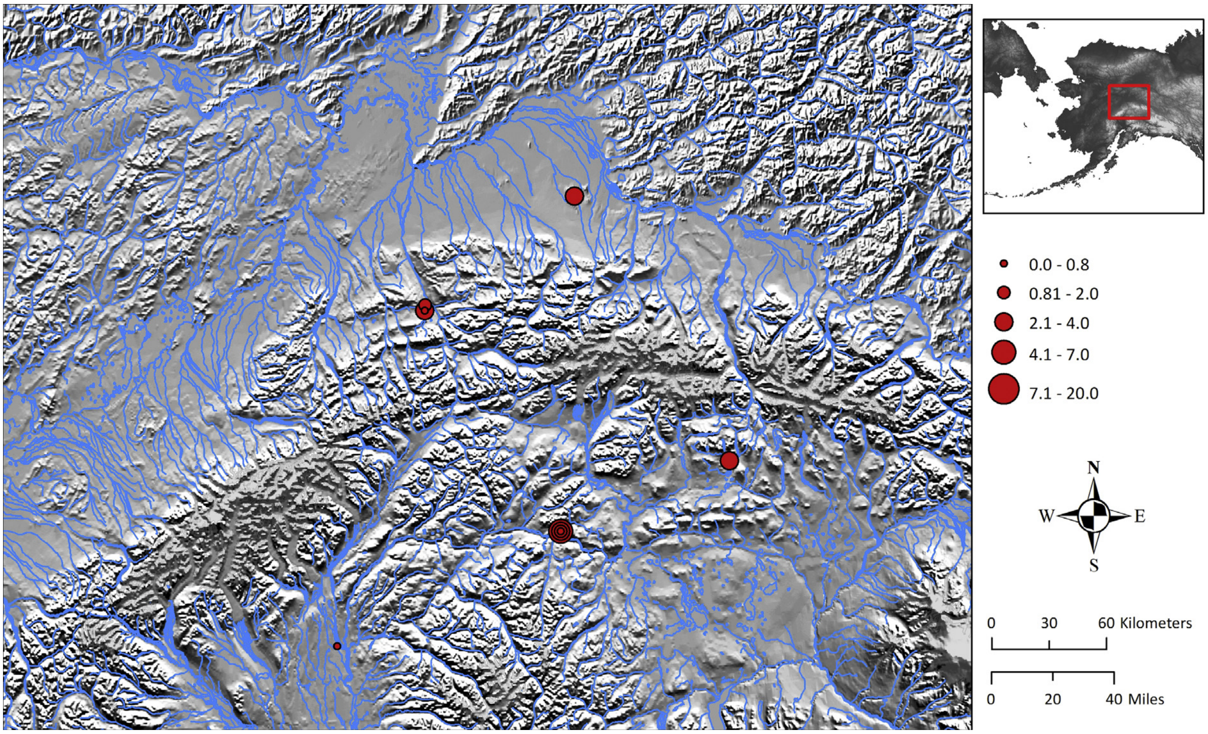

Fig. 14. Average weight (g) of artifacts from Group G.

4.7. Group I

Rhyolite artifacts assigned to Group I (n = 19) are pale yellowish brown (10YR 6/2) to brownish gray (5YR 4/1) and light brown (5YR 6/4) color, with some artifacts exhibiting a slight luster to them. This distinct rhyolite group is not well represented but artifacts assigned to this group range in age from the late Pleistocene to late Prehistoric (last 200 years). Sites containing this type of rhyolite are largely concentrated to the Nenana River valley with a few localities in the Tanana River valley and the upper Susitna drainage.

No microblade cores have matched the Group I signature, yet microblade technology is present in the form of a microblade, a

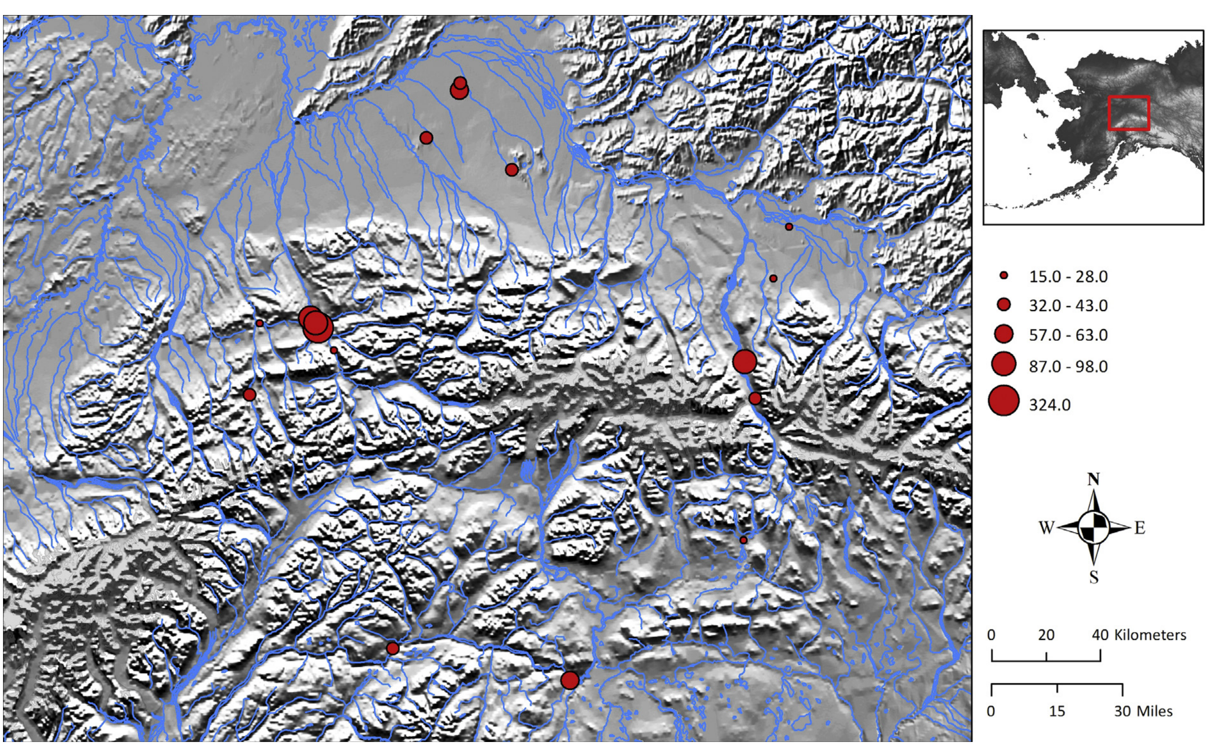

Fig. 15. Average maximum dimmension (mm) of artifacts measured from Group H.

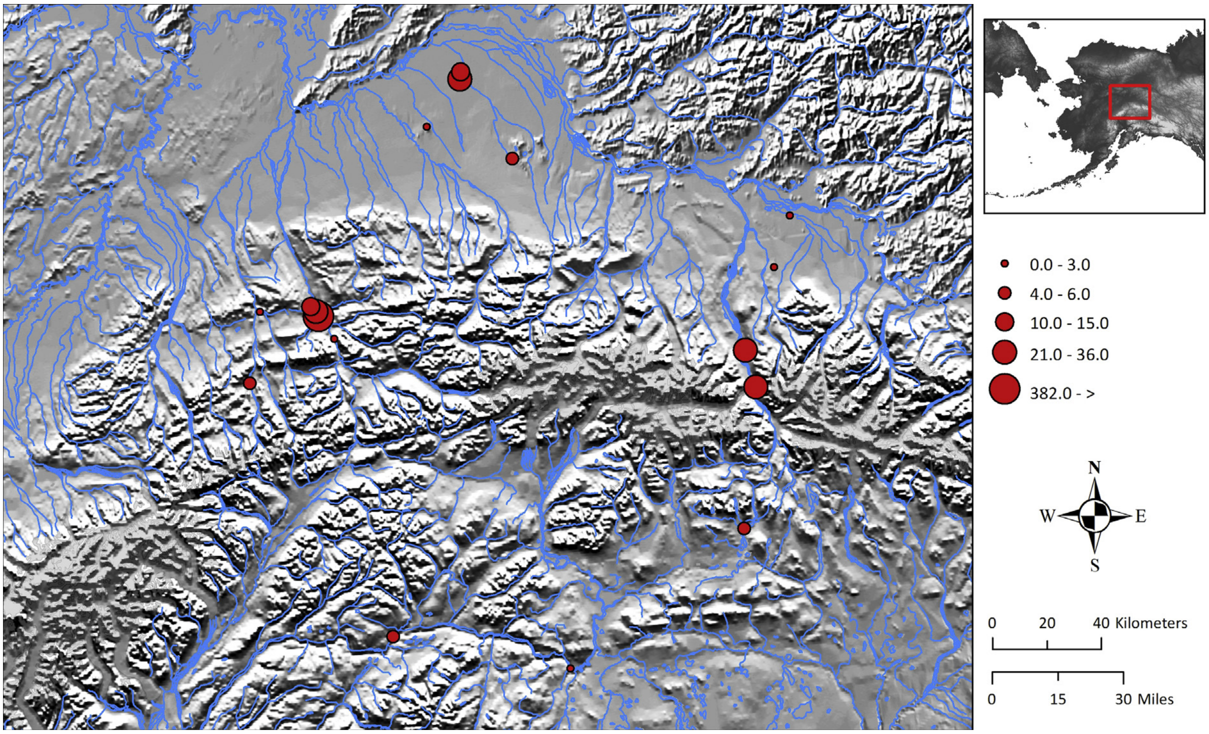

Fig. 16. Average weight (g) of artifacts from Group H.

burin, ridge spall, and a face rejuvenation flake. This would seem to indicate that Group I rhyolite is suitable for the manufacturing of microblade technology (n = 4; 21%) (Table 3), and likely bifacial technology as well. However, no bifacial material has been analyzed thus far. The largest and heaviest artifacts of Group I are found at sites in the Nenana River valley (Figs. 17 and 18) suggesting the geological source may be in the vicinity.

4.8. Group J

Rhyolite assigned to Group J (n = 21) is largely seen north of the Alaska Range, from Lake Minchumina in the west, to the Delta River in the East. The farthest north Group J extends is to the Tolovana 35 site near Livengood. The only site south of the Alaska Range in which this material has been identified so far is the Landmark Gap

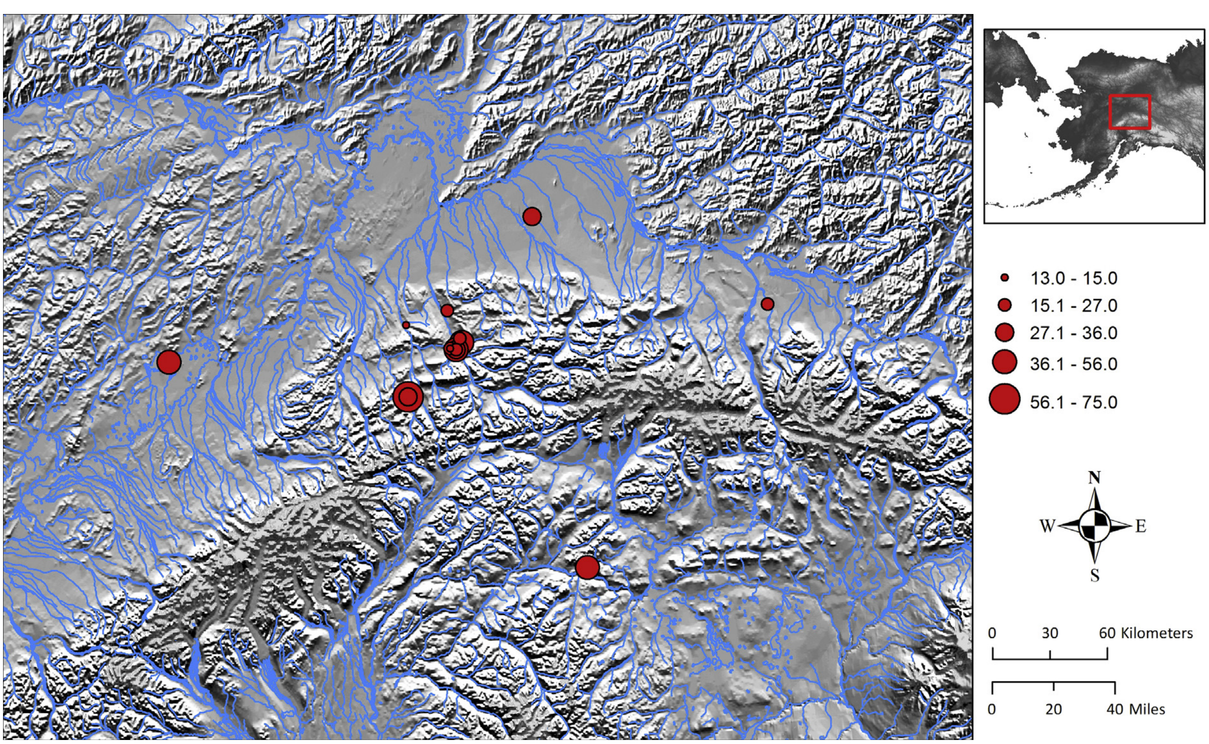

Fig. 17. Average maximum dimmension (mm) of artifacts measured from Group I.

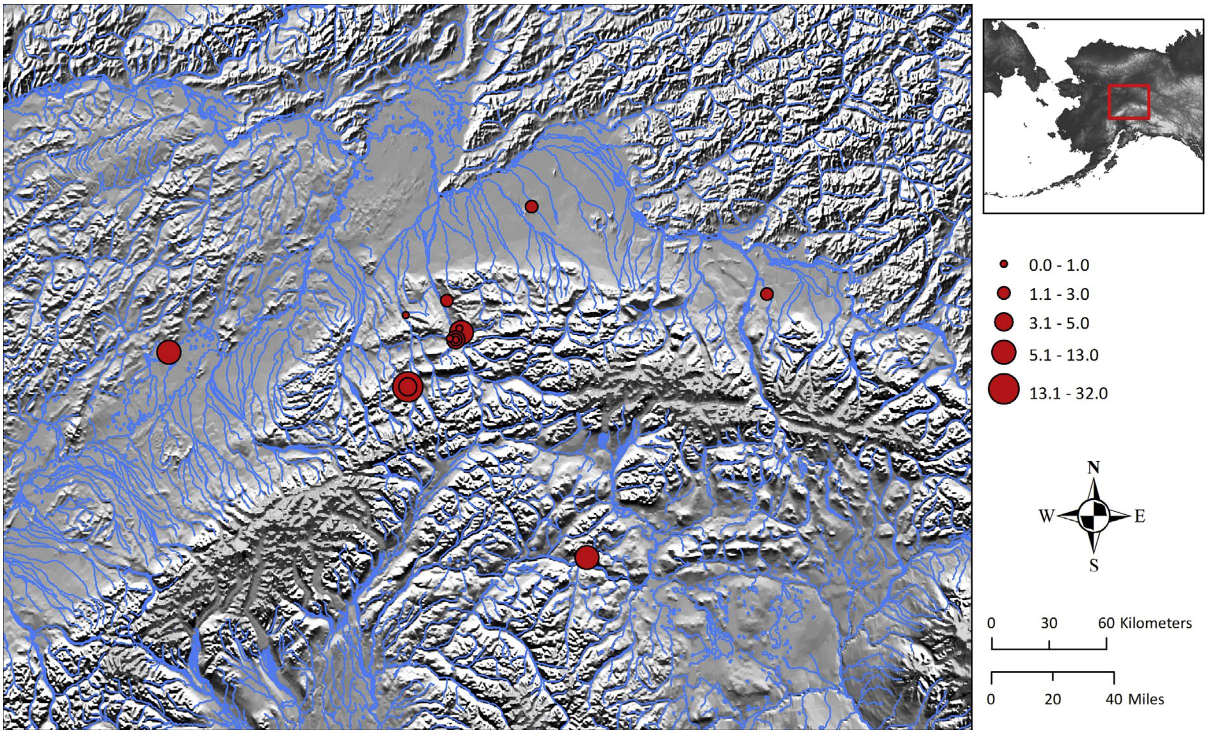

Fig. 18. Average weight (g) of artifacts from Group I.

Trail site, in the Tangle Lake area. The color of Group J artifacts ranges from olive gray (5Y 6/1) to pale orange and yellowish orange (10YR 8/2, 10YR 8/6).

The geologic source for Group J has not been identified, yet the highest concentrations of sites with Group J rhyolite within their assemblages are from the Nenana River valley, which suggests a source in the region. However, weight and maximum dimensions of artifacts analyzed does not support this (Figs. 19 and 20). Of the 21 artifacts analyzed seven of the artifacts are bifaces (Table 3), three of which are Chindadn points, artifacts considered to be

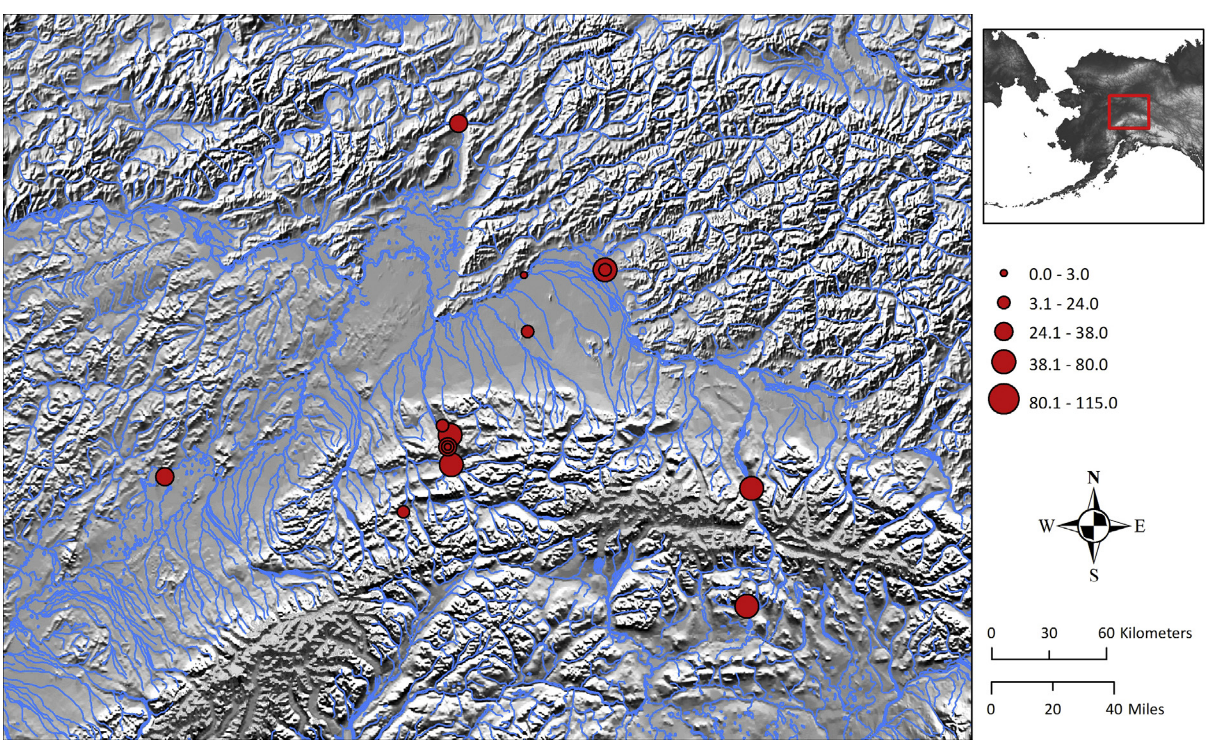

Fig. 19. Average maximum dimmension (mm) of artifacts measured from Group J.

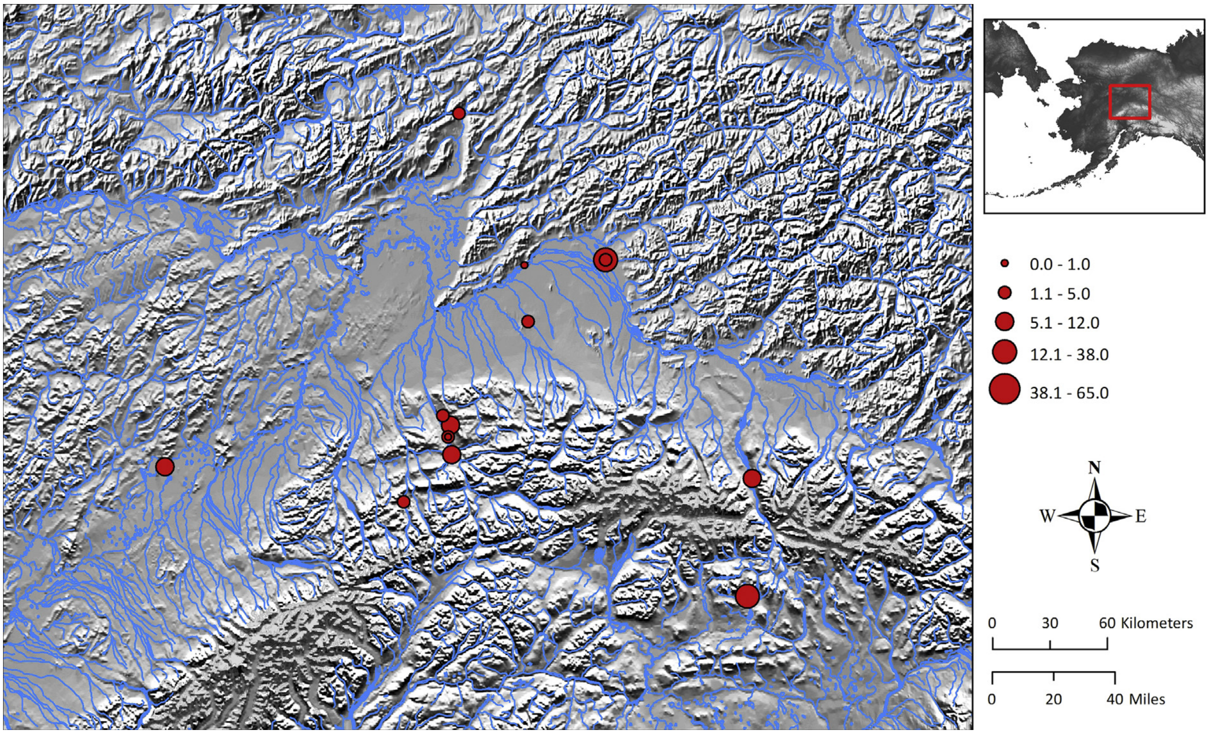

Fig. 20. Average weight (g) of artifacts from Group J.

chronological markers of the late Pleistocene (these artifacts have associated radiocarbon dates supporting late Pleistocene use of the material) (cf. Cook 1969; Holmes 2001; Goebel and Pontti, 1991; Dixon 1985, 1999), suggesting the source was accessible during the late Pleistocene. Group J rhyolite ranges in age from the late Pleistocene through late Holocene.

5. Patterns in the prehistoric use of rhyolite

Our preliminary results recognize that rhyolite was largely utilized prehistorically in interior Alaska. Geological sources for eight of the ten groups identified in this study remain unknown. Yet, tentative geochemical links between artifacts and geological specimens from the upper Talkeetna (Group G) and Teklanika Rivers (Group H), respectively, seem valid. Additional sampling and geochemical analyses from these sources are needed to confirm each source. Despite this limitation, interesting results have emerged concerning human procurement and use of rhyolite in prehistory.

By available archaeological measures five of the rhyolite sources identified in this study were discovered and used by the earliest inhabitants of interior Alaska who had settled the region by approximately 14,000 cal BP and saw continued use through the Holocene until the late Prehistoric period when flaked stone technology was replaced by the use of metal. This early and consistent, long term use of rhyolite in interior Alaska makes this a great test case for certain questions related to use and transport of rhyolite since it enables one to examine long term diachronic patterns.

Interesting variability can be seen in regard to how people used a given rhyolite source. Table 3 highlights the similarities and differences among each group in regard to the number of early stage decortication flakes, interior flakes, tools, and microblade technology for all samples analyzed. Groups A and I are the largest groups that contain microblade technology suggesting this material was ideal for the manufacturing of this technology. The remaining groups all contain some sort of microblade technology suggesting that even the coarsest grained rhyolite could be used to manufacture microblades, with the exception of Group H. An interesting aspect is that bifacial technology is represented within most of the rhyolite groups with the exception of Groups G and I, of which both of these groups contain some form of microblade technology. The opposite of this is seen in Group H which does not contain any microblade technology but does contain bifacial technology. Whether this represents a preference towards a particular rhyolite for the manufacturing of a specific tool or is misrepresented by our sample size remains to be seen. The only tool that is found throughout all rhyolite groups are unifacial tools. These are well represented throughout the entire sample size of each group analyzed thus far.

Groups A and B are the most extensively used rhyolite groups in interior Alaska and were exploited from the late Pleistocene through the late Prehistoric (Fig. 21). These two geologic sources appear to be located in the central Alaska Range, consistent with glacial chronologies that show the central Alaska Range as largely ice-free during the late Pleistocene/early Holocene (Dortch, 2006). An ice-free Alaska Range would have given people direct access to these raw materials and to a variety of other resources. This hypothesis is supported in the archaeological record at Teklanika West, where Component 2 contains preserved remains of bison (*Bison* sp.) in association with Group B rhyolite artifacts (Coffman, 2011; Coffman and Potter, 2011). Other sites in the foothills of the Alaska Range, e.g. Dry Creek (Powers et al., 1983), Panguingue Creek (Powers and Maxwell, 1986; Goebel and Bigelow, 1996) contain preserved to degrading faunal materials in association with both Groups A and B rhyolites.

Our results tentatively support the increased use of the uplands during the Middle Holocene (cf. Potter, 2008). This is supported by an increased use of Groups D, E, F, and G rhyolites; Group G is located in the uplands, and the others are believed to be located in

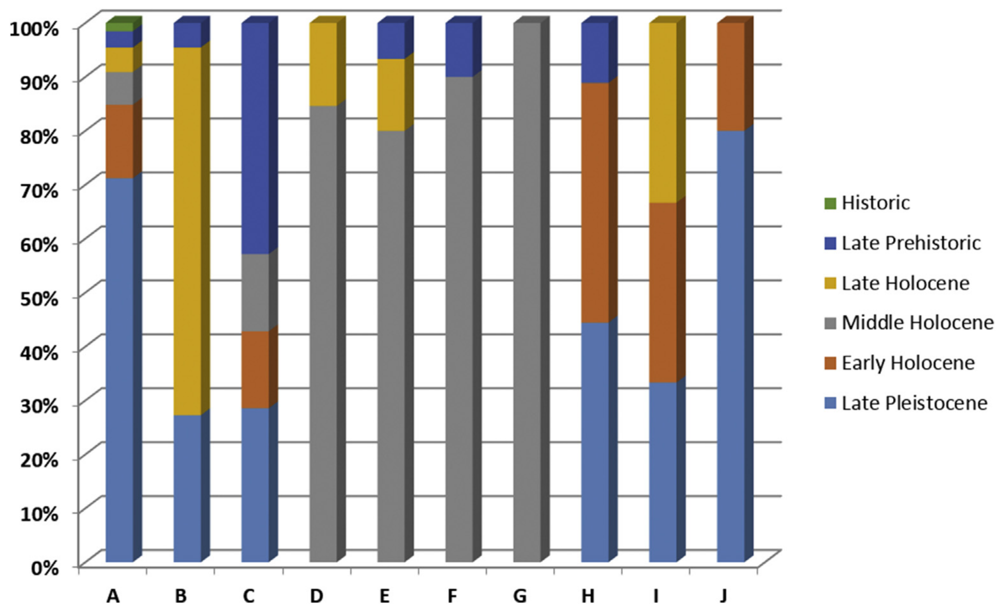

Fig. 21. Time period use of each different rhyolite group.

similar upland settings. Our sample size is small but the earliest these rhyolite groups appear prehistorically is in the Middle Holocene predominately in the Upper Susitna River valley and supports the hypothesis that humans were shifting resource exploitation to more upland resources (e.g. caribou and sheep) during this time (Potter, 2008). Conversely, the increased use of these groups may be linked to increased warming and melting of glacial ice in the Talkeetna Mountains and in southcentral Alaska. Such ice sheets would have receded significantly, exposing these "new" and untapped raw material resources to people.

Rhyolite as a whole is widely distributed throughout interior Alaska and no one group is solely concentrated to one specific region of interior Alaska, yet Groups A, B, and C have the widest distribution of all of the groups identified based on sample size. This probably reflects different flintknapping qualities within the stone, abundance, and nodule size of the material. These are questions to be addressed as source areas are discovered and documented. Despite these unknowns, this study is a first step in that process and has narrowed the search for geological source areas based on size and weight distribution of artifacts analyzed thus far. Additionally, at this time it is difficult to determine if some of these material groups are actually variations within a larger flow and/or source area, since there is some overlap with our principle component and other analysis results. Despite this, our results have definitely indicate that rhyolite can be geochemically characterized and presumed "source" clusters can be identified.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2015.02.015.

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