EXPLORING THE LITHIC LANDSCAPE OF THE NENANA VALLEY,

INTERIOR ALASKA

A Dissertation

by

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ABSTRACT

This dissertation focuses on the lithic record of the Nenana valley, interior Alaska, to inform on prehistoric toolstone provisioning in eastern Beringia. I approach the record from a behavioral and geological perspective by presenting new data integrating lithic analytical variables and geochemical sourcing of non-obsidian toolstones from late Pleistocene and early Holocene assemblages to explore provisioning strategies and how these change as humans learned the local landscape and adapted to significant environmental change.

Here, research is separated into three related chapters. The first of these focuses on comparing three cultural components from Owl Ridge, an important multicomponent site along the Teklanika River, Alaska. Results of lithic technological analysis show that humans at Owl Ridge engaged in different site activities and procurement behaviors through time, warranting cultural separation of the earliest site component from latter components proposed by previous researchers. Further, comparison of toolstone procurement behaviors show that visitors to Owl Ridge accumulated landscape knowledge as time passed.

The second article in this dissertation explores diachronic patterns in rhyolite procurement and use within the late Pleistocene and Holocene archaeological record of the Nenana river valley through the integration of lithic technological analysis, geological survey, and geochemical characterization. The results of this research expands our knowledge of the lithic landscape by identifying new artifact groups and

one new rhyolite source. In addition, diachronic patterns of rhyolite procurement and use are variable between time periods, indicative of behavioral adaptation to significant climate change and the accumulation of landscape knowledge through time.

This dissertation concludes with a chapter investigating diachronic patterns of basalt use through time in the Nenana valley. Following the same methodologies as the previous chapter, pXRF geochemical results show that basalt was procured locally through time, most likely from alluvial sources in the region. While some artifact groups could be identified, the geologic setting of the valley necessitates additional geochemical methods to successfully source basalts in this region.

Ultimately, this dissertation demonstrates the importance of integrating lithic technological analysis with geological surveys and geochemical techniques to characterize the lithic landscape of the Nenana valley, provide better insight into diachronic toolstone procurement and use behaviors in the region, and investigate scenarios of environmental adaptation and landscape learning.

DEDICATION

For my parents, Raymond and Carla Gore.

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1. INTRODUCTION

The Beringian archaeological record is vital to understanding the process of human dispersal into North America during the late Pleistocene. Genomic and archaeological evidence clearly shows ancient Beringians moved through this gateway region as they migrated from Northeast Asia to settle eastern Beringia (i.e., Alaska, USA, and Yukon, Canada) and landscapes beyond (Brandini et al. 2018; Fiedel 2022; Graf and Buvit 2017; Hoffecker and Elias 2007; Hoffecker et al. 2020; Llamas et al. 2016, 2017; Moreno-Mayar et al. 2018a, 2018b; Potter et al. 2017; Raghavan et al. 2015; Raff and Bolnick 2014; Sikora et al. 2019; Willerslev and Meltzer 2021). Initial archaeological investigations of Beringian sites in the Alaskan interior were driven by the search for evidence of the earliest humans in North America and to understand how the earliest Indigenous Americans and their descendants established themselves on the landscape. In decades since, the eastern Beringian record has yielded complex and variable archaeological assemblages prompting numerous hypotheses to explain them. The earliest descriptions of interior Alaskan assemblage variability focused on the creation of cultural typologies based on lithic morphologies and presence or absence of bifaces, blades, and microblade technologies (Anderson 1970a, 1970b; Dumond 1987, 1980; Dixon 1975; West 1967, 1980; see Goebel and Buvit 2011 for a recent review). Typological classification schemes were then debated, and still are today, although recent interpretations reach beyond descriptive typological definitions to explain archaeological complexity as reflections of human behavior. Explanatory factors contributing to assemblage diversity include the presence of distinct cultural groups or technological variants; behavioral responses to fluctuating climates; and shifting land-use strategies based on seasonality, topography, site-function or habitat (Bever 2001; Goebel et al. 1991; Goebel and Buvit 2011; Graf and Bigelow 2011; Holmes 2001; Lanoë et al. 2018; Potter et al. 2017; Powers and Hoffecker 1989; West 1996; Wygal 2011, 2018). Consensus on any one of these suggested explanations, however, continues to elude researchers (Bever 2001; Goebel and Buvit 2011).

Continuing to investigate factors contributing to such a variable Beringian record remains an important area of focus in Alaskan archaeology and is key in shaping our understanding of human dispersal into North America. This dissertation seeks to inform on this problem by exploring lithic variability through the lens of toolstone provisioning behaviors. Specifically, I consider the lithic record of the Nenana River valley in interior Alaska using a visual and geochemical approach, I integrate lithic technological analysis of site assemblages in the valley with geochemistry to characterize lithic materials (Andrefsky 1998; Odell 2004; Shackley 2008), and I discuss results of this research within the context of diachronic shifts in behavioral response to environmental change.

1.1. Themes of Research

1.1.1. Human Settlement of Beringia

Despite recent advances in paleogenomic research, questions remain regarding the timing and process by which humans settled the ecological region connecting Northeast Asia to North America, called Beringia, which spanned from the Verkhoiansk Range in the west to the Mackenzie River in the east (Hopkins 1997; Moreno-Mayar et al. 2018a, 2018b; Raghavan et al. 2015; Willerslev and Meltzer 2021). The earliest evidence of human presence in Beringia is found at the Yana RHS site, where humans left an archaeological signature characteristic of the middle Upper Paleolithic at 28-32 thousand years ago (ka) (Pitul'ko et al. 2004, 2012; Sikora et al. 2019). An unequivocal, comparably ancient site has yet to emerge in eastern Beringia. In fact, the archaeological record strongly indicates abandonment of western Beringia with the onset of full glacial conditions of the Last Glacial Maximum (LGM) (Goebel 2002; Graf 2008, 2009, 2010; but see Bourgeon et al. 2017; Vachula et al. 2019). Not until after the abatement of the LGM, during the late glacial, did humans return to Beringia. Two sites, Urez-22 in western Beringia and Swan Point in eastern Beringia, preserve composite osseous-microblade technologies and date to ~14.2 ka (Holmes 2001, 2011; Pitulko et al. 2017). Berelekh and Nikita Lake in western Beringia, however, date to around 13.8 ka and preserve a different toolkit with bifaces, blades, and ultra-thin *Chindadn* projectile points produced on flakes (Pitulko 2011; Pitulko and Pavlova 2016; Pitulko et al. 2017). After this time, the archaeological record of Beringia exhibits variable and complex technological patterns (Goebel and Buvit 2011a, 2011b; Graf and Bigelow 2011; Graf and Buvit 2017; Smith and Goebel 2018).

As humans settled eastern Beringia, interior Alaskan lithic assemblages in the Tanana and Nenana River valleys emerged with technologies focused on the production of end scrapers, side scrapers, gravers, wedges, and small, thin teardrop-shaped and triangular-shaped bifaces, resembling industries found in western Beringia (e.g., Ushki Lake, Nikita Lake, and Berelekh) (Goebel et al. 2003, 2010; Pitulko 2011; Pitulko et al.

2016). Microblade technologies were curiously absent until after 12.5 ka during the middle of the Younger Dryas stadial, despite their presence at Swan Point 1700 years earlier (Easton et al. 2007; Goebel et al. 1991; Gore and Graf 2018; Graf and Bigelow 2011; Hoffecker 2001; Pearson 1999; Powers and Hoffecker 1989; Powers et al. 2017). The end of the Pleistocene brought about substantial diversity in technologies across Beringia, with microblade production re-appearing variably alongside lanceolate-biface production in interior Alaska, as well as the appearance of lanceolate and fluted bifaces, similar to well-known Paleoindian assemblages in temperate North America (e.g., Clovis, Folsom, and Agate Basin complexes) (Bever 2001, 2008; Buvit et al. 2018; Goebel et al. 2013; Kunz and Reanier 1995; Pratt et al. 2020; Smith and DeWitt 2017; Smith and Goebel 2018; Smith et al. 2014). Technological diversity continued into the early-middle Holocene, when previous weapons systems persisted (e.g., composite osseous-microblade technologies and bifacial technologies) alongside notched points, scrapers, *tci-thos*, microblades, burins, and knives (Ackerman 2004, 2008; Esdale 2008, 2009; Pearson 1999; Potter 2008a, 2008b; Powers et al. 2017; Pratt et al. 2020).

Efforts to understand late Pleistocene and Holocene technological variability and the behavioral strategies that produced them have raised many questions to which there are few satisfactory answers. Ultimately, what do the variable technologies reveal about dispersal, settlement, mobility, and land-use strategies of ancient Alaskans from 14 ka – 5 ka? This overarching question guides research presented here. I seek to integrate lithic technological analysis and geochemistry to compare diachronic changes in toolstone procurement and selection strategies at both site and regional levels.

1.1.2. Lithic Technologies and Human Response to Environmental Change

Regional climate certainly influenced local environments and human technological strategies, but our knowledge of these processes in eastern Beringia is limited (Goebel and Buvit 2011a; Graf and Bigelow 2011; Mason et al. 2001). Eastern Beringians subsisted on a landscape subject to dynamic environmental variability, warranting a focus on land-use and mobility strategies as windows into technological response to climate change (Kelly 1992; Kuhn 1995). Palynological records provide a basis for reconstructing prehistoric environments in interior Alaska, but interpretations are hampered by poor faunal preservation and a lack of fine-grained regional analyses (Graf and Bigelow 2011). Nevertheless, broad technological trends are potentially coincident with changing climate regimes in this region (Graf and Bigelow 2011; Mason et al. 2001; Mason and Bigelow 2008).

Just before the Allerød interstadial, humans in eastern Beringia subsisted on an herbaceous-forb tundra carrying slotted composite-tools and microblades (Anderson and Brubaker 2004; Bigelow and Powers 2001; Hoffecker and Elias 2007; Holmes 2001, 2011). Faunal remains are especially sparse, but horse and mammoth remains are found at Tanana valley sites dating to this time period (Holmes 2001, 2011; Wygal et al. 2022). During the Allerød (~14 – 12.8 ka), a rise in Betula characterizes the shrub-tundra of interior Alaska where humans were equipped with small bifaces, unslotted osseous tools, and processing tools to hunt small mammals, birds, bison, wapiti and Dall sheep (Bigelow and Edwards 2001; Goebel et al. 2003; Graf et al. 2015; Potter 2008b; Powers et al. 2017; Wygal et al. 2022; Yesner 2007). The Younger Dryas stadial (~12.8-11.7 ka) brought drier and cooler climates to the interior (Bigelow and Powers 2001; DiPietro et al. 2017; Gaglioti et al. 2017; Graf and Bigelow 2011; Kokorowski et al. 2008). This time period saw the return of microblade technologies to toolkits alongside lanceolate bifaces, and the addition of salmon and hare to human diets (Halffman et al. 2015; Potter et al. 2014). Warming temperatures of the Holocene Thermal Maximum (HTM) at ~11-9 ka precipitated a rise of Populus in interior lowlands, followed by the full establishment of boreal *Picea* by the middle Holocene (Anderson and Brubaker 1994; Bigelow 1997; Graf and Bigelow 2011; Mason et al. 2001; Mason and Bigelow 2008). Early and middle Holocene toolkits are characterized by the continuation of microblade technologies and variable bifacial technologies (Ackerman 2004; Anderson 1988; Esdale 2008; 2009; Rasic and Slobodina 2008). While humans continued to hunt small game, bison, Dall sheep, and caribou, the spread of the boreal forest had significant ramifications for interior fauna: wapiti became extinct, bison and caribou populations were redistributed, and moose persisted on the landscape (Guthrie 2006; Mason 2001; Mason and Bigelow 2008).

How did changing environments and resource distribution alter human settlement, mobility, land-use patterns, and technologies, and to what degree? Currently, we are unable to elaborate on the intricacies of human-environmental interaction beyond the broad generalizations described above. In light of this, investigating raw material procurement and selection strategies at Owl Ridge (Chapter 2) and diachronic, regional patterns in rhyolite and basalt use (Chapters 3 and 4) contribute to these topics by considering the lithic record from an environmental perspective.

1.1.3. Integrating Lithic Technological Analysis and Geochemistry

Geochemical characterization techniques contribute significant knowledge to understanding behavioral patterns in the archaeological record (Eerkens et al. 2007, 2008; Glascock 2002; Liritzis and Zacharias 2011; Shackley 2005). Portable X-Ray fluorescence (p-XRF) geochemistry in particular is a popular non-destructive method often used to characterize archaeological obsidians and other volcanic toolstones (Coffman and Rasic 2015; Glascock 2020; Glascock and Ferguson 2012; Glascock et al. 1998; Grave et al. 2012; Pitulko et al. 2019). Obsidian is well-known and investigated in the archaeological record of eastern Beringia, but these raw materials make up very small proportions of the lithic assemblages of the Nenana River valley (Goebel 2011; Graf and Goebel 2009; Reuther et al. 2011; Slobodina et al. 2009). Determining broad mobility and procurement patterns based only on geochemical analyses of this normally rare raw material provides an incomplete view of provisioning behaviors present in the record (see Newlander 2015).

By contrast, fine-grained volcanic materials such as andesites, basalts, rhyolites, and dacites have been largely ignored in geochemical and raw material studies until recently, though they comprise significant amounts of the archaeological assemblages of the Nenana valley (Coffman and Rasic 2015; Gore 2021; Gore and Graf 2018; Graf et al. 2015, 2020; Graf and Goebel 2009; Goebel 2011; Powers et al. 2017). A geological, geochemical, and lithic technological approach incorporating analyses of common volcanic toolstones offers the opportunity to address questions of regional landscape use in a more holistic fashion that reaches beyond simple source assignment based on one or two pieces of obsidian. Chapters 3 and 4 seek to accomplish this through integrating my multi-year raw material survey, lithic technological analysis of Nenana valley assemblages, and pXRF geochemistry of commonly used non-obsidian toolstones to build upon previous studies (Coffman and Rasic 2015; Gore 2021; Gore and Graf 2018; Graf and Goebel 2009) and contribute to more comprehensive interpretations of the record.

1.1.4. Learning the Lithic Landscape: Provisioning Raw Materials

Many researchers have modeled the cognitive processes and expected behaviors of humans exploring unknown landscapes (Cannon and Meltzer 2022; Kelly and Todd 1988; Kitchel 2018; Loyola et al. 2019; Meltzer 2002, 2003, 2004, 2021; Purtill 2021; Rockman 2003, 2009; Rockman and Steele 2003). The archaeological signatures of humans on different ends of the landscape-learning continuum are expected to display patterns reflective of relative degrees of resource-knowledge (Fitzhugh 2004; Kelly and Todd 1988; Kuhn 1995). We know little, however, about how these learning processes occurred in interior Alaska as humans established themselves on the landscape and became acquainted with local resources (Graf and Goebel 2009). The oldest sites in interior Alaska are representative of the earliest unequivocal evidence of humans in the region and provide an opportunity to test suggested learning models (Fiedel 2022; Goebel et al. 2008). Landscape-learning is a complex and intricate process involving many environmental, cognitive, and social variables, many of which may be difficult to observe in the record (Kitchel 2018). Despite this complexity, this dissertation looks to the Nenana valley's lithic record to take the first steps toward understanding how the process of landscape learning unfolded in eastern Beringia.

Lithic toolkits are reflections of human behavioral adaptations because they are designed and employed to assist in procuring resources necessary for survival (Andrefsky 2009; Binford 1980; Nelson 1991). As such, studies of lithic technological organization can contribute to answering questions regarding human behavior, settlement systems, and economies of ancient Alaskans (Binford 1979; Graf 2010; Kuhn 1995, Nelson 1991; Odell 2004). High-quality lithic raw materials were important components of hunter-gatherer technological systems because their economic influence impacted the adaptive strategies and behavioral choices of hunter-gatherers, especially in risky environments where raw materials were unknown or potentially limited (Andrefsky 1994, 2009; Bleed 2002; Elston and Brantingham 2002; Kuhn 1995; Nelson 1991). Therefore, approaching the largely lithic record of interior Alaska from the perspective of toolstone procurement and provisioning can inform on questions related to landscape learning and assemblage variability (Andrefsky 1994, 2009; Ford 2011, 2012; Gore and Graf 2018; Graf and Goebel 2009). At present, few studies in interior Alaska (Coffman and Rasic 2015; Goebel 2011; Gore and Graf 2018; Graf and Goebel 2009; Reuther et al. 2011) have approached the record from a raw-material perspective despite its importance to behavioral interpretations. A major goal of this dissertation was to add to the small but growing number of lithic raw material studies in central Alaska.

1.2. The Nenana Valley Geography, Geology, and Archaeology

The sites in this study are located in the Nenana valley, interior Alaska. The valley is formed by the Nenana River, which bisects the Alaska Range mountains as it flows north through the northern foothills zone and terminates at its confluence with the Tanana River near the town of Nenana, Alaska (Ritter 1982; Wahrhaftig 1953). The foothills zone extends ~200 km east to west and ~60 km north to south and includes portions of Denali National Park and Preserve (DENA) (Ritter 1982; Wahrhaftig 1953; Thornberry-Ehrlich 2010). This region of the interior preserves many proxy records providing evidence of regional climate change from the late Pleistocene through the Holocene (Anderson and Lozhkin 2001; Bigelow and Edwards 2001; Bigelow and Powers 2001; DiPietro et al. 2017; Graf and Bigelow 2011; Kokorowski et al. 2008; Mason et al. 2001) as well as numerous multicomponent archaeological assemblages from well-stratified, intact contexts (Bowers 1980; Bowers and Reuther 2008; Goebel and Bigelow 1996; Goebel et al. 1996; Hoffecker and Powers 1996; Pearson 1999; Powers and Hoffecker 1989; Holmes 1988; Holmes et al. 2018).

The surface geology of the valley, initially mapped during the 1950's and later in the 1970's with the construction of the Alaska Railroad, reveals an array of geological formations that includes outcrops of cherts, basalts, rhyolites, and other igneous materials (Albanese 1980; Cameron et al. 2015; Csejtay et al. 1986; Wahrhaftig 1969). The geology of the valley is diverse, but not mapped in detail, complicating efforts to determine which specific lithic resources were available to be procured and used by ancient occupants in the valley (Gore 2021; Gore and Graf 2018; Graf and Goebel

2009). Ancient uplift and more recent glaciations of the mountains and foothills have resulted in a complex record of glacial moraines, alluvial formations, and valley terraces (Beget 2001; Ritter and Ten Brink 1983; Thorson 1986; Wahrhaftig 1958). Post-glacial deposits of loess and sand deposits atop these elevated surfaces preserve the valley's archaeological assemblages (Powers and Hoffecker 1989; Thorson and Bender 1985; Thorson 1986).

Numerous significant archaeological sites are located in the valley. During the 1960's, DENA park surveys resulted in the discovery of Teklanika West (Coffman 2011; Goebel 1996; West 1967). During the 1970's and 1980's, railroad and highway construction in this remote region spurred archaeological discoveries, and subsequent surveys produced more multicomponent sites with dates spanning the late glacial to the middle Holocene. These include Walker Road, Moose Creek, Panguingue Creek, Little Panguingue Creek, Dry Creek, and Owl Ridge in the northern foothills zone and Carlo Creek and Eroadaway in the southern upland portion of the valley (Bowers 1980; Bowers and Reuther 2008; Graf et al. 2015; Graf et al. 2020; Goebel and Bigelow 1996; Goebel et al. 1996; Gómez-Coutouly et al. 2019; Hoffecker and Powers 1996; Pearson 1999; Powers and Hoffecker 1989; Holmes 1988; Holmes et al. 2018). Houdini Creek was recorded during cultural resource management surveys in the 1990's and is one of the few reported sites in the valley only to contain Holocene cultural components (Pearson 1999; Powers et al. 2017; Potter et al. 2007). Excavations of many of these sites show that these assemblages are mostly lithic with only rare fragmentary faunal remains (Bowers 1980; Graf and Bigelow 2011; Pearson 1999; Potter 2007; Powers et al. 2017), due largely to the acidic nature of the region's sediments. The lithic portions of these assemblages are the subject of this dissertation because they are well-dated and well-preserved, positioning them as important proxies for studying human behavior and paleoenvironment.

1.3. Research Questions

This dissertation is separated into three independent chapters connected by the central themes of lithic technological provisioning, procurement, and environmental adaptation. These chapters are guided by the following research questions:

Question 1: How can the lithic landscape of the Nenana valley be defined and characterized?

Question 2: How did early Beringians and their descendants establish themselves on the Nenana valley landscape and respond to fluctuations in climate and change in biotic environment?

Question 3: How can geochemical characterization of non-obsidian raw materials aid in understanding how humans learned and interacted with the local lithic landscape through time?

Chapter 2 of this dissertation presents the results of a lithic analysis carried out on assemblages from the Owl Ridge site. Owl Ridge is a multicomponent site located along the Teklanika River, a major tributary of the Nenana River, and situated in the foothills zone about 30 km west of the Nenana valley's cluster of archaeological sites including Dry Creek, Walker, Road, and Panguingue Creek. Owl Ridge preserves three occupations dating from the Allerød interstadial to the early Holocene. In this chapter I interpret toolstone selection and procurement behaviors reflected in each of these assemblages based on lithic technological analyses I conducted. Specifically, this chapter uses primary and secondary reduction, bifacial and unifacial technologies, and technological formality as variables to explore technological activities at the site. I discuss the results of analyses of each assemblage, compare them with each other, and interpret human behavioral patterns within the context of the local lithic landscape and well-documented paleoenvironmental changes in interior Alaska. Although this chapter focuses on just three assemblages from one site, the analyses performed here were important in generating characterizations of the broader Nenana valley lithic landscape presented and discussed in Chapters 3 and 4. This chapter of my dissertation was previously published in the edited volume Lithic Technological Organization and Paleoenvironmental Change, edited by Robinson and Sellét (2018).

In Chapter 3, I build upon an important first study investigating rhyolite geochemistry in Alaska (Coffman and Rasic 2015). In this chapter, I report results of an extensive, multi-year raw materials survey in a first attempt to systematically describe the lithic landscape of the valley. I characterize the geochemistry of geological materials collected from rock outcrops and alluvial (e.g., creek bed and waterway) drainages and compare these with archaeological assemblages. I confirm previously defined rhyolite groups and characterize new rhyolite groups not yet reported. I integrate raw material survey results, a lithic technological analysis of the archaeological assemblages, and geochemical results to interpret differences in rhyolite group use and spatial patterning through time. Specifically, I focus on measures of rhyolite diversity and cortex presence and absence as variables that help inform on local and nonlocal rhyolite use, provisioning strategies, and indicators of landscape knowledge. I hypothesize scenarios for rhyolite use patterns within the context of regional paleoecological trends.

In Chapter 4, I use the same geochemical methods (pXRF) to explore basalt use within the same Nenana valley site assemblages used in Chapter 3. In this chapter, I compare four basalt outcrops in the valley with two outcrops from outside of the valley to assess their geochemical variability and relationship to each other. I then characterize basalts from alluvial settings across the valley and address spatial patterns and groups identified. Alluvial basalts are then compared with outcrop materials to establish their relationship with each other. The geochemistry of all geological materials collected from both outcrop and alluvial locations are then compared with basalt artifacts from assemblages to test the usefulness of pXRF geochemistry on mafic materials in the valley. I employ the presence/absence of artifact cortex as a relative means of measuring degrees of local or nonlocal toolstone use for basalts in each assemblage and discuss the implications of technological and geochemical results on human provisioning patterns in the valley. I explore how these patterns fit with current knowledge of technologies, toolstone-use, and environmental change in the Nenana valley record.

I conclude this dissertation in Chapter 5 by providing a summary of each chapter, pointing out the strengths and weaknesses of the methodologies used and their overall contribution to interior Alaskan archaeological research, and discussing relevant areas of future research. This dissertation set out to define the lithic landscape of the Nenana River valley to provide context for investigative, technological, and geochemical studies conducted on the late Pleistocene and Holocene sites therein. Ultimately, this research seeks to provide a more nuanced understanding of ancient Alaskan toolstone provisioning within the context of landscape-learning and behavioral adaptation to changing climate.

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2. TECHNOLOGY AND HUMAN RESPONSE TO ENVIRONMENTAL CHANGE AT THE PLEISTOCENE-HOLOCENE BOUNDARY IN EASTERN BERINGIA: A VIEW FROM OWL RIDGE*

2.1. Introduction

Archaeological investigations in Alaska are significant in providing information about initial human occupation of Beringia, the entry point from an Asian homeland for first Americans (Meltzer 2004; Goebel et al. 2008). Recent research in eastern Beringia has revealed a complex record of terminal Pleistocene-aged sites important to understanding how the Americans were settled. Shortly after initial colonization of eastern Beringia, so far identified at the Swan Point site and dated to ~14,100 calendar years before present (cal. BP) (Potter et al. 2014a), the Beringian record became highly variable. One case of this variability comes from central Alaska and is represented by two technological complexes, Nenana and Denali (Powers and Hoffecker 1989; Hoffecker 2001; Graf and Bigelow 2011; Graf et al. 2015). We explore this variability in central Alaska by examining how early and later inhabitants of the Owl Ridge site organized their technologies in response to Late Pleistocene and early Holocene environmental fluctuations. We use the established terms, Nenana complex and Denali complex, heuristically, not in an attempt to define human groups or archaeological

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traditions but to classify observed technologies that represent technological strategies humans adopted while responding to past environmental change. We focus specifically on lithic raw material (or toolstone) procurement and selection behaviors to explain how humans responded to climate change during this interval while arriving in central Alaska and subsequently settling in the region.

2.2. Background

2.2.1. Archaeological Context

As mentioned above, the earliest unequivocal evidence of humans in eastern Beringia comes from Swan Point, located in the middle Tanana Valley 100 km southeast of Fairbanks, Alaska, dating to 14,100 cal. BP, and containing a Siberian late Upper Paleolithic technology based on wedge-shaped microblade-core production (Gomez Coutouly 2011, 2012; Holmes 2011). Following this, humans continued occupying central Alaska through the Late Pleistocene and early Holocene (Potter 2008; Graf and Bigelow 2011), but toolkits changed. The regional pattern of technological variability that emerged after initial exploration has led some to recognize a Nenana complex chronologically and technologically distinct from the Denali complex first identified by West (1967). In this view, Nenana complex assemblages, found at several multicomponent sites in the Nenana and Tanana valleys, date to 13,500–13,000 cal. BP and contain unifacial tools (end scrapers, retouched blades and flakes, gravers, and wedges), diagnostic Chindadn-type bifacial points that are teardrop-shaped or triangular-shaped and sometimes only marginally retouched, other bifaces, and cobble tools (Powers and Hoffecker 1989; Hoffecker et al. 1993; Goebel et al. 1991; Yesner 1996, 2001; Hoffecker 2001; Graf and Goebel 2009; Graf and Bigelow 2011; Graf et al. 2015). Similar technologies dating to the same period of time have even been reported from the Ushki Lake and Berelekh sites in western Beringia (Dikov 1977; Mochanov 1977; Goebel et al. 2003, 2010; Pitulko 2011).

In contrast, Denali complex assemblages, many from the same multicomponent sites with temporally and stratigraphically distinct lower Nenana complex components, date to 12,600–10,000 cal. BP and contain toolkits with lanceolate and concave-based bifacial points, unifacial tools (side scrapers and retouched flakes), as well as burin and microblade technologies. In Nenana valley sites, lanceolate and concave-based points, burins, and microblade technologies are absent from older Nenana complex components (i.e., Owl Ridge, Dry Creek, Walker Road, Moose Creek) (Powers and Hoffecker 1989; Pearson 1999; Hoffecker 2001; Graf and Bigelow 2011; Graf et al. 2015). During recent investigations of the Teklanika West site, however, a lanceolate point was found in what appears to be a compressed stratigraphic context and palimpsest situation, where two horizontally overlapping artifact zones (components 1 and 2) were found in the same sedimentological unit unseparated by sterile deposits and associated with faunal remains dating to13,100–9700 cal. BP. Coffman (2011:106) concluded that the lanceolate point could be associated with component 1 but acknowledged it could be intrusive from component 2.

Mostly because a very early microblade-bearing component at Swan Point was found to predate 14,000 cal. BP, but also because two sites in the Tanana valley continue through the terminal Pleistocene to have bifacial points resembling Chindadn points from Nenana complex sites in the Nenana valley, some archaeologists argue Nenana complex and Denali complex variability represents different behavioral facies of a pan-Beringian archaeological tradition lasting>4000 years (Holmes 2011; Potter et al. 2014a) and presumably reflects no significant adaptive change to major climatic fluctuation over this timeframe. Thereby, depending on the situation, people selected different technological strategies, bifacial versus composite osseous-microblade hunting weapons, for different immediate needs such as hunting different animals during different seasons, extracting resources in uplands versus lowlands, or proximity to toolstone sources (Holmes2001; Gal 2002; Potter 2005; Wygal 2009, 2011; Graf and Bigelow 2011). A major issue with this reasoning is that we should expect to find Nenana and Denali complex artifacts together at some sites, but we do not observe this pattern. The only exception is the stratigraphically problematic Healy Lake site, where multiple components may have been excavated together as one (Erlandson et al. 1991; Cook1996; Hamilton and Goebel 1999). Additionally, faunal data do not support expectations of the related different-animal-during-different-seasons hypothesis. From the Dry Creek site, fauna found in both the Nenana and Denali components indicates hunting activities during the same season (late fall/winter) as well as hunting of the same animal type (Dall sheep) with the different weapon-system technologies (first Chindadn points, then osseous-microblade composite and lanceolate points). At Broken Mammoth, hunters used the same weapon system (Chindadn points) to dispatch different animal types during different seasons. Clearly, we cannot simply claim that microblade technology was selected only during a specific season and fora specific animal type compared with bifacial technologies. We argue the use of abroad-sweeping “Beringian Tradition” oversimplifies complex patterns observed in the early Beringian record and lumping together varied technological strategies found in stratigraphically and temporally discrete contexts obscures evident variability that needs to be explained.

At least three sites in the Nenana valley contain both Nenana and Denali assemblages in stratigraphically and chronologically separate geological contexts: Owl Ridge, Dry Creek, and Moose Creek (Pearson 1999; Graf and Bigelow 2011; Graf et al. 2015). Historically, proponents of separating Nenana and Denali complexes have argued this variability resulted from two different populations settling central Alaska from Northeast Asia (Goebel et al. 1991; Hoffecker et al. 1993; Hoffecker Elias 2007). This interpretation certainly fits well with the recently proposed Beringian standstill model for development of Native American genetic population differentiation hypothetically staged in Beringia or far Northeast Asia (Tamm et al.2007; Mulligan and Kitchen 2014; Raghavan et al. 2015). The hypothesis of different Beringian populations with different toolkits is difficult to test without abundant human skeletal remains preserving ancient DNA that would provide population-level genetic information. Recent skeletal finds associated with Denali complex technology at the Upward Sun River site in the Tanana Valley (Potter et al. 2011,2014b) evidence at least two mtDNA clades present in the same population, giving us important clues about social organization at this time and genetic relatedness of early Holocene Alaskans with other Native Americans (Tackney et al. 2015); however, we need preserved human DNA from earlier Beringian sites with Nenana complex technology to begin to test the different populations hypothesis. What does the chronological patterning of Beringian archaeological variability mean? We are more interested in understanding whether the patterns of variability can be explained as human response to variation in resource distribution resulting from climate change (following Mason et al. 2001; Graf and Goebel 2009; Graf and Bigelow 2011; Wygal 2011). We contend humans will select necessary tool-provisioning strategies to be successful in a given environmental situation and perceived landscape. In this paper we consider the observed differences between Nenana and Denali complexes the result of humans selecting different hunting strategies as they became increasingly familiar with the local landscape and responded to climate change and shifts in habitat and resource availability. Before delving into the details of our lithics study, we first review the central Alaskan paleoecological record to establish ecological parameters humans faced at the Pleistocene-Holocene boundary.

2.2.2. Paleoenvironmental Context

Paleoecologists working in Alaska have long been interested in identifying climatic fluctuations between about 15,000 and 10,000 cal. BP. Therefore, the paleoenvironmental record for the region is reasonably robust and can be used to infer major climatic events and changes in biome composition. Such data allow us to predict resource distributions for humans inhabiting the region and provide a means to evaluate paleoecological constraints faced by the region's earliest inhabitants. In particular we are interested in the effects of Northern Hemispheric climatic events such as the Older Dryas, Allerød, Younger Dryas, and Holocene Thermal Maximum on central Alaskans (Bigelow and Edwards 2001; Bigelow and Powers 2001; Kaufman et al. 2004;

Kokorowski et al. 2008; Graf and Bigelow 2011). These specific climatic events characterize the time before, during, and after hunter-gatherers inhabited Owl Ridge.

Regional late glacial pollen records, predating 14,000 cal. BP, indicate herb-tundra vegetation. The landscape would have been open with few trees and dominated by an herbaceous plant combination of short grasses, sedges, and *Artemisia* sp. (Bigelow and Powers 2001; Anderson et al. 2004). Animals would have included woolly mammoth, horse, bison, wapiti, and moose as well as other smaller species (Guthrie 2017, 2006; Meiri et al. 2014). By about 14,000 cal. BP, a birch and willow shrub-tundra vegetation community came to dominate the region (Bigelow and Powers 2001; Anderson et al. 2004; Brubaker et al. 2005). Rises in lake levels through the Allerød (14,000–13,000 cal. BP) indicate relatively warmer temperatures and higher humidity than immediately before or after this time (Abbott et al.2000; Bigelow and Edwards 2001). As a result, obligate grazers such as horse and mammoth went extinct by 13,500 cal. BP, while bison and wapiti (grazers who also browse) and moose (an obligate browser) populations were maintained (Guthrie 2006), and abundance of waterfowl in the Broken Mammoth faunal assemblage indicates the presence and use by humans of more mesophilic species (Yesner 2007).

In some regions of the Northern Hemisphere, the Younger Dryas was not significantly felt, but in northern latitudes its effects were more pronounced (Kokorowski et al. 2008). In fact, central Alaskan palaeoecological records suggest much drier conditions, especially north of the Alaska Range due to an interior Alaskan rain-shadow effect, reflected by a significant increase in Artemisia pollen, lowered lake levels, and deposition of eolian sand layers (Hu et al. 1993; Bigelow et al. 1990; Abbott et al. 2000; Bigelow and Edwards 2001; Bigelow and Powers 2001). Bison and wapiti populations were maintained during this arid interval; however, moose became far less prevalent (Guthrie 2006). Archaeological sites in the region also indicate the presence of caribou (Yesner 2001, 2007; Bowers and Reuther 2008).

Within a few centuries following the Younger Dryas and by 11,000 cal. BP, the onset of the Holocene Thermal Maximum had begun with expansion of *Populus*, representing the first trees to inhabit the Alaskan interior since marine oxygen isotope stage (MIS) 3 (~35,000–26,000 cal. BP). *Populus* is known to be cold-tolerant yet thrives in warm summer conditions. Regional lake levels were lower than today, indicating an early Holocene climate warmer and drier, especially during summer months. Following 10,000 cal. BP, *Picea* spread to the region and lake levels increased, signaling a shift from an open-forest parkland to boreal-forest biome and the relatively warm, moist conditions of today (Abbot et al. 2000; Barber and Finney2000; Bigelow and Powers 2001; Lloyd et al. 2006). Faunal compositions during the early Holocene also mimic the later Holocene pattern with wapiti extinct, but populations of moose and bison maintained (Guthrie 2006).

The paleoecological record of central Alaska indicates initial migrants from Siberia were faced with a frigid, dry landscape with little woody vegetation for fire production and maintenance at 14,100 cal. BP, though large mammal populations of the herb tundra would have provided high-protein resources and a source of slow-burning fuel once a fire could be established with wood (Crass et al. 2011). A fire fueled with bones, however, burns with a high flame and does not carry embers, so it is good for lighting, drying, and curing, but not necessarily for more thorough cooking (Théry-Parisot et al. 2002). Perhaps this is why only one interior Alaskan archaeological site to date has been recorded for the period just prior to the Allerød (Hoffecker and Elias 2007). During the Allerød, wetter conditions resulted in spread of shrub-tundra vegetation increasing burning opportunities for people so they could maintain fires for both cooking and curing as well as drying and warmth. Bison, wapiti, and moose were available for hunting and so were smaller wetland resources, such as waterfowl. During the Younger Dryas, a brief reversal to drier conditions meant that more mesophilic taxa, such as moose, were less available for human use (Yesner 2007). Following the Pleistocene, warmer and eventually more humid conditions returned and persisted, altering the biome of central Alaska. The eventual emergence of the boreal forest led to lower numbers and more dispersed large fauna with bison relegated to lowland settings, wapiti eventually becoming extinct locally, and solitary moose widely dispersed across the landscape. Below we use the archaeological record from Owl Ridge to test the hypothesis that technological changes during the terminal Pleistocene resulted from human response to climate change and associated changes in fuel and food resource distributions. We expect that human decisions to select specific adaptive strategies are reflected in the technologies they used and that these decisions were made in response to environmental change, such as change in composition, proportion, and distribution of natural resources around them (Nelson 1991; Kuhn 1995; Elston and Brantingham 2002; Andrefsky 2009; Graf 2010; Graf and Bigelow 2011).

2.3. Materials and Methods

2.3.1. Owl Ridge Basics

Owl Ridge is located in the northern foothills of the Alaska Range along the Teklanika River, a glacially fed tributary to the Nenana River (Figure 2.1). The site is situated in interbedded loess, cliff-head sand, and colluvial deposits capping a glacial outwash terrace of the Teklanika River and resting approximately 61 m above the confluence of

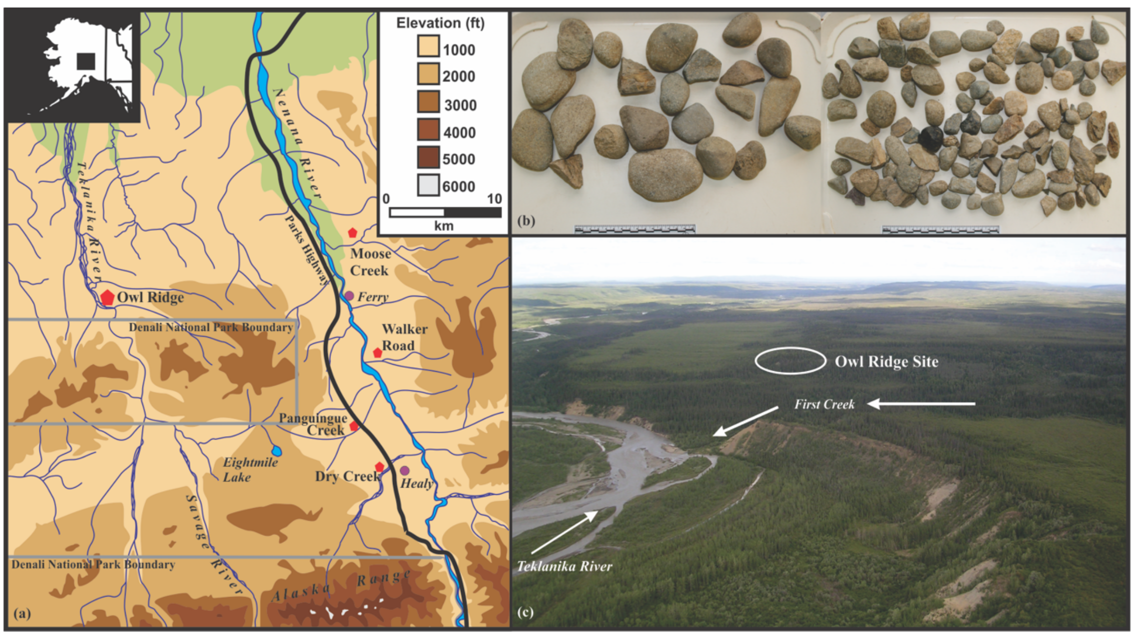

Figure 2.1. Map of the Nenana and Teklanika River Valleys with the location of the Owl Ridge site (a). Picture of two rock samples from the glacial outwash terrace that the site rests on (b). Picture of location of Owl Ridge Relative to the Teklanika River and First Creek floodplains (c).

the river and First Creek, a small clear stream draining the immediate foothills. Given conditions of the herb-tundra and shrub-tundra landscape, this location would have provided hunter-gatherers of the terminal Pleistocene an advantageous, unobstructed view of game and lithic resources located in the surrounding area as well as a source of clear water. The Owl Ridge site was initially discovered in 1976 during a backcountry survey of the Teklanika River (Plaskett 1976), and it was tested in 1977–1979 and 1982–1984 by the University of Alaska Fairbanks archaeologists. Following the 1980s testing project, three cultural components were identified. Based primarily on stratigraphy and several conventional radiocarbon(^{14}C) dates, Phippen (1988) assigned the lowermost component to the then recently defined Nenana complex and the upper two components to the Denali complex, one dating to the Younger Dryas and the other dating to the middle-late Holocene. In 2007, 2009, and 2010, we returned to Owl Ridge to conduct full-scale excavations, opening an additional 54 m^2. We found site deposits to be approximately 125 cm thick, consisting of three sandy loams, separated by two sand layers (Figure 2.2). The sandy loams represent three loess-deposition events: loess 1, loess 2, and loess 3. The lowermost sand, sand 1, is a relatively thin eolian deposit, most likely resulting from cliff-head sand deposition, and the upper sand, sand 2, is a thick set of colluvial deposits.

Three cultural components were found in three stratigraphically separated strata. The earliest, component 1, was found in the upper 5 cm of loess 1. One conventional ^{14}C date obtained by Phippen (1988) on a bulk charcoal sample provided an age of 11,340 ± 150 (Beta-11,209) ^{14}C BP, and an additional AMS date obtained by our team on a single piece of naturally occurring wood (*Salix* sp.) charcoal from loess 1within a component 1 artifact cluster provided the age of 11,056 ± 59 (AA-86969)^{14}C BP (Graf and Bigelow 2011). Together these dates indicate a range of occupation of about 13,300–13,000 cal.

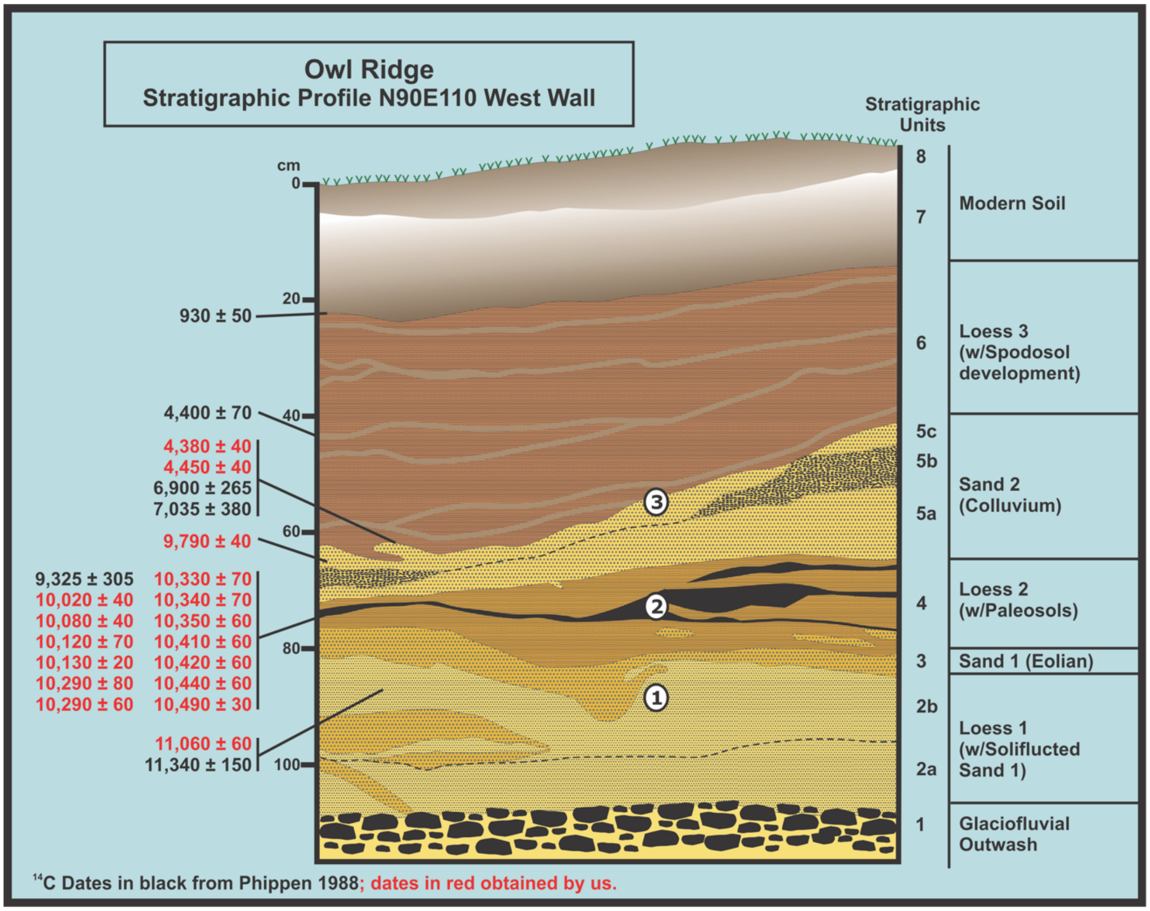

Figure 2.2. Representative stratigraphic profile of the Owl Ridge site showing stratigraphic locations of radiocarbon dates obtained and cultural components (1, 2 and 3) identified during site investigations.

BP (all ^{14}C dates in this chapter were calibrated using the Intcal13 curve in the Calib 7.0.2 downloadable program for MS Windows [Reimer et al. 2013]). Component 1, therefore, dates to the end of the Allerød and immediately prior to the Younger Dryas (Graf and Bigelow 2011). Component 2 artifacts were consistently found associated with a paleosol (buried A/B horizon) in loess 2. In our excavations, we obtained 13 radiocarbon samples of naturally occurring wood (*Salix* sp.) charcoal isolated in the paleosol and found within component 2 artifact concentrations. These dates overlap at 2-sigma standard deviation and range from 10,485 ± 25 (UCIAMS-71261) to 10,020 ± 40 (Beta-289,378) ^{14}C (12,550–11,315 cal.) BP, dating the paleosol and deposition of artifacts to the Younger Dryas (Graf et al. 2010; Graf and Bigelow 2011). Given that dated materials and artifacts from component 2 were found in a paleosol of loess 2, signaling a stable surface and relatively mild climate, plus they are directly overlying cliff-head sand deposits signaling a relatively windy, dry period, we argue that locally the Younger Dryas climatic reversal was brief and can be dated to the intervening 450 years between component 1 and component 2 site visits. Finally, component 3 artifacts were found near the contact of sand 2 with overlying loess 3, most within the upper 5 cm of sand 2 (Melton 2015). Two AMS dates on two wood (*Salix* sp.)charcoal samples from a possible hearth feature produced ages of 9880 ± 40 (Beta-330,127)and 9790 ± 40 (Beta-289,379) ^{14}C (11,390–11,170 cal.) BP. Together, stratigraphic and AMS data establish the site was visited three times at the Pleistocene-Holocene boundary: the first occupation at about 13,300–13,000 cal. BP or during the last centuries of the Allerød; the second sometime between 12,550–11,320 cal. BP during the global Younger Dryas chronozone, but after the local Younger Dryas climatic event; and the third occupation at about 11,390–11,170 cal. BP, immediately before the Holocene Thermal Maximum as forests were emerging in central Alaska. Given the regional sequence of climatic and biome changes that occurred from the Allerød through the Holocene Thermal Maximum, with Owl Ridge, we have a unique opportunity to examine human adaptive response by members of a small-scale society to fairly rapid shifts in local climate.

Lithic assemblages analyzed for this paper include excavated materials collected by Peter Phippen currently housed at the University of Alaska Fairbanks Museum of the North, as well as materials collected from our excavations during the 2007–2010 field seasons. Taken together, the analyzed Owl Ridge lithic assemblage presented here totals 4104 artifacts. An additional 223 artifacts were found in excavation squares at the bluff edge where stratigraphy was compressed into <50 cm of deposits, and assignment of these pieces to specific stratigraphic units and cultural components could not be confidently undertaken, and therefore are omitted from our analysis presented here.

2.3.2. Technological Organization and Human Response to Environmental Change

One way to gain a clearer picture of how people responded to environmental change is to explore how they organized their technologies, subsistence, and land use strategies. The terminal Pleistocene archaeological record in central Alaska, however, is largely a lithic record. Faunal preservation is almost nonexistent with only a handful of sites preserving identifiable specimens (e.g., Dry Creek, Broken Mammoth, Carlo Creek, Swan Point, Upward Sun River, and Gerstle River Quarry) (Bowers 1980; Yesner 2001; Potter 2007; Graf and Bigelow 2011; Graf et al.2015), and of these only the Gerstle River Quarry and Broken Mammoth assemblages have been analyzed beyond number of identified specimens (Potter 2007; Yesner 2007). Therefore, with the data at hand, little about subsistence organization can be directly garnered from the record. We are left to rely mostly on the lithic record to reconstruct how people organized themselves on the landscape, how they made a living, and why. Owl Ridge is no exception to this pattern. Here we analyze the lithic assemblages from the site's three terminal Pleistocene components to explore changes in technological organization, provisioning, and use of the lithic landscape.

Because climate in central Alaska was variable during the terminal Pleistocene and resource distributions changed as a result of this variability, we expect humans to have altered their mobility and technological strategies in response. We approach this problem from a human ecology, resilience theory perspective (Redman 2005; Cooper and Sheets 2012; Birks et al. 2015). Humans organize mobility, subsistence, and technological strategies around solving the problem of procuring food (Binford 1980; Bleed and Bleed 1987; Nelson 1991; Kuhn 1995; Morgan 2009). Human interaction with the environment guides technological, subsistence, and land-use decisions. In response to changing climate and resource availability and distribution, humans may show resilience by staying in the changing environment but making necessary alterations to behavioral strategies and adapting to the changing ecosystem. In contrast, however, they may decide to migrate or even resist change and be driven to extinction (Redman 2005; Fitzhugh 2012; Birks et al.2015). Decisions to alter technological organization or the selection of specific strategies for making, curating, transporting, and discarding tools happen in response to resource distribution, productivity, and predictability (Binford 1979; Shott 1986; Bamforth 1991; Nelson 1991; Andrefsky 2009). To explain technological behavioral patterns reflected in the archaeological record in central Alaska and how these patterns may represent human response to climate and environmental change, this paper will examine toolstone procurement and selection behaviors represented in components 1, 2, and 3 at Owl Ridge. By analyzing variables that inform on ways toolstones were procured then selected for tool manufacture, we can make inferences regarding how site occupants used their landscape. By comparing the cultural occupations, we will detect behavioral responses to environmental change through time.

As central Alaskan climate, biomes, and landscapes changed throughout human occupation (13,300–11,200 cal. BP) at Owl Ridge, we expect to see changes in the technological strategies and ways people used the site and surrounding landscape as they responded to these shifts. This will help us document and consider the resilience of hunter-gatherers in the region during the last major global warming event.

We examine lithic raw material availability (lithic landscape), variability, and transport to explain toolstone procurement at the site. The availability and distribution of potential toolstones affect decisions to procure those materials (Kuhn 1995; Andrefsky 2009; Graf 2010). Below, we discuss current knowledge of the lithic landscape local to the site and within the greater Nenana and Teklanika Valleys. We consider frequency of raw material classes, such as cryptocrystalline silicate (CCS) or the fine-grained cherts and chalcedonies, microcrystalline silicate (MCS) or coarse-grained cherts, andesite, basalt, rhyolite, and other less common raw materials or quartzites, granodiorites, and greywackes, by archaeological component to understand toolstone variability. This allows us to assess which available resources in the lithic landscape were economically significant to the inhabitants of Owl Ridge and whether these procurement patterns changed through time. In our analyses we identified toolstones through visual inspection. Geochemical characterization and sourcing studies have been successfully accomplished on Alaskan obsidians (Reuther et al. 2011); however, because obsidian is lacking from the Owl Ridge assemblage and little is known about specific basalt and rhyolite sources in central Alaska (but see Coffman and Rasic 2015 for preliminary investigation of rhyolite use), we did not use geochemical characterization to identify specific raw material source locations. One of us (Gore) is currently working on geochemical characterization of all local basalts and andesites from the Nenana valley. In this study, we identified the presence of cortex on toolstones to explore relative degrees of transport. We assume specific toolstone types always found without cortex originated offsite and were not locally procured. Toolstone types expressing cortex, especially alluvial cobble cortex, were locally procured on-site in the glacial outwash or nearby in the creek and river alluvium. Variables we used to highlight toolstone transport behaviors include number of toolstone types expressing cortex and, therefore, representing locally procured raw materials, frequency of nonlocal toolstone types in the site assemblage, and frequency of local versus nonlocal toolstones by component.

We used three integrative lithic variables to explore technological activities: primary versus secondary reduction activities, formal versus informal technologies, and bifacial versus unifacial technologies (Graf and Goebel 2009). To understand how Owl Ridge foragers selected toolstones for these activities, we considered each variable first by toolstone type and second by nonlocal/local toolstone. Primary reduction artifacts related to core reduction and tool-blank production include cores, cortical spalls, flakes (>1 cm^2 in total dimension), blade-like flakes, bladelets, microblades, technical spalls (diagnostic of blade or microblade-core production), and angular shatter (Graf and Goebel 2009). Secondary reduction artifacts related to tool manufacture and rejuvenation include tool trimming flakes or "retouch chips" (<1 m^2 in total dimension), biface-thinning flakes, burin spalls, and tools (Graf 2008; Graf and Goebel 2009). Formal technologies include prepared cores (blade and microblade cores) and tools manufactured to have long use-life histories (bifaces, side scrapers, end scrapers, and combination tools). Informal or expediently produced cores and tools include flake cores, tested cobbles, retouched flakes and blades, gravers, burins, and cobble tools. These tools evidence little retouch, shaping, preparation, and short use-life histories (Kuhn 1995; Graf 2008, 2010; Andrefsky 2009; Graf and Goebel 2009). Bifacial technologies include all bifaces and bifacial thinning flakes (Graf 2008; Graf and Goebel 2009). Unifacial technologies include all unifacial tools and retouch chips with smooth platforms, representing debitage removed from unifacial edges (Graf 2008; Graf and Goebel 2009).

2.4. Results

2.4.1. Character of the Owl Ridge Lithic Assemblage

The analyzed Owl Ridge assemblage totaled 4104 artifacts (Table 2.1), 894 from component 1, 1343 from component 2, and 1867 from component 3. Within component1 there was 1 tested cobble, 870 debitage pieces, and 23 tools. Debitage includes cortical spalls, flakes and flake fragments, blade-like flakes, bladelets, a blade core tablet, angular shatter, retouch chips, biface-thinning flakes, and burin spalls. Four triangular-shaped bifacial points manufactured on flake blanks were identified in the tool assemblage, but only one of these was found in a nearly complete condition, only missing its tip (Figure 2.3a). Other tools included bifaces, retouched flakes, and an anvil

Table 2.1. Presentation of artifact types by component.

Artifact Class	Component 1	Component 2	Component 3
Cores			
Unidirectional Flake Cores	0 (0.0%)	1 (0.1%)	0 (0.0%)
Bidirectional Flake Cores	0 (0.0%)	0 (0.0%)	2 (0.1%)
Multidirectional Flake Cores	0 (0.0%)	2 (0.1%)	1 (0.1%)
Tested Cobbles	1 (0.1%)	6 (0.5%)	6 (0.3%)
Subtotal	*1 (0.1%)*	*9 (0.7%)*	*9 (0.5%)*
Debitage			
Technical Spalls	1 (0.1%)	2 (0.1%)	1 (0.1%)
Cortical Spalls	87 (9.7%)	83 (6.2%)	367 (19.7%)
Flakes	527 (58.9%)	694 (51.7%)	1141 (61.1%)
Resharpening Flakes	158 (17.8%)	342 (25.5%)	162 (8.6%)
Biface Thinning Flakes	77 (8.6%)	95 (7.1%)	81 (4.3%)
Burin Spalls	1 (0.1%)	4 (0.3%)	0 (0.0%)
Blade-like Flakes	7 (0.8%)	11 (0.8%)	2 (0.1%)
Blades	3 (0.3%)	1 (0.1%)	2 (0.1%)
Microblades	0 (0.0%)	3 (0.2%)	1 (0.1%)
Angular Shatter	9 (1.0%)	65 (4.9%)	78 (4.2%)
Subtotal	*870 (97.3%)*	*1300 (96.8%)*	*1835 (98.3%)*
Tools			
Bifaces	15 (1.7%)	10 (0.7%)	4 (0.2%)
Side Scrapers	0 (0.0%)	4 (0.3%)	3 (0.1%)
End Scrapers	0 (0.0%)	2 (0.1%)	1 (0.1%)
Burins	0 (0.0%)	1 (0.1%)	0 (0.0%)
Combination Tools	0 (0.0%)	1 (0.1%)	1 (0.1%)
Retouched Flakes	7 (0.8%)	5 (0.4%)	7 (0.3%)
Scraper on Cobble	0 (0.0%)	0 (0.0%)	1 (0.1%)
Planes	0 (0.0%)	3 (0.2%)	0 (0.0%)
Hammerstones	0 (0.0%)	6 (0.4%)	6 (0.3%)
Anvil	1 (0.1%)	0 (0.0%)	0 (0.0%)
Abraders	0 (0.0%)	1 (0.1%)	0 (0.0%)
Flaked Pebble	0 (0.0 %)	1 (0.1%)	0 (0.0%)
Subtotal	*23 (2.6%)*	*34 (2.5%)*	*23 (1.2%)*
Component Totals	***894 (100%)***	***1343 (100%)***	***1867 (100%)***

stone. In component 2 there were 9 cores, 1300 debitage pieces, and 34 tools. Cores

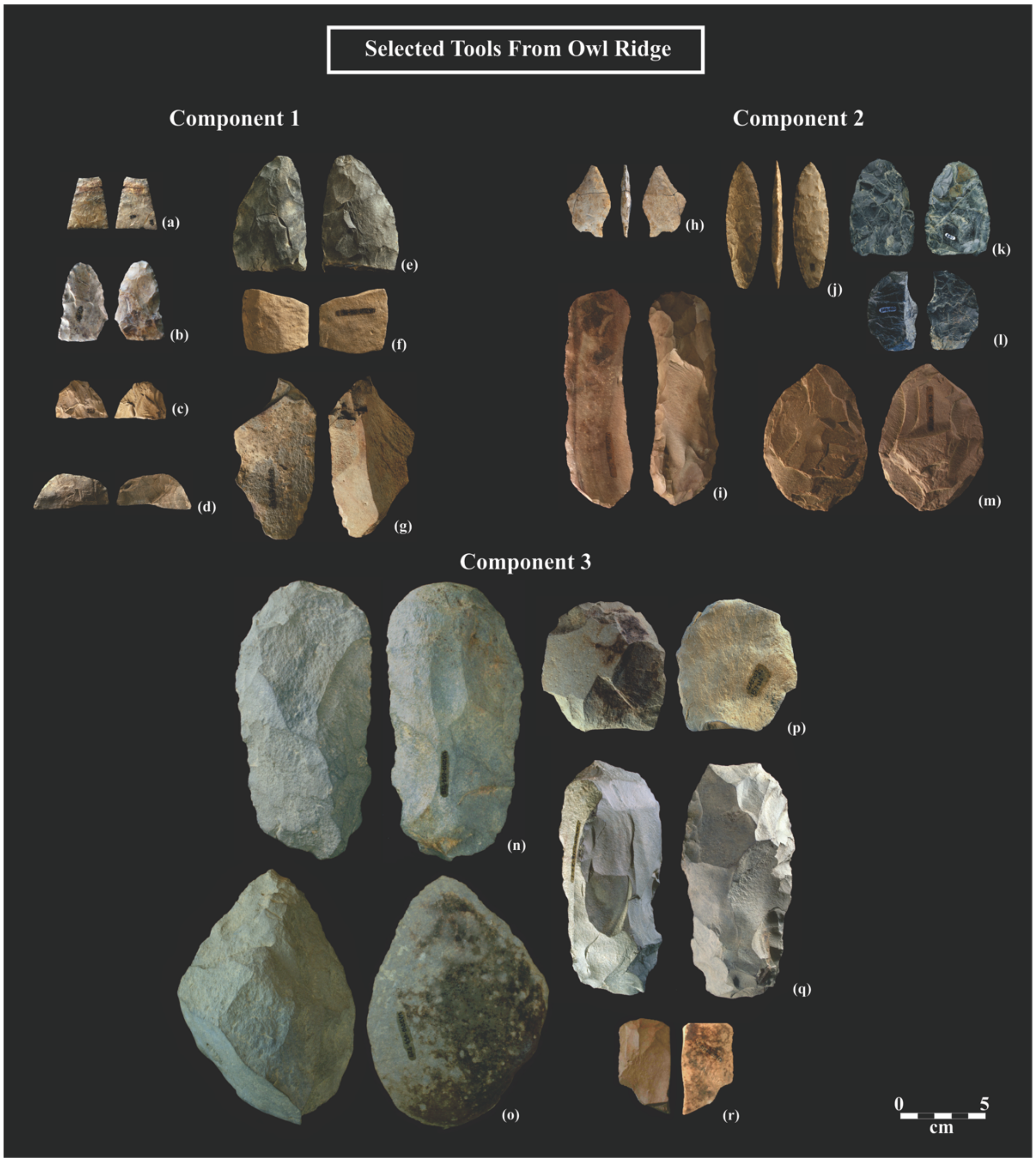

Figure 2.3. Representative sample of tools in each component at Owl Ridge. Component 1 artifacts shown include triangular shaped Chindadn point (a), bifaces (b-e), scraper fragment (f), and retouched flake (g). Component 2 artifacts include a concave-based point (h), double ended scraper (i), lanceolate point (j), bifaces (k, m), and retouched flake fragment (l). Component 3 artifacts include bifaces (n, q) an end scraper (r), a retouched flake (p), and a cobble-spall scraper (o).

included tested cobbles and unidirectional flake cores. Debitage consisted of cortical spalls, flakes and flake fragments, blade-like flakes, one proximal blade, microblades, microblade-reduction technical spalls, angular shatter, retouch chips, biface-thinning flakes, and one burin spall. Three lanceolate-shaped bifacial points made on biface tool blanks were identified in the tool assemblage. The rest of the tools included bifaces, a scraper-biface combination tool, side scrapers, end scrapers, a dihedral burin, retouched flakes, and cobble tools (scraper planes, hammerstones, and an abrader). In component 3, there were a total of 9 cores, 1835 debitage pieces, and 23 tools. Cores included tested cobbles, bidirectional flake cores, and a multidirectional flake core. Debitage included cortical spalls, flakes and flake fragments, a blade-like flake, a blade midsection, a microblade, angular shatter, retouch chips, and biface-thinning flakes. Tools consisted of bifaces, a scraper-biface combination tool, side scrapers, an end scraper, retouched flakes, a cobble-spall scraper, a cobble tool, and hammerstones.

2.4.2. Raw Material Procurement

2.4.2.1. Lithic Landscape

Today, the local lithic landscape within 5 kilometers surrounding the Owl Ridge site is characterized by glaciofluvial outwash terraces, alluvium and floodplain deposits of the Teklanika River and First Creek, and exposures of adjacent bedrock formations and associated colluvium. Bedrock formations include the Nenana Gravel formation, a Tertiary-aged conglomerate of ancient northern Alaska Range alluvium (Wahrhaftig 1958, 1970a), and the Metamorphic Rocks North of Fish and Panguingue Creeks (MRNFPC) formation complex primarily composed of schist and slate and presumed to date to the Paleozoic/Precambrian (Wahrhaftig 1970a). The site rests directly on the Healy glacial outwash terrace of the Teklanika River, presumed to date to MIS 3 or before (Wahrhaftig 1958; Thorson 1986; Dortch et al. 2010). Glacial outwash in this area contains gravels reworked from the Birch Creek formation in the Alaska Range and from both Nenana Gravel and MRNFPC formations in the foothills immediately nearby the site. Together the common rock types include gneiss, gabbro, diabase, andesite, basalt, quartz-sericite schist, quartzite, slate, and metachert (Wahrhaftig 1958, 1970a; Wahrhaftig and Black 1958).

A few dispersed basalt and rhyolite dikes, presumed to have formed during the early Tertiary, are mapped in the Birch Creek formation far upslope in the Alaska Range. Today, the nearest of these include several basalt dikes located about 30 km south of the site along the divide (western slope of Mt. Healy) between the Nenana and Teklanika Rivers (Wahrhaftig 1970a). The nearest rhyolite dikes are mapped about 31 km east of Owl Ridge at the headwaters of Eva Creek and 43 km southeast on Sugarloaf Mountain, both locations lie on the east side of the Nenana River (Wahrhaftig 1970b, 1970c). A raw material survey in the immediate vicinity of Owl Ridge during the 2007, 2009, and 2015 field seasons confirmed that all raw material classes discussed above are present in both the glacial outwash on-site and in the creek and river floodplain deposits near the site. These locally available stone clasts come in the form of well-rounded to sub-rounded small boulders, cobbles, and pebbles of more brittle stones (e.g., schist, slate, and metachert) found mostly in the small cobble to pebble sizes (Figure 2.1b).

2.4.2.2. Raw Material Variability

Raw material classes present in the Owl Ridge lithic assemblage in order of prevalence included andesite, CCS, MCS, basalt, rhyolite, and other toolstones such as quartzite, granodiorite, and greywacke (Table 2.2). Examining toolstone variability, two general patterns emerged. First, more artifacts were manufactured on andesite than all other raw materials combined, and its use dramatically increased through time. In contrast, the pattern is reversed for the next economically important raw materials. CCS and to a lesser extent MCS decreased in importance through time. Basalt and rhyolite show a similar relationship, where the use of basalt increased through time in tandem with andesite, but rhyolite use decreased through time, similar to CCS and MCS (Table 2.2).

Table 2.2. Toolstone variability by component.

Raw Material Class	Component 1	Component 2	Component 3	Total
CCS	308 (7.5%)	255 (6.2%)	91 (2.3%)	654 (16.0%)
MCS	209 (5.1%)	190 (4.6%)	95 (2.3%)	494 (12.0%)
Andesite	248 (6.0%)	734 (17.9%)	1241 (30.2%)	2223 (54.1%)
Basalt	37 (0.9%)	48 (1.2%)	256 (6.2%)	341 (8.3%)
Rhyolite	74 (1.9%)	3 (<0.1%)	46 (1.1%)	123 (3.0%)
Other	18 (0.4%)	113 (2.8%)	138 (3.4%)	269 (6.6%)
Total	**894 (21.8%)**	**1343 (32.7%)**	**1867 (45.5%)**	**4104 (100%)**

2.4.2.3. Raw Material Transport

We expect the presence of cobble cortex on specific raw material types to indicate these as local toolstones, whereas complete absence of cortex on specific raw material types establishes these as nonlocal toolstones. Table 2.3 illustrates the number of individual toolstones never expressing cortex by component and, therefore, the frequency of nonlocal toolstone types by component. Sixty percent of the toolstone types in component 1 are nonlocal varieties, 45% are nonlocal in component 2, and 34% are

Table 2.3. Frequency of toolstone types never expressing cortex.

Component	Total Number of Toolstone Types	Number of Toolstone Types Without Cortex
Component 1	35	21 (60%)
Component 2	31	14 (45%)
Component 3	38	13 (34%)

nonlocal in component 3. The number of nonlocal toolstones transported to the site decreased after initial occupation of the site.

Further examination of which of these toolstone types are local and nonlocal shows some varieties of CCS, MCS, and nearly all rhyolites were nonlocal (Figure 2.4), whereas all andesites and basalts were procured locally. Local toolstones dominated the Owl Ridge assemblage but there were differences through time (Figure 2.5). Though frequencies of nonlocal toolstones were low in all three components (12–1%), there were significantly more-than-expected nonlocal materials transported to the site by component 1 inhabitants and significantly less than expected procured by both component 2 and component 3 inhabitants. Together, raw material transport variables indicate site occupants became increasingly reliant on the procurement of local toolstones.

2.4.3. Raw Material Selection

2.4.3.1. Primary and Secondary Reduction Activities

Primary reduction activities dominated all three components with 71% of the component 1, 63% of the component 2, and 85% of the component 3 assemblages comprised of primary reduction pieces; however, there was more-than expected

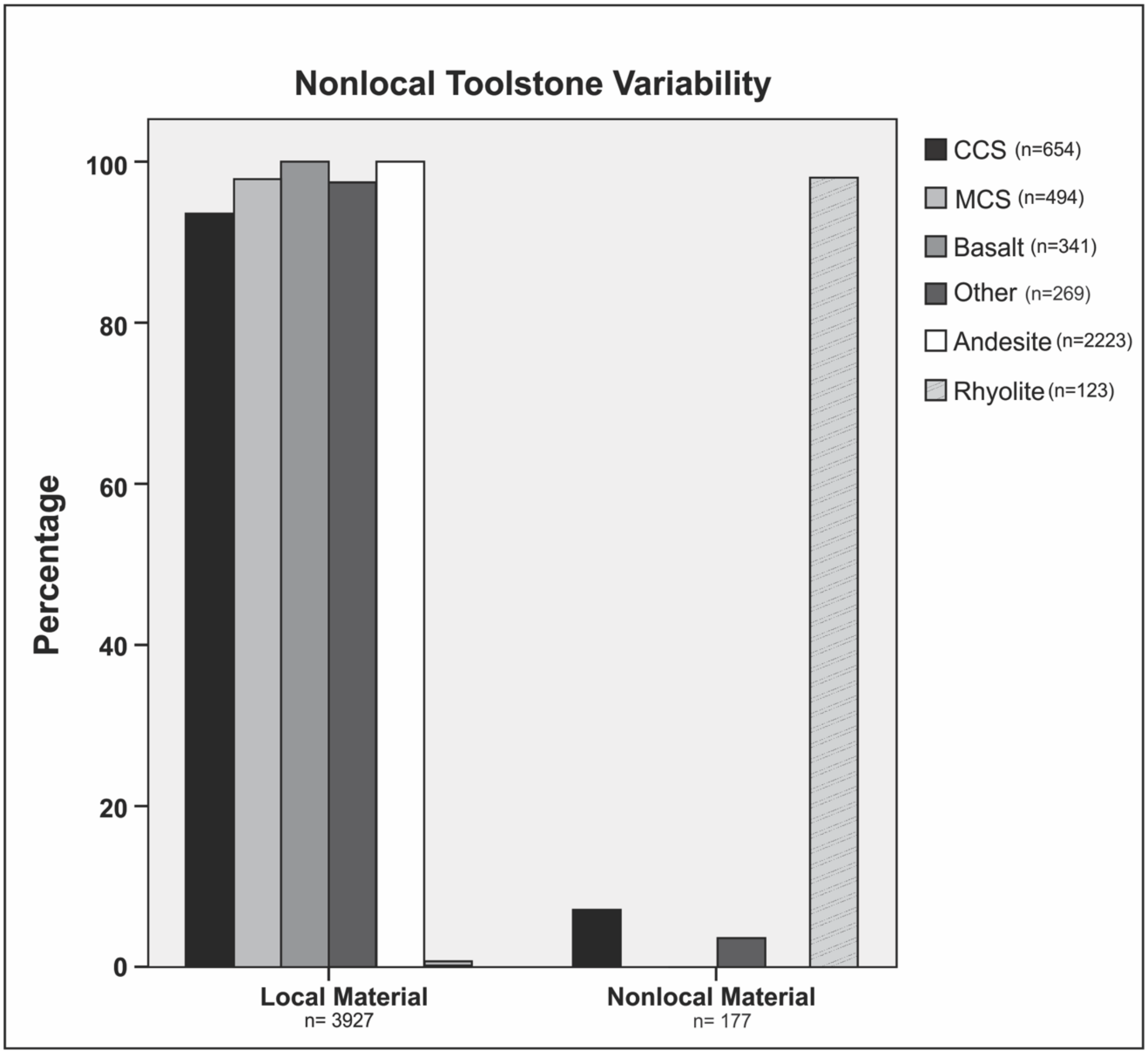

Figure 2.4. Bar chart expressing which toolstone types are local and nonlocal.

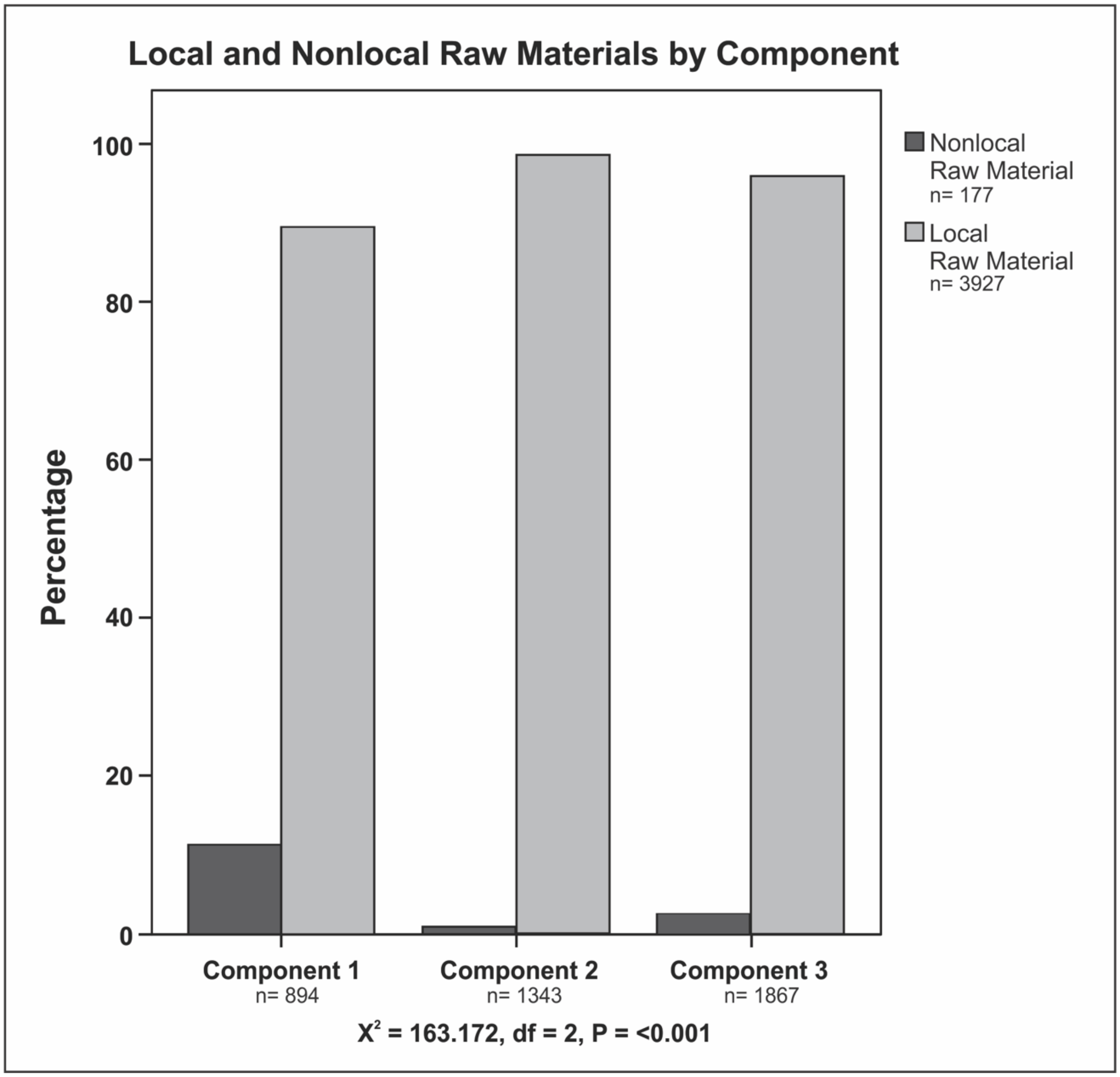

Figure 2.5. Bar chart showing local and nonlocal toolstones by component.

secondary reduction during the component 1 and component 2occupation episode but more-than-expected primary reduction during the component3 occupation (Table 2.4). Technological activities during the occupation events reflected by components 1 and 2 centered more on tool shaping and maintenance, while activities during component 3 occupation centered more on initial steps of tool-blank production.

Table 2.4. Primary and secondary reduction activities by component.

		Primary	Secondary	Total
Component 1	Count Expected Count % Total (within component)	627 662.1 (70.8%)	258 222.9 (29.2%)	885 885 (100.0%)
Component 2	Count Expected Count % Total (within component)	806 956.2 (63.1%)	472 321.8 (37.0%)	1278 1278 (100.0%)
Component 3	Count Expected Count % Total (within component)	1523 1337.7 (85.2%)	265 450.3 (14.8%)	1788 1788 (100.0%)
Total	Count Expected Count % of Total	2956 2956 (74.8%)	995 995 (25.2%)	3951 3951 (100.0%)
$\chi^2 = 202.935$; df = 2; $P < 0.001$. Note no (0.0%) cells have expected counts less than 5. The minimum expected count is 222.87.				

Generally speaking, chert (CCS and MCS) and/or fine-grained igneous (FGI) toolstones (basalt, andesite, and rhyolite) dominated both primary and secondary reduction activities in all three components (Figure 2.6), meaning higher-quality, fine-grained toolstones were selected over lower-quality, coarse-grained alternatives. Examining toolstone selection by component for primary versus secondary reduction, we found some interesting patterns. For primary reduction activities, cherts were selected more than expected compared with other toolstones and FGI in component 1, but during

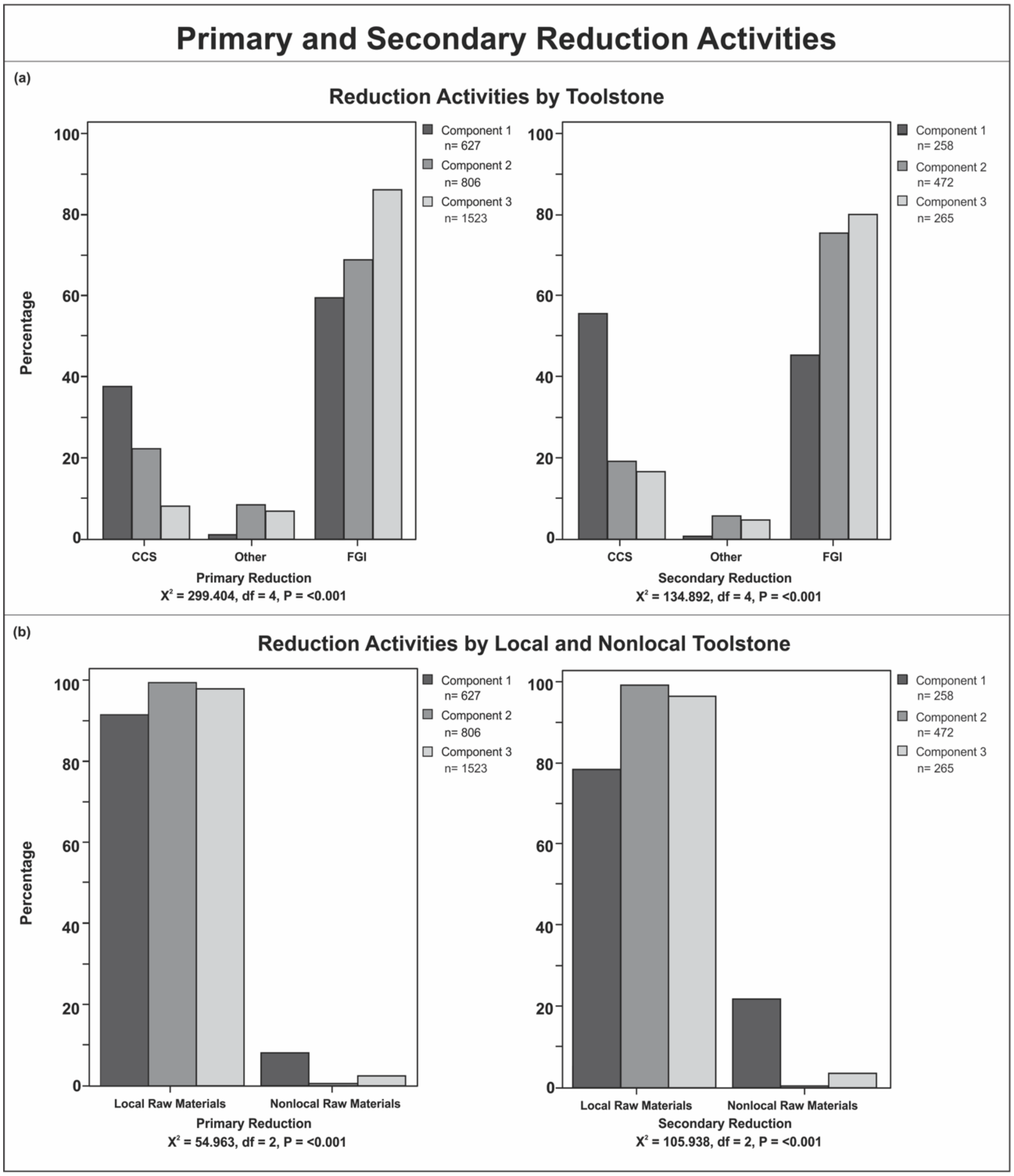

Figure 2.6. Primary and secondary reduction activities by toolstone types (a) and local and nonlocal toolstones (b).

the component 2 occupation, chert and other toolstones selected more than expected compared with FGI, and in component 3 other toolstones and FGI were selected more than expected compared with chert. For secondary reduction activities, component 1 occupants again preferred chert over the other toolstones, component 2 occupants preferred other toolstones and FGI over chert, and component 3 inhabitants selected FGI over the others. Through time, the importance of chert as a toolstone decreased and was eventually replaced by FGI.

When examining reduction activities by local versus nonlocal toolstones, component1 exhibited greater-than-expected selection of nonlocal toolstones for both primary and secondary reduction activities, whereas both components 2 and 3 evidenced greater-than-expected selection of local raw materials for both primary and secondary reduction (Figure 2.6b), indicating the use of more nonlocal toolstones during the initial site visit, especially for secondary reduction activities, compared with later visits to the site.

2.4.3.2. Formal and Informal Technologies

Comparing the frequencies of formal versus informal technologies, both components1 and 2 had more-than-expected formal technologies, whereas component 3had less-than-expected formal technologies (Table 2.5). Through time, more effort was spent on production and maintenance of informal technologies at Owl Ridge. Similar to reduction activities, formal and informal technologies were patterned toolstone selection (Figure 2.7). For formal technologies, chert was selected at the expense of the other toolstones in component 1, but during the component 2 and component 3 occupations, other toolstones were selected more than chert. For manufacturing informal activities, component 1 occupants again preferred chert over the other toolstones, but component 2

Table 2.5. Formal and informal technologies by component.

		Formal	Informal	Total
Component 1	Count	262	632	894
	Expected Count	221.3	672.7	894
	% Total (within component)	(25.8%)	(70.7%)	(100.0%)
Component 2	Count	481	862	1343
	Expected Count	332.5	1010.5	1343
	% Total (within component)	(35.8%)	(64.2%)	(100.0%)
Component 3	Count	273	1594	1867
	Expected Count	462.2	1404.8	1867
	% Total (within component)	(14.6%)	(85.4%)	(100.0%)
Total	Count	1016	3088	4104
	Expected Count	1016.0	3088.0	4104
	% of Total	(24.7%)	(75.3%)	(100.0%)
$\chi^2 = 201.044$; df = 2; P < 0.001. Note no (0.0%) cells have expected counts less than 5. The minimum expected count is 221.32.				

occupants selected both chert and other toolstones over FGI, and component 3 inhabitants preferred both FGI and other toolstones over the chert. Through time, Owl Ridge foragers came to prefer cherts less and FGI more. This is especially true for the production and maintenance of more formal technologies. Examining local versus nonlocal selection for production and maintenance of formal versus informal technologies, the main difference between components is nonlocal toolstones were preferred more for formal technologies by component 1 flintknappers, whereas for both components 2 and component 3 occupants preferentially selected local toolstones for both formal and informal technologies (Figure 2.7b).

2.4.3.3. Unifacial and Bifacial Technologies

There was no significant difference between the components in the production and maintenance of unifacial versus bifacial industries; however, component 1 had more bifacial and less unifacial technologies present compared with the other two components

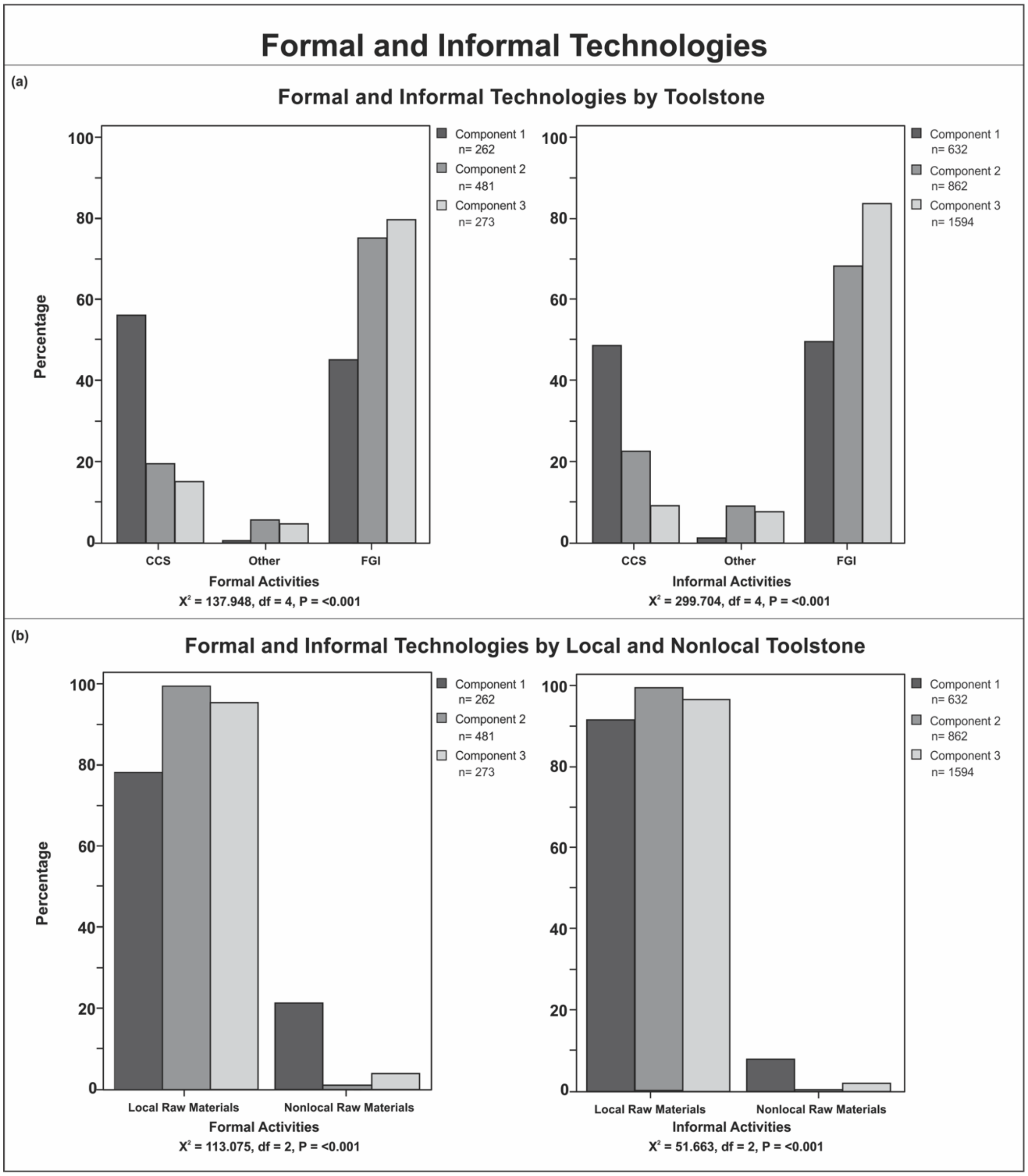

Figure 2.7. Informal and formal technologies by toolstone types (a) and local and nonlocal toolstones (b).

(Table 2.6). This pattern was upheld when looking at the number of bifacial tools relative to unifacial tools in Table 2.1. Toolstone selection for bifacial versus unifacial reduction was patterned (Figure 2.8). For bifacial technologies, both components1 and 2

Table 2.6. Unifacial and bifacial tool production by component.

		Unifacial	Bifacial	Total
Component 1	Count Expected Count % Total (within component)	119 128.3 (56.4%)	92 82.7 (43.6%)	210 210.0 (100.0%)
Component 2	Count Expected Count % Total (within component)	168 166.7 (61.3%)	106 107.3 (38.7%)	274 274.0 (100.0%)
Component 3	Count Expected Count % Total (within component)	154 146 (64.2%)	86 94.0 (35.8%)	240 240 (100.0%)
Total	Count Expected Count % of Total	441 441.0 (60.8%)	284 284.0 (39.2%)	725 725.0 (100.0%)
χ^2 = 2.888; df = 2; P= .236. Note no (0.0%) cells have expected counts less than 5. The minimum expected count is 82.65.				

evidenced greater-than-expected selection of chert over other toolstones, whereas component 3 evidenced greater-than-expected selection of FGI over the others. For unifacial reduction, component 1 had more-than-expected chert, component 2 had more-than-expected other toolstones, and component 3 preference was for FGI (Figure 2.8a). Similar to the other variables, these data indicate preference for chert in component 1 for both bifacial and unifacial reduction with an increased reliance on volcanic raw materials and other toolstones for production of all tool technologies in both components 2 and 3.

Exploring local versus nonlocal toolstone selection for bifacial and unifacial technologies, again we found similar patterning. For bifacial reduction, component1 had more-than-expected nonlocal toolstone and components 2 and 3 had more-than-expected local toolstones. For unifacial reduction, component 1 had more-than-expected nonlocal

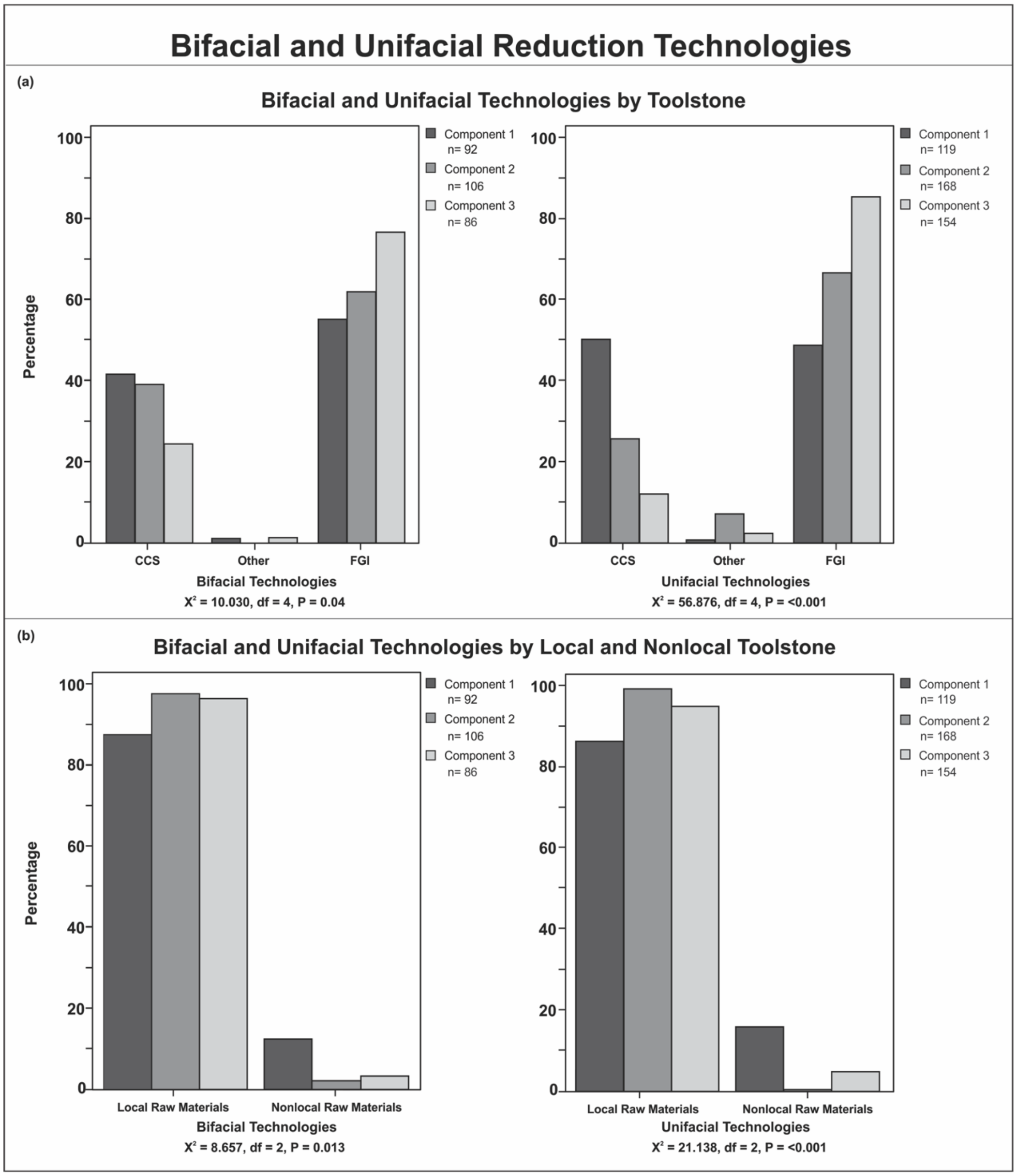

Figure 2.8. Bifacial and unifacial reduction technologies by toolstone type (a) and local and nonlocal toolstones (b).

toolstones, component 2 had more-than-expected local toolstones, and component 3 evidenced no selective differences between nonlocal and local toolstones (Figure 2.8b). During the component 1 occupation, there was clear preference for nonlocal toolstones for both bifacial and unifacial activities. For component 2, the preference was for local toolstones, and for component 3 there was a preference for local toolstones for bifacial reduction, but no clear preference in unifacial reduction.

2.5. Discussion

The goals of this study were threefold. We wanted to detect differences in toolstone procurement and selection behaviors between three temporally distinct cultural components at the Owl Ridge site. We also aimed to explore how these differences inform on lithic variability in Late Pleistocene-early Holocene archaeological sites in central Alaska. Finally, we wanted to understand how humans responded to global warming at the Pleistocene-Holocene boundary. Below we discuss findings of our study of the Owl Ridge lithic industries in the context of these goals.

2.5.1. Do Lithic Raw Material Procurement and Selection Behaviors Change Through Time at Owl Ridge?

The three cultural components at Owl Ridge have small artifact assemblages with low tool counts and diversity and the landform on which the site rests is very narrow (45 m wide). These factors, combined with lithic refit analysis, indicated the site was a repeatedly used logistical camp (Melton 2015). The site was used for special tasks and never as a long-term base camp location. We did not excavate the entire surface area; however, of the nearly 80 m^2 excavated, only 4327 artifacts were found in total. Despite the fact that the site served a similar purpose through time, data presented in this paper establish clear differences in the specific ways the site was used.

Beginning with component 1, we found the tools left behind were few but dominated by bifaces, including four triangular Chindadn points, and retouched flakes, indicating the site served as a hunting camp where hunted resources were procured and initially processed presumably for transport elsewhere. No extensive processing occurred at this time because few formal processing activities were represented. Technological activities centered on both primary and secondary reduction with greater focus on informal, expedient core reduction and both bifacial and unifacial tool production and maintenance. Component 1 hunters selected both nonlocal and local toolstones for all reduction activities but preferred chert, especially the nonlocal variety. They brought nonlocal toolstones with them, mostly as finished and formal tools that they refurbished, but they also procured some of the local toolstones found in the glacial outwash at the site or in floodplain deposits nearby. These toolstones were also used to manufacture tools transported away from the site, suggesting component 1 inhabitants retooled while visiting Owl Ridge.

The content of tools discarded during the component 2 occupation signals manufacture and maintenance of lanceolate bifacial points, scrapers, and other processing tools, suggesting component 2 occupants produced and maintained both a hunting and processing toolkit at the site. Very few nonlocal toolstones were carried to the site at this time. Mostly foragers procured locally available stones during their visit, arriving to the site nearly empty handed. Presumably, they took tools made on the local raw materials with them when they abandoned the site.

The artifact assemblage from component 3 indicates mostly primary reduction activities coupled with the manufacture and maintenance of unifacial tools. Therefore, site activities seem to be centered on processing behaviors. Different from component 1 but similar to component 2, toolstone procurement by component3 hunter-gatherers was mostly local; however, slightly more nonlocal toolstones make up the component 3 assemblage compared with component 2. Toolstone-selection variables indicate these hunter-gatherers focused on local FGI for all reduction activities, but again these activities concentrated on primary reduction and expedient tool production, behaviors differing from earlier visits to the site.

2.5.2. How Can We Explain Lithic Variability at Owl Ridge and in Central Alaska During the Late Pleistocene-Early Holocene?

Our results indicate toolstone procurement and selection changed through time at Owl Ridge. As the site was first visited during the late Allerød, just a few hunters carried with them lightweight, Chindadn-type projectile points and camped at this spot for a short period of time, given that only 894 artifacts make up the component1 assemblage. Perhaps they found the ridge provided an excellent lookout for fauna traversing this stretch of the Teklanika River Valley. To date, this occupation event represents the first known in the valley. Toolstone procurement and selection centered on both nonlocal and local toolstone. Hunters seem to have retooled with some local fine-grained chert and FGI resources. Our data suggest component 1 was a visit by foragers relatively unfamiliar with the local lithic landscape and, therefore, represents landscape learners in this specific context (Kelly 2003; Meltzer 2003).

About 500 years later the site was revisited by hunters using different hunting technologies, based on presence of lanceolate bifacial points and perhaps microblade-osseous composite projectile technology as microblades and two microblade-core technical spalls were also discovered in the component 2 assemblage. Component 2 occupants may have stayed longer at the site because both hunting and processing tools were made, refurbished, and discarded there. Procurement and preference for mostly local toolstones indicate they knew the lithic landscape better than initial visitors half a millennium earlier.

Component 3 represents the third and final visit to Owl Ridge about 200 years following component 2 and by a group focused even more on processing activities. Though one bifacial point and one microblade were found, the rest of the tool assemblage consists of various processing tools. Very similar to component 2, toolstone procurement and selection were almost exclusively local raw materials. We are certain that the foragers visiting Owl Ridge during this final, early Holocene occupation episode knew the local lithic landscape well because they preferred, and relied on, the local raw materials. Perhaps they came to Owl Ridge to procure and use andesite from the alluvium as well as capture and process food resources other than medium-large game, given the composition of their toolkit. Though speculative, these data may indicate that women used the site at this time, given that northern hunter-gatherer groups are known to focus primarily on hunted resources with men contributing most directly to hunting, and women engaging in tasks more supportive in nature, such as procuring smaller game, preparing food and other hunted resources, and mending or fixing tools (Halperin

1980; Jarvenpa and Brumbach 2006; Waguespack 2005) and processing activities were the focus during this final visit.

Our results indicate the behaviors responsible for production and maintenance of tool technologies and procurement and selection of toolstone during the component 2 and component 3 occupations were more similar to each other than either was to those reflected in the component 1 assemblage. We find that Phippen's (1988; Hoffecker et al. 1996) separation of components 1 and 2 into two temporally and technologically distinct complexes, Nenana and Denali, was warranted chronologically, descriptively, and behaviorally. Component 1 and components 2 and 3 represent two different toolstone procurement and selection strategies, one employed prior to the Younger Dryas l, and one immediately following it. This does not mean the site was visited by two different groups of people. Our data indicate Owl Ridge inhabitants became increasingly knowledgeable of their local (Teklanika valley) environment through time in a stepwise fashion. These changes reflect gradual behavioral adaptation by hunter-gatherers to their surroundings as they became part of a changing ecosystem responding to fluctuating terminal Pleistocene climatic conditions. We recognize the limitation of basing regional interpretations on analyses from a single site; however, this study is unique and future work considering additional sites should either support or refute our hypothesis.

2.5.3. How Did Central Alaskans Respond to Changing Environments at the Pleistocene-Holocene Boundary?

Climatic data for central Alaska indicates that between about 14,000 and 10,000 cal. BP, the region experienced several climatic shifts and associated environmental changes. In a nutshell, late glacial climate was first cold and dry, shifted to warmer and moister conditions during the Allerød, reversed to cool and arid conditions during the Younger Dryas, gradually warmed into the Holocene with the first Holocene millennium warm and arid, and increasingly warmer and wetter by the onset of the Holocene Thermal Maximum at ~10,000 cal. BP. During this 4000-year period, the biome shifted from herb tundra to shrub tundra to open-forest parkland to closed boreal forest.

Though our data at the Owl Ridge site are not robust enough to provide detailed answers to the question of how central Alaskans responded to Pleistocene-Holocene boundary climatic and environmental change, it does support findings in the Nenana valley of initial occupation of the Alaska Range foothills during the Allerød. In the Teklanika valley, they were beginning to learn the local lithic landscape when the Younger Dryas occurred. Given data from other sites in the region and Owl Ridge, these initial inhabitants were not manufacturing or maintaining lanceolate or microblade-composite spear technologies but using thin triangular-shaped and teardrop-shaped bifacial points as weapon tips (Powers and Hoffecker 1989; Goebel et al. 1991; Pearson 1999; Graf and Goebel 2009). Their technologies were relatively expedient and based on faunal data from the Broken Mammoth site in the Tanana Valley, foragers at this time were subsisting in a shrub-tundra biome, hunting a wide variety of small and large faunal resources (Yesner 2007).

Between about 13,000 and 12,500 cal. BP, the Younger Dryas cold and dry period is evidenced at regional archaeological sites by the appearance of culturally sterile sand units (Bigelow et al. 1990; Goebel et al. 1996; Graf and Bigelow 2011; Graf et al. 2015). This period of colder and drier climate affected the distribution and composition of floral and faunal resources, perhaps limiting availability of subsistence resources and the presence of humans. After this brief dry period, however, we see people using the region again. In fact, at Owl Ridge component 2 artifacts are found in a paleosol, indicating development of a relatively stable land surface and slightly moister conditions than during the previous centuries. The hunting technology, lanceolate bifacial points, and microblade-composite-tool technology was strikingly different from that used by initial inhabitants and suggests a focus on larger-game hunting (Guthrie 2006; Graf and Bigelow 2011). Paleoecological data are still too coarse-grained to understand faunal resource composition and availability for this period, but perhaps relatively dry conditions from the Younger Dryas still prevailed, and bison, wapiti, and caribou were sought after in an open-forest parkland environment (Guthrie 2006; Graf and Bigelow 2011). Certainly, the changes in toolstone selection represent an increased familiarity of the Teklanika valley as hunter-gatherers settled into the region.

Stratigraphically between components 2 and 3, the Owl Ridge profile evidences a major colluvial depositional event when humans were not present. Deposition of15–25 cm of colluvial sands in about 200 years indicates a brief period of torrential rains and likely relatively warm, wet conditions. Immediately following this, humans revisited the site one final time, but this time focused on other resources since they did not leave behind hunting tools as before. After 11,000 cal. BP as climate became even warmer and more humid, boreal-forest vegetation and biome spread into the region, and humans never returned to Owl Ridge. Perhaps the spread of the boreal-forest vegetation limited views from the site so that it no longer provided an overlook of the river valley to humans.

Through the Pleistocene-Holocene transition, evidence suggests humans were present at sites like Owl Ridge until boreal forest spread into the region. We contend terminal Pleistocene hunter-gatherers in central Alaska were reasonably resilient, only leaving the immediate foothills during the coldest several centuries of the Younger Dryas stadial. Given that occupation events immediately following the Younger Dryas evidence foragers with learned knowledge of the local lithic landscape, we assume these were the descendants of people who visited the Teklanika River before.

2.6. Conclusions

With this paper, we set out to compare the lithic assemblages of components 1, 2, and 3 from the Owl Ridge site to investigate how people were using lithic raw materials through time as they settled in the region and responded to climate change and local environmental shifts. The study of toolstone procurement and selection strategies helps us address how people responded to changing resource availability. Our results indicate that initial occupants were not as familiar with the local lithic landscape compared with later inhabitants. These later inhabitants had learned where to find local raw materials and obviously had become familiar with the landscape around them. Our findings confirm clear chronostratigraphic, technological, and land-use differences between Nenana complex and Denali complex assemblages in the greater Nenana valley. We conclude that the differences in toolstone procurement and selection strategies and organization of technologies observed at Owl Ridge represent increased landscape familiarity as people settled in the region and responded to changing environmental conditions at the end of the Pleistocene.

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3. RHYOLITE PROCUREMENT AND USE IN THE NENANA VALLEY, CENTRAL ALASKA

3.1. Introduction

The current archaeological record of human dispersal and settlement in Beringia is becoming increasingly complex. New paleogenomic studies confirm ancient Beringians arose from an Asian population, but specifics regarding the timing and dispersal of these populations leave us with more questions than answers when reconciling the archaeological and genetic records (Flegontov et al. 2019; Fu et al. 2013; Graf and Buvit 2017; He et al. 2012; Hoffecker et al. 2014; Moreno-Mayar et al. 2018a, 2018b; Raff and Bolnick 2014; Raghavan et al. 2014; Reich et al. 2012; Sikora et al. 2019; Skoglund et al. 2015; Wells et al. 2001). The earliest known and well-accepted archaeological sites in eastern Beringia post-date the hypothetical arrival of first Beringians predicted by geneticists. These sites, dating from about 14.2-12 thousand years ago (ka), express a complicated, highly variable lithic record. This pattern persists throughout the Holocene. Explanations of the variability are just as complicated, ranging from distinct human groups to site-function differences to changing responses to fluctuating climate and resource availability from the late Pleistocene through Holocene (Esdale 2008; Goebel and Buvit 2011; Gore and Graf 2018; Graf and Bigelow 2011; Hoffecker 2001; Holmes 2011; Mason et al. 2001; Odess and Rasic 2007; Potter 2008a, 2008b; Potter et al. 2014; West 1996; Wygal 2011). Agreement on the most plausible explanations, however, still eludes us (Goebel and Buvit 2011; Graf and Buvit 2017).

How did the earliest Beringians adapt to their surroundings as they arrived in interior Alaska and learned the landscape, and how did they respond to fluctuations in climatic regimes as they settled-in?

Because there is a rich record of archaeological sites in the Nenana River valley (herein referred to simply as the Nenana valley), this region provides an excellent case study for examining initial human dispersal and landscape learning in interior Alaska. All the valley's site assemblages consist of lithic artifacts; therefore, one of the best ways to address landscape learning behaviors in this context is to reconstruct the local lithic landscape by characterizing lithic raw material (toolstone) availability so that inferences about procurement can be made. This paper maps the rhyolite lithic landscape in the valley by presenting results of a detailed lithic raw material survey, geochemically characterizing samples from both rhyolite outcrops and dozens of alluvial collection locations and comparing these natural occurrences to rhyolite artifacts from several local sites to assess if, and to what degree, any of these potential source materials were used. The main objective is to map the rhyolite lithic landscape in the Nenana valley with the ultimate goal of explaining how humans used this resource when technologically provisioning, landscape learning, and settling into the uplands of interior Alaska.

3.2. Background

3.2.1. Settlement of Beringia

Despite recently developed models requiring a pre-14 ka presence in eastern Beringia, especially along a coastal route of migration, the interior Alaskan record still preserves the earliest unequivocal sites with well-stratified cultural components thought to be representative of the arrival of humans in eastern Beringia (Graf et al. 2015, 2020; Graf and Buvit 2017; Holmes 2011; McLaren et al. 2019; Potter et al. 2018). Many Beringian sites preserve cultural components spanning the Allerød, Younger Dryas (YD), Holocene Thermal Maximum (HTM) chronozones, and beyond into the middle Holocene, though Holocene-aged components in eastern Beringia are often underreported and understudied (but see Esdale 2008, 2009).

The earliest evidence of human occupation in Beringia comes from the middle Upper Paleolithic occupation at Yana RHS in northwestern Beringia, with stone and osseous implements dating to 33 ka (Pitulko et al. 2004, 2014, 2017; but see Pitulko et al. 2016). Though sites of similar age are found south and west of Yana in subarctic and arctic Eurasia (Graf and Buvit 2017; Pavlov 2017), the next-oldest Beringian site occurs much farther to the east at Swan Point (Holmes 2011; but see Bourgeon et al. 2017; Cinq-Mars 2001). Here in central Alaska, a late Upper Paleolithic occupation found in the lowest cultural zone, CZ4, dates to 14.2 ka and preserves wedge-shaped microblade cores and the microblades removed from them, which are meant for insertion into slotted bone tools (Gómez-Coutouly and Holmes 2018; Hirasawa and Holmes 2017; Holmes 2011). The intervening 19,000 years, when humans are conspicuously absent from the Beringian record, coincide with the last glacial maximum (LGM) or the last time glaciers were at their farthest extent and harsh climates severely constrained human settlement across the far north (Buvit et al. 2016; Clark 2009; Graf 2009; Graf and Buvit 2017; Hoffecker 2007; Tallavaara et al. 2015; Wren and Burke 2019; but see Hoffecker et al. 2016).

Following the climatic amelioration of the late glacial, humans began to re-settle Beringia, this time extending into Alaska. The sites of Berelekh, Nikita Lake, and Ushki Lake in northwestern and western Beringia have bifaces, blades, and distinctive teardrop-shaped and waisted bifacial points dating to 14.2-13 ka in their lowest layers. In several Tanana and Nenana valley sites the lowest archaeological layers contain teardrop and triangular-shaped projectile points similar to those found in western Beringia and not found with the microblade-bearing composite tool technology observed at Swan Point (Goebel et al. 1991; Goebel et al. 2003, 2010; Gore and Graf 2018; Graf et al. 2015, 2017, 2020; Graf and Bigelow 2011; Holmes and Hirasawa 2017; Pearson 1999; Pitulko et al. 2014, 2017; Potter et al. 2014; Younie and Gillispie 2016). These often-diminutive bifacial points are manufactured on flakes, sometimes with minimal bifacial retouch, distinguishing them technologically from other bifacial projectile points of terminal Pleistocene Beringia (Goebel et al. 1991), and perhaps suggesting their use was not always as weapons but also as processing tools (Goebel and Pontti 1991; Goebel and Potter 2016; Younie 2015).

At the onset of the YD at 12.8 ka (Gaglioti et al. 2017) and thereafter, a change in technological variability is evident across Beringia. In the Tanana valley lowlands of Alaska, sites exhibit biface-based assemblages consistent with those in the previous Allerød interstadial, while sites along the Alaska Range uplands in the Nenana, Tanana, and Susitna valleys, as well as at Ushki Lake in Kamchatka have a combined lanceolate bifacial projectile and wedge-shaped microblade-core industry, not unlike Diuktai during the late glacial in northeastern Siberia (Mochanov 1977) that also includes burins, side scrapers, and notches as part of the toolkit (Ackerman 2011; Dikov 1968; Goebel et al. 1991, 2003, 2010; Gore and Graf 2018; Graf and Bigelow 2011; Graf et al. 2015, 2020; Pearson 1999). Less than a millennium after the onset of the YD, fluted bifaces associated with other Paleoindian projectile point technologies appear across eastern Beringia from the Seward Peninsula to the Brooks Range (Buvit et al. 2019; Goebel et al. 2013; Kunz and Reanier 1995; Smith et al. 2014). Sites in interior Alaska dating to the HTM, 11.7 ka, contain only biface or flake-based toolkits (e.g., Carlo Creek), only microblade technologies (e.g., Little Panguingue Creek), or both microblades and bifaces (e.g., Dry Creek, Moose Creek, Owl Ridge) (Bowers 1980; Gómez Coutouly et al. 2019; Graf et al. 2020; Powers et al. 2017).

The early-to-middle Holocene record of eastern Beringia is as complex as the late glacial, with the emergence of notched projectile points across Alaska at sites like Onion Portage, Palisades, Tuktu, Landmark Gap, and others, found variably alongside burins, *tci-tho* scrapers, knives, microblade technologies, and stemmed, concave-based, and lanceolate bifacial points (Hare et al. 2004, 2012; Rasic 2011). Much like industries from previous millennia, middle Holocene sites preserve little fauna and are largely lithic except for the Agiak Lake and Pond sites that preserve caribou bones and drive lines (Ackerman 2004; Anderson 1968a, 1968b, 1988; Esdale 2008; Giddings 1964; Giddings and Anderson 1986; Potter 2007, 2008a, 2008b; Rasic and Slobodina 2008). Beyond application of the broadly descriptive "mobile hunter-gatherer," these data do not currently identify major shifts or patterns in adaptive strategies, mobility, land-use, and technological choices that accompanied humans as they continued to make their living during the Holocene (Esdale 2008, 2009; Potter 2008a, 2008b).

The eastern Beringian record is complex, variable, and in some regions and periods, underreported. Thus, we do not currently have detailed understanding of specific social, economic, and environmental adaptive processes undertaken by human settlers on the landscape. Because the archaeological record of interior Alaska is largely lithic, studies of technological organization, such as raw material use, must be undertaken to investigate past human behaviors (Gore and Graf 2018; Graf and Goebel 2009; Kuhn 1995, 2004; Nelson 1991). While raw material procurement was likely embedded within other resource-specific tasks to reduce risk and energy costs (Binford 1979, 1980), quality toolstone was a valuable and important economic resource to ancient humans because it significantly shaped life decisions (Andrefsky 1994a, 2009; Braun 2004; Elston 2013; Gould and Saggers 1985; Surovell 2009).

Toolstone procurement strategies are influenced by a complex array of variables such as technological goals (e.g., portable cores, planned and curated or expedient tools), mobility levels, raw material availability and accessibility, nodule size, knappability, distance-to-source, ease of embedding into larger resource-use strategies, and social and political factors (e.g., exchange and territoriality) (Andrefsky 1994a, 2009; Bettinger 1987; Binford 1979, 1980; Blades 1999; Blumenschine et al. 2008; Ford 2007, 2011; Kuhn 2020; Rockman 2003; Surovell 2009). Because acquiring raw materials for toolkit-use likely played a large role in hunter-gatherer lifeways, understanding the distribution, abundance, and properties of toolstones on a landscape is important in reconstructing overall adaptive strategies (Andrefsky 1994a; Bamforth 1986; Graf and Goebel 2009).

3.2.2. Establishing the Nenana River Valley Lithic Landscape

As humans settle into unknown environments, they must discover and familiarize themselves with resource patches to exploit them. How did initial inhabitants of the NRV provision themselves on the "lithic landscape," and how did behavioral strategies change as humans adapted to this landscape? I am interested in these large research questions, particularly in contributing to the identification of potential sources of known lithic materials in the region to essentially map the lithic landscape of this key area. A lithic landscape may be defined as the physical distribution of available and usable materials in a given area (Gould and Saggers 1985). Effectively defining the layout of the Nenana valley's lithic landscape provides a baseline of the availability of local toolstones. With this baseline established, we may employ both qualitative and quantitative analyses to deduce which toolstones are local or exotic to comprehensively describe past toolstone procurement and selection strategies (Ford 2011; Graf and Goebel 2009). The overarching goal of this paper is to contribute to building lithic landscape knowledge through a focus on archaeological rhyolites, an important toolstone used in the region.

Advances in understanding Beringian raw material procurement have been made mostly through regional obsidian studies (Cook 1995; Goebel et al. 2008; Grebbenikov et al. 2018; Reimer 2015; Reuther et al. 2011; Slobodina 2009; Speakman et al. 2005, 2007); however, obsidian artifacts are rare in assemblages across the interior, especially within the Nenana valley. Though yielding valuable information, efforts focused only on one type of a rare toolstone provide a limited view of the range of raw material activities represented in an entire lithic assemblage. The archaeological record shows that once arriving in the valley, humans relied upon fine-grained volcanic materials (FGVs) such as basalt, andesite, dacite, rhyolite, and obsidian as well as other rock types (e.g., cherts, chalcedonies, and quartzites) to make their toolkits (Bowers 1980; Coffman and Rasic 2015; Gómez-Coutouly et al. 2019; Gore 2021; Gore and Graf 2018; Graf and Goebel 2009; Powers et al. 2017; Pearson 1999). Cherts have been investigated in the Brooks Range (Malyk-Selivanova et al. 1998) and southeastern Alaska (Lawler 2019), but aside from these studies, relatively few specific source regions are known and described in detail (Gore 2021; Graf and Goebel 2009).

Artifacts produced on FGV toolstones are amenable to geochemical sourcing analysis, making them useful proxies in studies of procurement and mobility (Phillips and Speakman 2009; Shackley 1992b, 2011). The application of non-destructive geochemical methods such as pXRF has long been employed to investigate the movement of obsidians in Beringia (Goebel et al. 2008; Reuther et al. 2011), but geochemical analysis of other archaeologically abundant materials is still in its infancy, especially in interior Alaska (Coffman and Rasic 2015; Gore 2021; Lawler 2019). Knowledge of non-obsidian FGV toolstones has been limited, with intermediate and mafic volcanics minimally considered (but see Gore and Graf 2018), despite their prevalence in the record of interior Alaska and potential to inform on prehistoric landscape use within the region (Gore 2021; Graf and Goebel 2009; Graf et al. 2015, 2020). Important first steps at characterizing the distribution and nature of rhyolite artifacts in the interior were recently undertaken by Coffman and Rasic (2015), who were the first to characterize rhyolites present in interior Alaskan archaeological assemblages using pXRF geochemistry. Here, a rhyolite group is defined as a geochemically similar grouping of artifacts in which specimens share similar trace-element signatures, and therefore, presumably originate from the same toolstone source. Coffman and Rasic (2015) identified 10 geochemically distinct groups and called for an increase in additional raw materials survey and geochemical studies to locate geographic sources for rhyolite groups. This paper builds upon Coffman and Rasic's previous study (2015) by replicating rhyolite groups present in a region-specific context, but it goes beyond this study by adding new groups to the list and quantitatively linking, through geochemical analysis, geographic source locations to some of these rhyolite groups as well as considering how rhyolite transport can explain hunter-gatherer provisioning and landscape learning behaviors in the region.

As climate fluctuated from the late glacial to Holocene and eastern Beringian landscapes changed, humans had to respond to shifting resource availability (e.g., water, toolstones, and animals). Climate warmed and precipitation increased during the HTM, and the encroaching boreal forest may have obscured or otherwise hindered access to previously important toolstone resources such as rhyolite, and/or significantly affected land-use strategies by re-organizing or redistributing food resources impacting access to lithic resources. Here, I seek to investigate whether such situations may be evident in patterns of rhyolite use in the Nenana valley, building upon previously conducted raw material studies in the region.

3.3. Materials

3.3.1. The Nenana River Valley and its Geology

The Nenana River is a northward-flowing tributary of the Tanana River, bisecting the Alaska Range before flowing through foothills and flats and debouching into the Tanana. Here, the extent of the Nenana valley encompasses the Nenana River watershed, bounded by Broad Pass and the Reindeer Hills to the south, the Teklanika River basin to the west, the Wood River basin to the east, and the confluence of the Nenana and Tanana rivers near the city of Nenana to the north. Apart from a handful of sites located within the Alaska Range, archaeological sites in the Nenana valley are concentrated within the northern foothill zone extending approximately 30 km beyond the front of the Alaska Range and situated within a series of loess sequences and aeolian deposits atop glacial outwash terraces (Powers and Hoffecker 1989; Ritter 1982; Thorson and Hamilton 1977; Wahrhaftig 1958).

The hard-rock geology of the valley, located in the central Alaska Range as well as surrounding foothills, is complex and diverse (Csejtey et al. 1986; Wahrhaftig 1953, 1970a, 1970b, 1970c; Wahrhaftig et al. 1969) and has been studied since the mid-20th century because of mining activities and railroad construction. As such, areas beyond the railroad corridor and outside of the mines are largely generalized and limited to non-specific formation descriptions (Cameron et al. 2015; Csejtey et al. 1986; Wahrhaftig 1953, 1970a, 1970b, 1970c, 1987; Wahrhaftig et al. 1969; but see Albanese 1980).

Rocks in the valley downstream from the mountain and foothill slopes are found as cobbles and boulders in Pleistocene-aged glaciofluvial outwash terraces and Holocene-aged alluvium and floodplain deposits of the Nenana River and its tributaries. Bedrock formations include the early Pleistocene-aged Nenana Gravel primarily composed of sandstones, conglomerates, granites, schist, and other intrusive rocks abundant in the Alaska Range (Sortor et al. 2021; Wahrhaftig 1958; Wahrhaftig et al. 1969). To the north, the main formation is the Middle Devonian-aged Totatlanika Schist consisting of metavolcanics, schists, and gneisses (Csejtey et al. 1986, 1992). Running east to west, the Paleozoic-aged Keevy Peak formation is composed of meta-sedimentary and meta-igneous rocks including quartzites, quartzes, schists, slates, and interbedded marble (Athey et al. 2006; Csejtey et al. 1992; Frost et al. 2002; Wahrhaftig 1968). Running east to west in the southern portion of the valley, the Cantwell formation is a Paleocene to Late Cretaceous sequence of mudstones, sandstones, conglomerates, coals, andesites, basalts, and rhyolites (Csejtey et al. 1992; 1986; Gilbert et al. 1976; Wolfe and Wahrhaftig 1970). To the south, west, and north, portions of the Paleozoic Birch Creek Schist formation are mapped (Albanese 1980; Csejtey et al. 1992; Wahrhaftig 1970a, 1970b, 1970c); this formation extends to the Yukon-Tanana uplands north of the Tanana River and is comprised of schists, quartz-sericite schists, and quartzites (Csejtey et al. 1992; Wahrhaftig 1953, 1970a, 1970b, 1970c).

Surface geography of the valley is diverse in igneous formations and intrusions (Clautice et al. 1999; Csejtey et al. 1986, 1992; Nye 1978; Wahrhaftig 1953, 1970a, 1970b, 1970c; Wahrhaftig et al. 1969; Wilson et al. 1998). Igneous rock types, from hornblende andesites, basaltic lapilli, cinders, and bombs to diabase and rhyolite outcrops, have been recorded in the valley over the past several decades (Albanese 1980; Albanese and Turner 1980; Frost et al. 2002); however, most are only generally described and not mapped in geological detail (Albanese and Turner 1980; Csejtey et al. 1992; Robinson et al. 1990; Wahrhaftig et al. 1953). Despite this, several specific rhyolite outcrops are known within the Alaska Range including in the headwaters of Eva Creek, on Sugarloaf Mountain, and inside Denali National Park and Preserve (DENA) (Csejtey et al. 1986; Gilbert et al. 1976; Nye 1978; Thornberry-Ehrlich 2012; Wahrhaftig 1953, 1970a, 1970b, 1970c; Wahrhaftig et al. 1969).

3.3.2. Archaeological Sites in the Nenana Valley

The Nenana valley has an abundance of well-stratified sites with preserved lithic assemblages whose occupations date from the late glacial through the Holocene, providing an appropriate area to investigate questions regarding shifts in lithic resource procurement and land-use strategies in response to landscape learning and climate change. Most archaeological sites in the valley are situated on top of the Pleistocene-aged Healy glacial-outwash terrace overlooking waterways, and many contain multiple cultural occupations with dates ranging from the late Pleistocene to the late Holocene (Hoffecker and Elias 2007; Powers and Hoffecker 1989; Ritter and Ten Brink 1986; West 1996). I analyzed the lithic artifact assemblages in the valley to compare to materials encountered during raw material survey to identify toolstone sources utilized in prehistory. Nineteen lithic assemblages come from 10 archaeological sites: Owl Ridge, Dry Creek, Walker Road, Moose Creek, Panguingue Creek, Eroadaway, Carlo Creek, Little Panguingue Creek, Teklanika West, and Houdini Creek (Figure 3.1). The ages of each archaeological component (e.g., Dry Creek C1) are presented in Table 3.1. Most of these site components are well-dated, though some (e.g., Moose Creek C4 and Carlo Creek C2) have no radiometric dates. These were assigned age estimates based on stratigraphic position to dated stratigraphy and cultural occupations, volcanic tephras, and regional valley stratigraphy (Bowers 1980; Pearson 1999). Seven assemblages (Owl Ridge C1, C2, C3; Dry Creek C1, C2, C4 materials from 2011 excavations; Little Panguingue Creek) were analyzed at the Center for the Study of the First Americans, Texas A&M University and 14 assemblages (Dry Creek C1, C2, C4 materials from 1970's-80's excavations; Panguingue Creek C1, C2, C3; Houdini Creek; Teklanika West C3; Walker Road; Moose Creek C1, C2, C3, C4; Carlo Creek C2; and Eroadaway) were analyzed at the University of Alaska Museum of the North.

3.4. Methodology

3.4.1. Rock Survey and Collection of Geological and Archaeological Samples

3.4.1.1. Field Survey

This study draws upon data from an extensive, multi-year raw material survey conducted from 2014-2017 to derive the presence and extent of both outcrop and alluvial locations of knappable lithic materials and their proximity to known archaeological sites in the valley (Figure 3.1). The survey area extends from Rex Bridge in the north to Windy Creek in the south and from the Teklanika River in the west to California Creek in the east, including several focused areas of survey. I recorded rhyolite outcrops within the

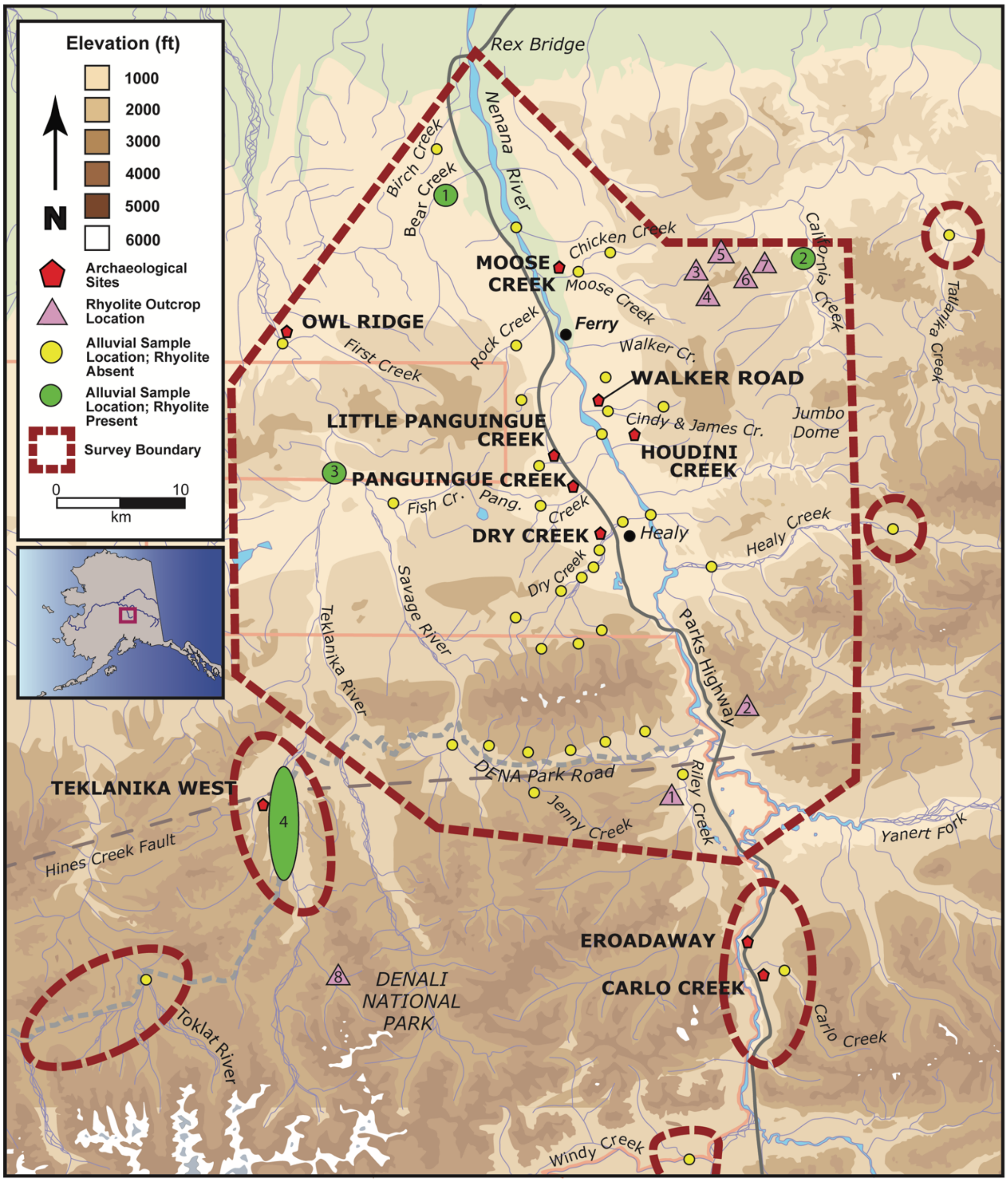


Figure 3.1. Map of archaeological sites, sample locations, and survey boundaries in the Nenana River Valley. Rhyolite outcrops: 1: Triple Lakes; 2: Sugarloaf Mountain; 3: Ferry 1; 4: Ferry 2; 5: Ferry 3; 6: Ferry 4; 7: Ferry 5; and 8: Calico Creek rhyolite (approximate location reported by Coffman and Rasic [2015]; this location was not sampled during survey). Rhyolite alluvial samples: 1: Bear Creek; 2: California Creek; 3: Savage and Teklanika Confluence; 4: Teklanika River. Adapted from Gore and Graf 2018.

Table 3.1. Radiocarbon dates for site assemblages from the Nenana valley used in this study.

Site Assemblage	Artifact Sample (n = 675)	Calibrated Date (ka BP)[1]	Radiocarbon Dates	Reference
Dry Creek C1	48	13.5-13.3 ka	11,510 ± 40 (UCIAMS-135114) 11,530 ± 50 (BETA-315411) 11,580 ± 40 (UCIAMS-135113) 11,635 ± 40 (UCIAMS-135112)	Graf et al. 2015
Walker Road	98	14.1-13.3 ka	11,820 ± 200 (BETA-11254) 11,010 ± 230 (AA-1683) 11,170 ± 180 (AA-1683) 11,300 ± 120 (AA-2264)	Goebel et al. 1996; Hamilton and Goebel 1999
Moose Creek C1	22	13.2-13.0 ka	11,190 ± 60 (BETA-96627)	Pearson 1999
Owl Ridge C1	31	13.3-12.8 ka	11,060 ± 60 (AA86969)	Graf et al. 2020
Eroadaway	8	12.9-12.5 ka	10,890 ± 40 (BETA-24155) 10,570 ± 50 (BETA-368365)	Holmes et al. 2018
Moose Creek C2	14	12.7-12.5 ka	10,500 ± 60 (BETA-106040)	Pearson 1999
Owl Ridge C2	33	12.5-11.4 ka	10,485 ± 25 (UCIAMS-71261) 10,420 ± 60 (AA-86960) 10,340 ± 75 (AA-86963) 10,020 ± 40 (BETA-289382)	Graf et al. 2020[2]
Panguingue Creek C1	4	12.2-11.4 ka	10,180 ± 130 (AA-1686) 9,836 ± 62 (GX-17457)	Goebel and Bigelow 1992
Owl Ridge C3	33	11.3-11.2 ka	9,880 ± 40 (BETA-330172) 9,790 ± 40 (BETA-289379)	Graf et al. 2020
Dry Creek C2	127	11.1-10.4 ka	9,480 ± 35 (UCIAMS-135115) 9,460 ± 40 (BETA-315410)	Graf et al. 2015

Table 3.1 Continued

Site Assemblage	Artifact Sample (n = 675)	Calibrated Date (ka BP)[1]	Radiocarbon Dates	Reference
Little Panguingue Creek C2	30	9.6 ka	8,620 ± 40 (Beta-431673)	Gómez-Coutouly et al. 2019
Panguingue Creek C2	52	9.0 - 8.4 ka	7,850 ± 180 (BETA-15093) 7,130 ± 180 (BETA-15094) 7,430 ± 270 (AA-1688) 7,595 ± 405 (GX-13012)	Powers and Maxwell 1986; Goebel and Bigelow 1996
Houdini Creek	42	8.8 ka	7,880 ± 60 (Beta-74737)	Potter et al. 2007
Teklanika West C3	32	7.7 - 7.5 ka	6,770 ± 50 (BETA-276455) 7,030 ± 40 (BETA-292107) 7,330 ± 40 (GX-18518)	Coffman 2011; Goebel 1996
Carlo Creek C2	26	7.5 – 6.0 ka	--	Bowers 1980
Moose Creek C3	8	6.6 - 6.4 ka	5,680 ± 50 (BETA-106041)	Pearson 1999
Panguingue Creek C3	4	6.4 ka	4,510 ± 95 (GX-13011) 5,620 ± 65 (SI-3237)	Powers and Maxwell 1986
Moose Creek C4	24	6.4 - 4.0 ka	--	Pearson 1999
Dry Creek C4	39	3.9 - 3.5 ka	3,430 ± 75 (SI-2332) 3,655 ± 60 (SI-1934) 4,670 ± 95 (SI-1937)	Powers et al. 2017

[1]Radiocarbon date ranges calibrated using Reimer (2020) calibration curve in OxCal online software.
[2]Representative dates selected; for full list of all dates, see Graf et al. 2020.

drainages, and rivers) within the survey boundaries to identify the locations of potential sources for rhyolite artifacts found in the archaeological assemblages in the valley. Outcrop collection locations include lithic deposits occurring as *in situ* outcrops from bedrock, previous lava flows, or intrusive sills, while alluvial collection deposits include reworked, erosional, and/or redeposited lithic materials such as glacial till and streambed gravels (Glascock et al. 1998). At each alluvial collection location, a 1-x-1-m square was laid out, and each rock found within the square and measuring > 1 cm in maximum linear dimension was tallied to record total makeup of alluvium represented at that location. All rhyolite materials within the square were collected for geochemical analysis. Each alluvial location was further subjected to pedestrian survey of an area of no less than 500 m both downstream and upstream of the collection square. Supplementary toolstones were recorded to provide an additional means of characterizing available toolstones in each waterway.

Selection of sampling locations was directly informed by extant geologic maps of the valley and locations of known archaeological sites. All *in situ* outcrops sampled were located using geologic maps, and at least 20 samples were collected from each outcrop (with rock hammers and sledge) for geochemical pXRF analysis (following Glascock et al. 1998; Shackley 2008). In alluvial locations, 20 samples of rhyolite were collected if present, though the rarity of these rocks in some locations limited the number of collected specimens to < 20.

3.4.1.2. Artifact Sample Selection

The rhyolite artifact sample selected for geochemical comparison with geological samples numbered 675 specimens. Prior to selection, all artifact assemblages were subjected to basic lithic technological analysis in which artifact class and type, raw material class and type, cortex amount, and artifact size class were scored (Appendix A). For each site assemblage, rhyolite artifacts were chosen for geochemical study based on these variables so that a representative sample was selected to ensure distant rhyolite sources would not be underrepresented (Eerkins et al. 2007). A minimum of 20 samples for each assemblage was attempted, though sample numbers vary per site due to low rhyolite density in the assemblage (e.g., Moose Creek C2 and C3 [Pearson 1999]) or absence of secure provenance information of an assemblage (e.g., Panguingue Creek C1 and C3 [Powers and Maxwell 1986]).

3.4.2. Geochemical Analysis

3.4.2.1. Collecting the Geochemical Data

Geochemical analyses were conducted using a portable Bruker Tracer III-V energy dispersive X-ray fluorescence spectrometer equipped with a rhodium (Rh) tube and a silicon PIN diode detector owned by the Center for the Study of the First Americans, Texas A&M University, operating at 40kV and 40μA from an external power source. All selected samples exceeded 3 mm in thickness, and were placed with the flattest, cleanest surface directly in front of the instrument window to allow full exposure to X-rays during sampling (Hughes 2010). Each sample was run for 180 live count seconds, the minimum amount necessary for accurate elemental counts for FGV materials (Fertelmes 2014). Bruker's 6-mil Cu (copper), 1-mil Ti (titanium) and 12-mil Al (aluminum) filter was placed in the beam path to concentrate on mid-range elements well-suited for the characterization of obsidian, rhyolites, and other fine-grained volcanics (following Coffman and Rasic 2015; Ferguson 2012; Grave et al. 2012; Palumbo et al. 2015; Reimer 2018). Nine elements were measured, including Manganese (Mn), Iron (Fe), Gallium (Ga), Thorium (Th), Rubidium (Rb), Strontium (Sr), Yttrium (Y), Zirconium (Zr), and Niobium (Nb). X-ray counts were processed using the S1PXRF program provided by Bruker, and peak intensities of these elements were calculated as ratios to the Compton peak of Rhodium (Rh) and converted to parts per million (ppm) counts using Bruker's S1CalProcess. This program converts measurements to elemental concentrations derived from known values of forty obsidian and other FGV standards, cross-checked by neutron-activation analysis (NAA) and inductively-coupled mass-spectrometry (ICP-MS) conducted the University of Missouri Nuclear Reactor (MURR) (Ferguson 2012; Speakman 2012).

3.4.2.2. Analyzing the Geochemical Data

Geochemically based rhyolite groups of both geological samples and archaeological samples were identified using exploratory approaches (e.g., multivariate principal components analysis, scatter plot matrices, and elemental biplots) following Glascock et al. (1998). These approaches were performed using MURRAP statistical routines and GAUSS runtime software, an open-source program available from the University of Missouri Archaeometry Laboratory (https://archaeometry.missouri.edu/gauss.html). Before analysis of the data was performed, elemental measurements with zero values were replaced with a constant value 65% of the detection limit of the given element, then all elemental measurement values were log transformed (base 10) to control for variability in magnitude between measurements of elements (following Aitchinson 1999; Glascock et al. 1998; Lubbe et al. 2021). Statistical operations relied on the use of mid-Z elements commonly employed in obsidian and FGV sourcing studies (Sr, Rb, Y, Zr, and Nb) to define initial clusters because they are appropriate for sourcing volcanic materials and accurately measured by pXRF instruments (Grave et al. 2012; Shackley 1988).

Examination of the geochemical data included in this paper was done in four parts. First, outcrops were examined to determine the degree to which they could be differentiated from each other. Second, outcrops were compared to alluvial rhyolite samples to determine geochemical relatedness (i.e., whether rhyolite visible in the alluvium today originated from these outcrops). Third, artifact samples were analyzed to assess if rhyolite groups (i.e., groupings of rhyolite artifacts geochemically related and likely originating from the same source) exist, following Coffman and Rasic (2015). Finally, fourth, artifact rhyolite groups were compared to the outcrop and alluvial geological samples to determine if there are any matches, thereby, identifying likely sources. In this study, a "source" is a geochemically characterized rock with a known geographical location, either an outcrop, set of outcrops, and/or alluvium in a streambed, that shares its geochemical signature with artifacts (Ozbun 2015; Shackley 2008).

The formation of rhyolite groups and subsequent comparisons of these groups with geological samples were conducted in two stages. First, groups were explored by performing a principal components analysis (PCA) on the variance-covariance matrix of the data helping to define initial clusters, then values for the first five principal components were plotted in bivariate and trivariate plots to identify discrete clusters of artifacts. These were initially placed together in groups. Confidence ellipses for each preliminary group were calculated at 90%, representing probability intervals surrounding each group, drawn at a constant Mahalanobis distance (MD) from each group centroid. Unassigned artifacts were then plotted against these preliminary groups, and those that fell within a 90% confidence ellipse around a given group were included in that group.

With each artifact addition or removal, a new group centroid was calculated, producing a new confidence ellipse for comparison with the data. This process was repeated until no additional samples could be added or removed from artifact groups. Second, provisional artifact groups based on the PCA results were then re-examined under the same analytical protocol using bivariate plots of logged raw compositional data (ppm) to verify specimen inclusion within artifact groups. Artifacts were added to or removed from identified groups if necessary. If group membership for a sample was ambiguous even after examining bivariate plots of principal components and logged elemental concentrations, the group membership probabilities for that specimen were calculated. This calculation is based on the MD distance of each sample to the constructed reference groups, with samples jackknifed from each reference group before distance and probability calculations were made. The artifact in question was removed or added to the group based on this calculation. The observation and construction of geochemical groups matching those previously identified by Coffman and Rasic (2015) was aided by the inclusion of 16 artifacts also analyzed in their study.

3.4.3. Rhyolite Transport, Provisioning Strategies, and Landscape Learning

Ultimately, the goal of this study is twofold: first, to geochemically identify the rhyolite lithic landscape, using the methods discussed above; and second, to bridge these data with a set of variables to explain human use of this rhyolite landscape through time. Below I review the bridging theoretical framework, focusing on the three behavioral aspects of rhyolite transport, technological provisioning strategies, and landscape learning, and present the variables that can potentially help us understand them (Table

3.2). To consider changes in rhyolite use through time, site assemblages are grouped into time periods that correspond to global paleoclimatic events so that diachronic comparisons can be made. Sites dating between 13.5 ka and 12.8 ka are grouped together as "Allerød" sites, those dating between 12.5 ka and 11.7 ka are termed "YD" sites, sites dating between 11.7 ka and 9 ka are "early Holocene" sites, and those dating to 8-3.5 ka are "middle Holocene" sites. Finally, comparative statistics on variables outlined in this sub-section were performed in IBM SPSS and the open-source program R v. 3.5.0 (R Core Team, 2021) using the *pgirmess* package version 1.7 (Giradoux et al. 2021).

3.4.3.1. Rhyolite Transport

This paper defines toolstone transport in terms of distance and direction an artifact was carried between its source discard locations. Distance and direction can only be precisely measured when both locations are known. If a rhyolite source was identified and matched with rhyolite artifacts in this study, then transport distance was measured, and direction noted. Here, I define a local raw material source as one positioned within 20 linear km of a site. Therefore, nonlocal sources are those exceeding 20 linear km from a site. Ethnographic studies suggest this distance is an appropriate estimate of the average maximum distance a forager will travel in one day (Surovell 2009).

Often, however, precise locations are unknown and relative measures of distance and direction are used. In these cases, when rhyolite groups are identifiable, yet their locations are unknown, I assume the distance traveled between site and toolstone source increases the cost of procuring and transporting that stone raw material. Therefore, if the transport distance between a site and a rhyolite source is short, meaning a rhyolite group represents a local source, then I expect the frequency of that rhyolite group to be high in the site assemblage. In contrast, if a site is located far away from the source, then artifacts of that rhyolite group should be present in low frequencies. Another way to infer if a rhyolite group is local or nonlocal to a site is by characterizing cortex amounts within that group by site (Gore and Graf 2018; Graf and Goebel 2009) and is predicated on the assumption that the main source(s) of rhyolite in the valley would have been alluvial given the ubiquity of alluvial cobbles present in Pleistocene glaciofluvial deposits and Nenana Gravel formation. When an actual distance to source measurement cannot be made, this study assumes that cortex frequencies will decrease as distance to source increases. Therefore, if rhyolite groups contain many cortical pieces, then they are relatively local and represent intraregional sources, whereas rhyolite groups with few or no instances of cortex represent nonlocal, extra-regional sources (Gore and Graf 2018; Graf and Goebel 2009). Therefore, rhyolite transport can be interpreted through frequency of rhyolite groups, considering both within the valley and within each site, and presence of cortex.

3.4.3.2. Provisioning Strategies

This study assumes humans in prehistory employed technologies to effectively subsist upon the landscape (Kelly 2001; Kuhn 1995). As such, the largely lithic record of Alaska has the potential to inform on past foraging and land-use strategies. Interpretations of the lithic record are guided by the expectation that lithic technologies reflect a spectrum of behaviors indicative of provisioning strategies (Kuhn 1995). The two ends of that spectrum are provisioning place versus provisioning individuals.

Provisioning place happens when foragers locate their sites at or near resources, whereas provisioning individuals occurs when individuals within a group "gear up" or prepare themselves with toolkits that will serve them for long periods of time or when they find themselves far from lithic resources (1978, 1979; Graf 2010; Kelly 1988; Kuhn 1991, 1995; Parry and Kelly 1987).

Table 3.2. Expectations of rhyolite transport and technological provisioning.

Variables	**Transport Expectations**	
	Local	***Non-Local***
Diversity of Rhyolite Groups	High	Low
Cortex Presence in Rhyolite Groups	High	Low
	Provisioning Strategy Expectations	
	Place	***Individuals***
Local Rhyolite Transport	High	Low
Non-Local Rhyolite Transport	Low	High

In the context of this rhyolite study and at a general level, I expect a pattern of reliance on local rhyolites to reflect a strategy based on provisioning place, whereas reliance on nonlocal rhyolites represents a strategy based on provisioning individuals (Tables 3.2 and 3.3). Depending on how mobile members of the group are, however, the strategy could involve varying degrees of rhyolite transport. For example, if the overall strategy of a foraging group is to provision place at a base camp yet some members regularly participate in long-distance forays, I expect those traveling long distances to gear up and provision individuals to prepare for the tasks performed at the distant foray location. In this context, I also expect both local and nonlocal rhyolites to be present in associated assemblages, but with local materials dominating. Conversely, if the entire foraging group is moving and practicing a provisioning-individuals strategy, then I expect to see mostly nonlocal rhyolites in the assemblages; however, some of the material could be local because some of the sites in the foraging system may be located

Table 3.3. Expectations of landscape learning.

Variables	**Landscape Learning Expectations**	
	Learners	***Experts***
Rhyolite Group Diversity	High	Low
Rhyolite Transport	Mostly Nonlocal	Mostly Local
Rhyolite Provisioning Strategy	Individuals	Place

at or near rhyolite sources. This study uses the variable of rhyolite transport to understand provisioning strategies.

3.4.3.3. Landscape Learners

When humans are new to a region, they will be landscape naïve, not knowing where to find all or the best resources, including toolstones. As they forage in this new location, they will learn but this process takes time (Fitzhugh 2004; Gore and Graf 2018; Graf and Goebel 2009; Meltzer 2002, 2003; Rockman 2003; Steele and Rockman 2009). Landscape learners should be expected to bring more diverse raw materials with them because they do not know where to find local raw materials. As they learn the rhyolite landscape, they discover, test, and gradually include more local rhyolite sources into their toolkits and become less reliant on nonlocal rhyolites. Therefore, if an assemblage contains a high diversity of rhyolite groups, or more groups to the total groups expressed in the valley, then I expect this represents landscape novices. If an assemblage contains a low diversity of rhyolite groups, then it likely represents landscape experts. Rhyolite group diversity is used as a variable to determine landscape learning (Fitzhugh 2004).

Linear relationships and the coefficient of determination (R^2) are used to estimate diversity values for total artifacts sampled compared with total number of rhyolite groups. Data are log transformed (base 10) to control for varied sample sizes. Because R^2 reflects the goodness of fit between the regression line and the data variables ranging from zero to one with a value of zero indicating the dependent and independent have no relationship, position above the best-fit line indicates higher-than-expected diversity and position below the best-fit line indicates less-than-expected diversity (Odell 1996).

Rhyolite transport and provisioning strategies are used to further assess landscape learning. If rhyolite transport is mostly nonlocal, then this pattern reflects landscape learners who did not know where to find local rhyolites. If, however, rhyolite transport is mostly local, then these were procured by experts that knew where to find them. To minimize risks of foraging in an unknown location and being unprepared, newcomers are expected to have used a provisioning-individuals strategy until they became familiar with where local rhyolites occur with certainty. As humans settle in and learn where to find local rhyolites, they may begin to shift strategies toward more place-oriented rhyolite provisioning. Therefore, I expect novice landscape learners to have provisioned individuals with mostly nonlocal rhyolites and landscape experts to have used provisioned place with local rhyolites (Table 3.3).

3.5. Results

3.5.1. Raw Material Survey

While surveying 42 river and creek drainages for knappable raw materials available in alluvium deposits, I found the primary rock types in these drainages to be low-quality, non-knappable rocks. These materials primarily include schists, schistose, quartz, and quartzites, but some fine-grained igneous materials are present as well (Table 3.4). Geologists have previously mapped outcrops of rhyolite at several localities in the Nenana valley, including in the Cantwell Formation in the vicinity of Riley Creek and the road entrance into Denali National Park, as well as in the foothills to the east of the Nenana river near the village of Ferry at the headwaters of Eva Creek and the Liberty Bell mine (Athey et al. 2006; Csejtey et al. 1992; Thornberry-Ehrlich 2012; Wahrhaftig 1985; Wahrhaftig and Black 1958). During multi-year raw materials surveys, I identified and sampled seven outcrops of rhyolite from these mapped locations (Figure 3.1). Details of these rhyolites are presented below.

Table 3.4. Raw material survey results of samples collected from select alluvial locations.

Select Survey Locations	Basalt		Rhyolite		Andesite		Chalcedony		Chert		Non-Knappable Materials		Total	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Savage and Teklanika Confluence	20	16%	1	1%	0	0%	0	0%	0	0%	103	83%	124	100%
First Creek	15	12%	0	0%	21	17%	0	0%	1	1%	84	69%	121	100%
Dry Creek East	67	36%	0	0%	0	0%	0	0%	0	0%	119	64%	186	100%
Dry Creek Pt. 2	5	4%	0	0%	0	0%	0	0%	2	2%	107	94%	114	100%
Dry Creek Pt. 4	15	3%	0	0%	0	0%	0	0%	3	1%	473	96%	491	100%
Cottonwood Creek	8	5%	0	0%	0	0%	1	1%	0	0%	124	94%	132	100%
Tatlanika Creek	1	0%	0	0%	0	0%	0	0%	3	1%	438	99%	442	100%
California Creek	1	0%	1	0%	0	0%	0	0%	21	9%	204	90%	231	100%
Savage River	3	2%	0	0%	0	0%	0	0%	1	1%	192	98%	196	100%
Jenny Creek	0	0%	0	0%	0	0%	0	0%	0	0%	223	100 %	223	100%

Table 3.4 Continued.

Select Survey Locations	Basalt		Rhyolite		Andesite		Chalcedony		Chert		Non-Knappable Materials		Total	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
DENA 1	0	0%	0	0%	0	0%	0	0%	0	0%	166	100 %	166	100%
DENA 2	0	0%	0	0%	0	0%	0	0%	0	0%	105	100 %	105	100%
Riley Creek	1	1%	0	0%	0	0%	0	0%	0	0%	136	99%	137	100%
Upper Moose Creek	0	0%	0	0%	0	0%	0	0%	2	1%	190	99%	192	100%
Cindy and James Creek*	6	5%	0	0%	0	0%	0	0%	8	7%	100	88%	114	100%
Teklanika River	13	7%	10	6%	0	0%	0	0%	9	5%	142	82%	174	100%
Toklat River	22	13%	0	0%	0	0%	0	0%	0	0%	145	87%	167	100%
Rock Creek	5	3%	0	0%	0	0%	0	0%	0	0%	178	97%	183	100%
Little Panguingue Creek	9	5%	0	0%	0	0%	0	0%	2	1%	183	94%	194	100%
Carlo Creek	56	15%	0	0%	0	0%	0	0%	3	1%	310	84%	369	100%
Panguingue Creek	15	4%	0	0%	0	0%	0	0%	13	4%	324	92%	352	100%
Slate Creek	7	1%	0	0%	0	0%	0	0%	7	1%	475	97%	489	100%
NW Dry Creek	4	3%	0	0%	0	0%	0	0%	1	1%	149	97%	154	100%
Fish Creek	0	0%	0	0%	0	0%	0	0%	3	1%	401	99%	404	100%
Nenana River 1	1	0%	0	0%	0	0%	0	0%	8	2%	362	98%	371	100%
Nenana River 2	41	13%	0	0%	0	0%	0	0%	4	1%	267	86%	315	100%
Nenana River 3	33	23%	0	0%	0	0%	0	0%	0	0%	108	77%	141	100%
Nenana River 4	54	33%	0	0%	0	0%	0	0%	0	0%	109	67%	163	100%
Nenana River 5	87	20%	0	0%	0	0%	0	0%	2	0%	348	80%	437	100%
Chicken Creek	6	1%	0	0%	0	0%	0	0%	8	2%	423	97%	437	100%
Windy Creek	271	84%	0	0%	0	0%	0	0%	0	0%	51	16%	322	100%
Suntrana at Healy Creek	0	0%	0	0%	0	0%	0	0%	0	0%	508	100 %	508	100%
Walker Creek	23	15%	0	0%	0	0%	0	0%	2	1%	131	84%	156	100%

3.5.1.1. Sugarloaf Mountain Rhyolite

The Sugarloaf Mountain rhyolite is located ~16 km southeast of the town of Healy. There are multiple exposures of rhyolite on the mountain, though not all are easily accessible. Samples reported in this study were obtained from an exposure on the south side of the mountain accessed by following animal trails to the top. Rhyolite at this ~500-m long exposure is weathered and actively eroding. Nodules are available as fragmented, angular scree deposits mostly ranging in size from < 5-30 cm in maximum linear dimension with few larger nodules. These materials are low quality, chalky in texture, and range from light grey to light tan in color.

3.5.1.2. Triple Lakes Rhyolite

The Triple Lakes rhyolite is located on a ridge upslope of Riley Creek in DENA along a popular hiking trail, ~5 km south of the park entrance. The exposure is ~ 50 m wide on top of the ridge and extends westward downslope to a creek tributary where it is largely obscured by boreal forest and scrub vegetation. Nodules are weathered, fragmented, and exhibit angular structure, ranging in size from < 5-20 cm in maximum linear dimension. This rhyolite is chalky in texture and light tan in color.

3.5.1.3. Ferry Group Rhyolites

The remaining five rhyolite outcrops are located in the foothills 14 km east of the village of Ferry, near the active Liberty Bell Mine, and produced from Oligocene-aged intrusive sills into schist bedrock (Csejtey et al. 1992). The Ferry 1 rhyolite outcrop is 2 km southwest of the Liberty Bell mine. Recent bulldozer activity created a 30-40 m exposure. Ferry 2 rhyolite outcrop is located 1.5 km northwest of Ferry 1 rhyolite. This exposure is small, approximately 10-20 m wide. Three more exposures, Ferry 3, Ferry 4, and Ferry 5 are present on the high ridge 1-2 km north of Eva Creek at the Liberty Bell Mine. These three exposures trend north to south and are spaced ~300 m apart. Each exposed area of rock ranges from 300-400 m in length. Rhyolites from these outcrops tend to range in color from white to light tan, have platy structure, and are chalky in texture. Rock can be extracted in 10-30 cm nodules, but this material is very brittle and prone to platy breakage.

3.5.2. Geochemical Analysis of Rhyolite Outcrops and Alluvial Sample Locations

3.5.2.1. Rhyolite Outcrops

The seven outcrop-location rhyolites identified and collected in this study were evaluated to assess inter-outcrop variability. Basic statistical summaries of each outcrop's geochemical data are listed in Table 3.5, and results of a principal components analysis are shown in Figure 3.2 and Table 3.6. Confidence ellipses of the first two principal components (Figure 3.2), with a cumulative variance of 91.2%, show slight overlap between Ferry 1, 3, 4, 5, and Sugarloaf; between Ferry 4 and 5; and between Triple Lakes, Ferry 3, 5, and Sugarloaf rhyolites. The Ferry 2 sample does not overlap with any of the other outcrops in this comparison. Plots of additional PCs and logged elemental concentration data, however, help to differentiate most overlapping groups. PCs 2 and 4 (38.2% cumulative variance) differentiate Ferry 3 and 5 from Sugarloaf (Figure 3.3a). The elements Zr and Nb differentiate Ferry 3 from Ferry 5, and Triple Lakes from Sugarloaf (Figure 3.3b). Three-dimensional plots of PCs 1, 2, and 4 (94.1% combined variance) differentiate Ferry 1 and 3 (Figure 3.4a); and PCs 2, 3, and 5

Table 3.5. Statistical summaries of minimum, maximum, mean, standard deviation (St Dev), and percent standard deviation (%SD) of element concentrations (ppm) measured from outcrop sample locations.

Outcrop	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Ferry 1	Mn	61.19	211.05	115.79	39.34	33.98
N = 20	Fe	3630.54	23158.37	8935.53	5553.00	62.15
	Zn	7.36	33.89	15.95	6.78	42.49
	Ga	9.32	26.22	17.89	3.98	22.24
	Rb	171.54	263.27	214.68	28.26	13.16
	Sr	137.69	265.34	216.41	36.21	16.73
	Y	12.79	41.25	19.66	6.58	33.47
	Zr	85.44	164.38	130.11	22.63	17.39
	Nb	9.76	23.75	15.96	3.06	19.18
	Th	10.21	38.20	17.48	8.76	50.12
Outcrop	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Ferry 2	Mn	11.25	583.46	119.46	135.68	113.58
N = 20	Fe	1349.99	9994.88	3462.48	1832.98	52.94
	Zn	5.86	44.00	13.21	8.55	64.68
	Ga	2.51	17.02	9.46	3.19	33.69
	Rb	6.31	30.65	14.62	7.08	48.40
	Sr	2.04	46.15	22.30	13.41	60.15
	Y	3.29	17.65	7.35	3.10	42.15
	Zr	23.67	71.73	42.09	10.99	26.10
	Nb	0.47	4.70	2.12	1.12	52.81
	Th	0.01	4.52	1.29	1.30	100.76
Outcrop	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Ferry 3	Mn	4.26	450.85	71.60	92.10	128.63
N = 20	Fe	1919.03	15409.16	6848.11	3705.87	54.12
	Zn	2.93	27.63	12.65	6.65	52.59
	Ga	11.83	19.94	17.06	2.18	12.79
	Rb	72.86	224.56	119.88	40.34	33.65
	Sr	17.12	150.06	58.14	41.86	72.00
	Y	11.04	122.65	25.60	23.76	92.80
	Zr	58.54	148.98	77.45	18.65	24.09
	Nb	9.89	28.65	19.13	4.52	23.60
	Th	11.11	16.77	13.75	1.83	13.28
Outcrop	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Ferry 4	Mn	44.08	132.77	80.32	24.88	30.97

Table 3.5 Continued.

N = 20	Fe	1595.39	8553.46	4762.00	1622.45	34.07
Outcrop	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
	Zn	7.65	71.73	47.35	18.06	38.15
	Ga	9.82	22.76	18.95	3.13	16.52
Outcrop	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
	Rb	135.14	321.92	242.22	48.57	20.05
	Sr	54.31	158.89	118.59	27.38	23.09
	Y	18.66	107.77	34.74	22.47	64.68
	Zr	56.73	122.54	77.39	13.77	17.79
	Nb	14.74	39.70	22.77	6.11	26.82
	Th	14.35	34.65	21.53	5.30	24.61
Outcrop	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Ferry 5	Mn	29.76	137.83	80.64	28.60	35.46
N = 20	Fe	1211.18	9561.48	2820.66	1989.66	70.54
	Zn	4.26	16.64	10.05	3.44	34.17
	Ga	7.57	21.63	14.02	4.01	28.58
	Rb	96.41	261.04	175.34	54.74	31.22
	Sr	21.98	98.40	50.48	22.67	44.91
	Y	11.68	73.40	23.83	13.48	56.56
	Zr	66.09	130.92	96.00	17.06	17.77
	Nb	3.18	12.47	7.94	2.26	28.46
	Th	7.60	40.94	16.54	9.26	56.02
Outcrop	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Sugarloaf	Mn	82.85	869.66	257.05	181.16	70.48
Mountain	Fe	3224.23	10923.04	5249.46	1782.22	33.95
N = 20	Zn	17.72	76.58	42.37	18.21	42.97
	Ga	15.57	25.87	20.13	2.63	13.08
	Rb	203.57	557.97	366.38	106.76	29.14
	Sr	2.57	26.99	10.10	7.71	76.30
	Y	30.84	91.18	59.91	13.70	22.86
	Zr	54.41	70.88	62.97	4.45	7.06
	Nb	12.67	24.64	19.79	4.00	20.21
	Th	13.63	25.94	19.08	3.35	17.58
Outcrop	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Triple	Mn	21.54	309.13	109.56	69.03	63.01
Lakes	Fe	1420.06	12011.21	7569.19	2610.31	34.49
N = 20	Zn	12.64	37.11	23.26	8.40	36.13
	Ga	5.17	20.42	14.27	3.76	26.33
	Rb	45.30	186.38	124.87	49.42	39.58

Table 3.5 Continued.

	Sr	5.30	25.53	12.12	5.74	47.39
Outcrop	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
	Y	11.48	173.96	32.39	35.65	110.08
	Zr	51.83	105.92	85.63	13.32	15.56
	Nb	5.93	18.10	9.50	2.44	25.65
	Th	5.80	12.70	9.85	1.80	18.25

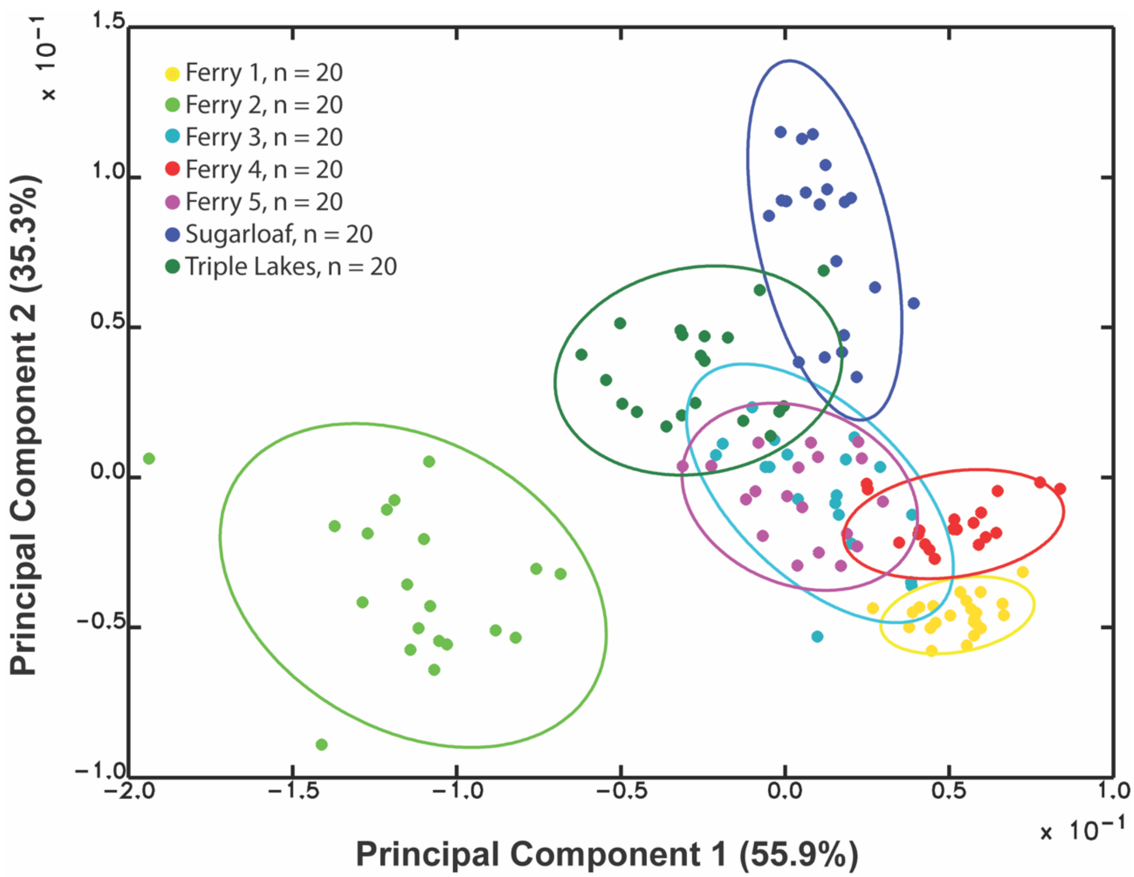


Figure 3.2. Logged (base 10) biplots of principal component 1 and 2 scores for rhyolites sampled from seven rhyolite outcrop locations in this study. Ellipse confidence intervals drawn at 90%.

Table 3.6. Eigenvalue, percentage of variance, and element score for each principal component calculated from the variance-covariance matrix of concentration data (log-10 ppm) for rhyolite outcrop samples.

Principal Component		Eigenvalue	% Variance	Cumulative % Variance	
1		0.4372	55.93	55.93	
2		0.2759	35.30	91.23	
3		0.0341	4.36	95.59	
4		0.0227	2.90	98.49	
5		0.0118	1.51	100.00	
Element	**PC 1**	**PC 2**	**PC3**	**PC4**	**PC5**
Rb	0.60	0.35	-0.69	-0.19	0.12
Sr	0.52	-0.83	0.09	-0.17	0.10
Y	0.30	0.37	0.61	-0.63	-0.11
Zr	0.18	-0.05	-0.07	0.16	-0.97
Nb	0.50	0.23	0.38	0.72	0.18

(41.4% cumulative variance) differentiate Ferry 3 from Triple Lakes (Figure 3.4b). Ferry 5 could not be confidently differentiated from Ferry 3 or Triple Lakes rhyolite in any of the analyses. These slight overlaps between sample locations may be due to shared parent material contributing to each rhyolite flow during its genesis. Otherwise, the overall geochemical results suggest that most of these regional rhyolite outcrops are geochemically distinct from one another.

3.5.2.2. Alluvial Samples

Although rhyolites are present in and around the Nenana valley, I found them at only four alluvial sample localities: Bear Creek, California Creek, Teklanika River, and the confluence of the Savage River with the Teklanika River. At all four findspots, the rhyolite comprises less than 10% of the bed load makeup (Table 3.4). Table 3.7 lists statistical summaries of elemental concentrations for each sample location.

The alluvial samples were compared to rhyolites collected from outcrop contexts. Figure 3.5a shows the first two PCs, summarizing 83.9 % of total variance (Table 3.8).

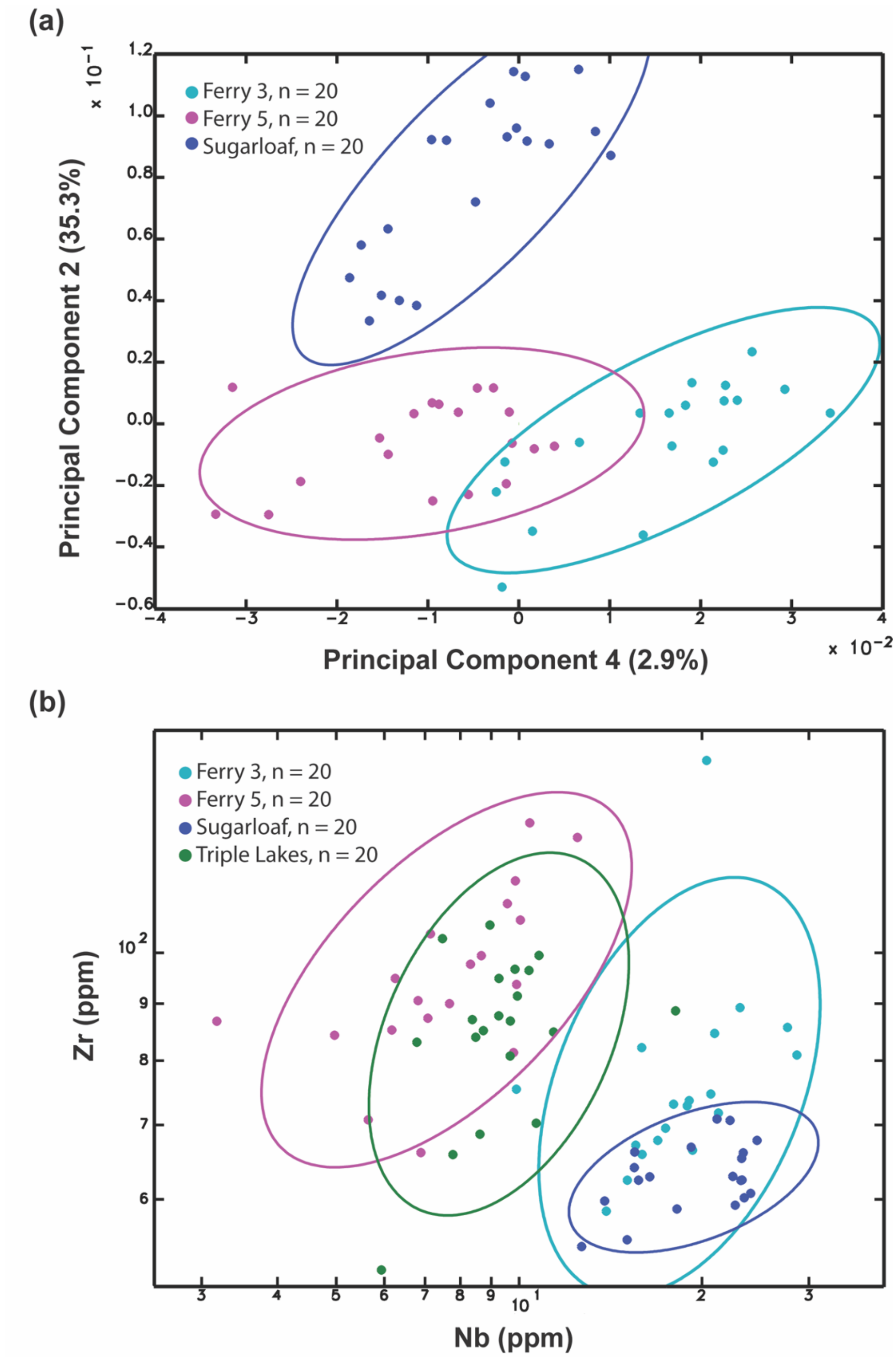


Figure 3.3. Logged (base 10) biplots of (a) rhyolite outcrop samples comparing principal components 2 and 4 scores of Ferry 3, Ferry 5, and Sugarloaf rhyolites and (b) Nb and Zr (ppm) values for Ferry 3, Ferry 5, Sugarloaf, and Triple Lakes rhyolites. Ellipse confidence intervals drawn at 90%.

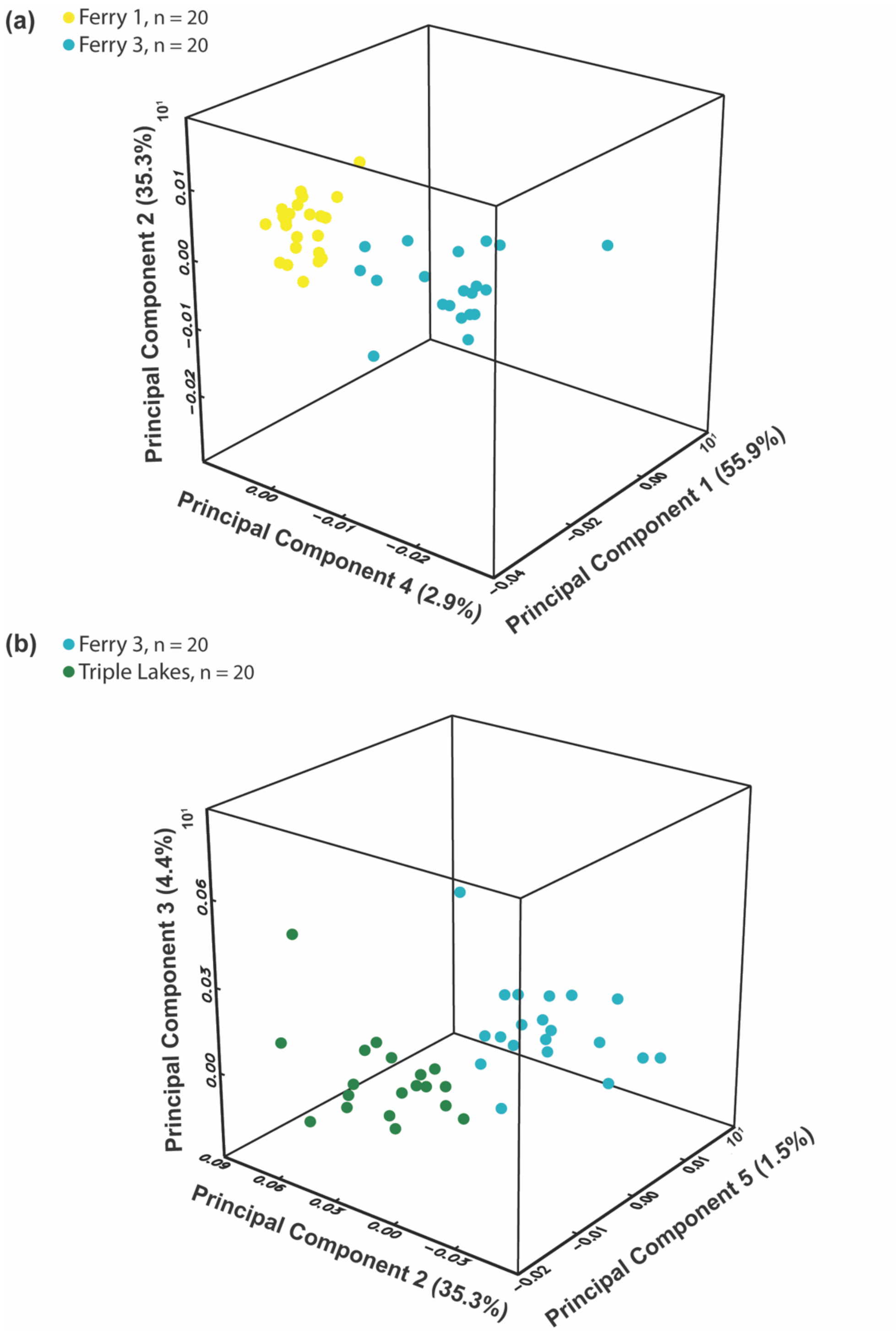


Figure 3.4. Logged (base 10) 3D plots of rhyolite outcrops sampled in this study, comparing (a) principal components 1, 2, and 4 scores of the Ferry 1 and Ferry 3 rhyolites and (b) principal components 2, 3, and 5 scores of the Ferry 3 and Triple Lakes rhyolites.

Table 3.7. Statistical summaries of minimum, maximum, mean, standard deviation (St Dev), and percent standard deviation (%SD) of element concentrations (ppm) measured from alluvial samples collected from each alluvial collection spot.

Sample	Element	Min	Max	Mean	St Dev	%SD
California Creek (N = 2)	Mn	190.27	405.09	297.68	151.90	51.03
	Fe	6021.65	9492.02	7756.83	2453.92	31.64
	Zn	15.48	31.28	23.38	11.17	47.77
	Ga	19.90	20.79	20.34	0.62	3.07
	Rb	179.43	198.58	189.00	13.55	7.17
	Sr	46.42	62.22	54.32	11.17	20.57
	Y	45.58	48.79	47.19	2.27	4.81
	Zr	102.70	171.80	137.25	48.86	35.60
	Nb	32.00	38.31	35.15	4.46	12.68
	Th	12.19	21.08	16.64	6.29	37.78
Sample	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Bear Creek (N = 2)	Mn	62.94	1135.13	599.03	758.15	126.56
	Fe	12586.94	25039.91	18813.43	8805.58	46.80
	Zn	61.20	134.92	98.06	52.13	53.16
	Ga	15.11	25.27	20.19	7.18	35.57
	Rb	185.37	236.91	211.14	36.44	17.26
	Sr	20.46	23.29	21.87	2.00	9.14
	Y	40.76	50.51	45.63	6.89	15.11
	Zr	549.00	706.16	627.58	111.12	17.71
	Nb	35.45	49.14	42.29	9.68	22.89
	Th	19.01	22.65	20.83	2.57	12.34
Sample	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Teklanika River (N = 23)	Mn	70.80	1089.70	305.49	277.19	90.73
	Fe	3681.07	33096.17	12819.91	7490.47	58.43
	Zn	23.09	128.00	72.03	29.60	41.10
	Ga	13.75	24.92	19.78	3.01	15.23
	Rb	41.32	240.49	142.15	55.78	39.24
	Sr	6.79	114.46	30.36	27.32	89.98
	Y	23.47	89.22	60.29	18.15	30.11
	Zr	118.30	624.44	306.97	137.85	44.91
	Nb	10.63	47.15	29.99	9.07	30.23
	Th	7.21	23.80	16.41	4.23	25.79
Sample	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Confluence of Savage and Teklanika	Mn	139.05	1749.46	507.72	408.94	80.55
	Fe	5636.63	53700.45	25842.64	11448.51	44.30
	Zn	63.63	310.54	140.39	62.25	44.34

Table 3.7 Continued.

Sample	Element	Min	Max	Mean	St Dev	%SD
Confluence of Savage and Teklanika Rivers	Ga	16.15	27.95	21.76	3.19	14.66
	Rb	93.34	229.62	175.21	41.02	23.41
	Sr	7.11	70.74	33.22	16.20	48.77
	Y	42.40	111.49	71.12	16.30	22.92
	Zr	196.99	661.74	461.21	178.54	38.71
	Nb	18.91	46.79	35.73	8.39	23.48
	Th	12.84	24.38	18.92	3.70	19.54

Table 3.8. Eigenvalue, percentage of variance, and element score for each principal component calculated from the variance-covariance matrix of concentration data (log-10 ppm) for outcrop and alluvial samples.

Principal Component	Eigenvalue	% Variance	Cumulative % Variance
1	0.4098	51.23	51.23
2	0.2617	32.71	83.94
3	0.0843	10.53	94.47
4	0.0263	3.29	97.76
5	0.0719	2.24	100.00

Element	PC 1	PC 2	PC3	PC4	PC5
Rb	0.54	0.02	-0.69	-0.45	-0.18
Sr	0.23	-0.95	0.07	0.17	-0.11
Y	0.43	0.29	0.09	0.62	-0.58
Zr	0.37	0.07	0.71	-0.57	-0.19
Nb	0.58	0.10	0.09	0.25	0.76

The majority of alluvium groups away from outcrop samples. Some alluvial samples appear to fall within the 90% confidence interval of Sugarloaf Mountain, Triple Lakes, and Ferry 3, 4, and 5 rhyolites, including 10 samples from the Teklanika River and three samples from the Savage and Teklanika confluence (Figure 3.5a); however, these alluvial pieces are separated from the outcrop locations by the third PC (Figure 3.5b). Comparisons of alluvial rhyolites to outcrops suggest they are not derived from the outcrops sampled in this study. These results are expected given none of the sampled outcrops is located near headwaters of major tributaries within the vicinity of the

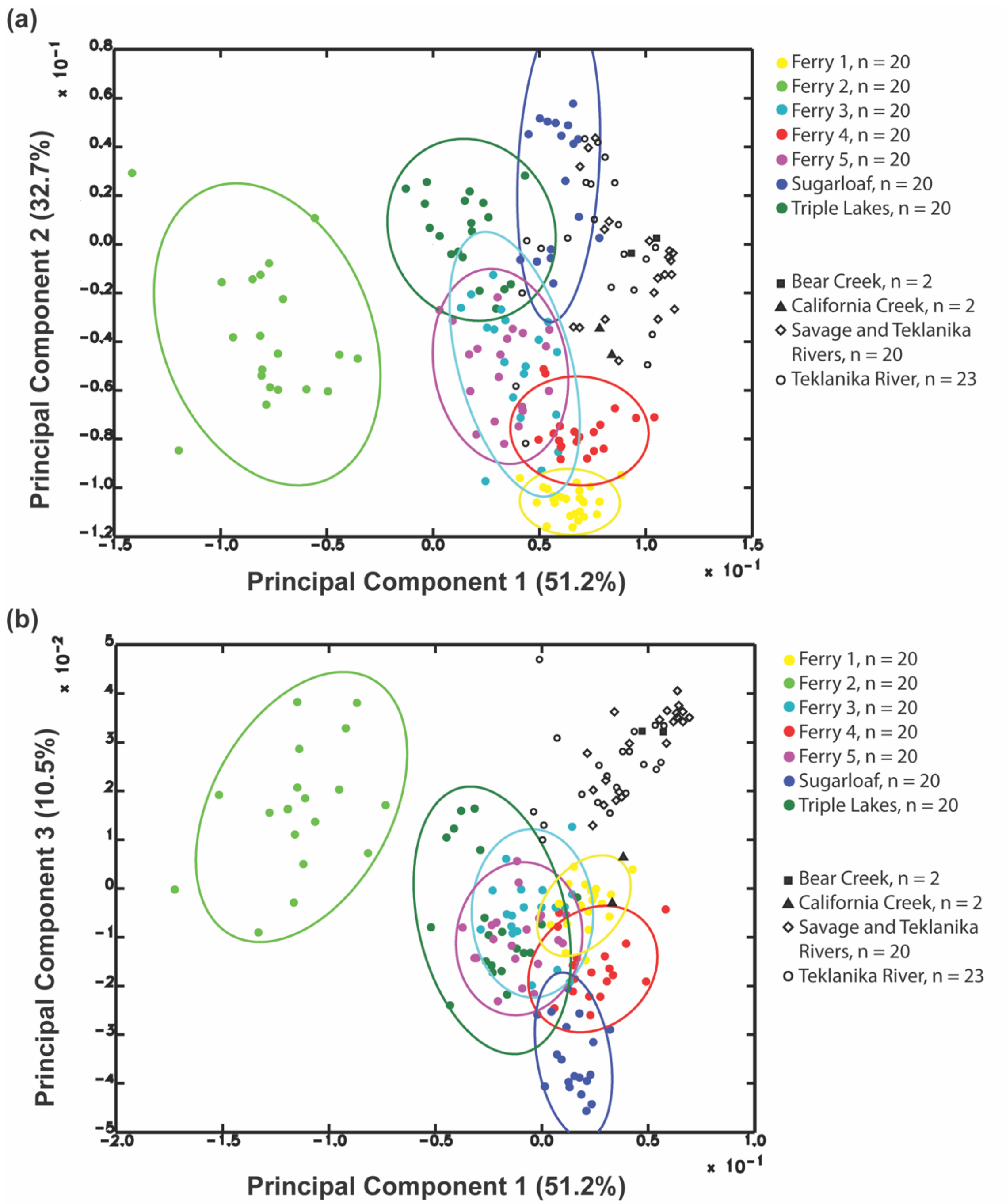


Figure 3.5. Logged (base 10) biplots comparing alluvial and outcrop samples by (a) principal components 1 and 2 scores and (b) principal component 1 and 3 scores. Ellipse confidence intervals drawn at 90%.

alluvium sampled. Alluvial samples reported here likely originated from rhyolite outcrops that either

3.5.3. Geochemical Analysis of Rhyolite Artifacts

I analyzed 675 rhyolite artifacts for their geochemical signature using pXRF analysis. This led to the assignment of 633 artifacts to 14 distinct geochemical groups and 42 artifacts that could not be assigned to any these groupings (Table 3.9). Tables 3.10 and 3.11 present geochemical summary data for each group as well as parameters of the associated principal components analysis, respectively. Ten groups reported here, A, B, C, D, E, F, G, H, I, and J, replicate those previously reported by Coffman and Rasic (2015); however, groups K, L, M, and N are newly identified, significantly adding to the variability found among prehistoric sites in central Alaska and specifically within the Nenana valley. The series of biplots in Figure 3.6 visualize these 14 groupings, with PCs 1 and 2 comprising 88.2% of the total variance (Figure 3.6a). Biplots of both PCs 1 and 3 and PCs 1 and 4 show groups A, I, L, and N are discrete (Figures 3.6b, 3.6c). When considering PCs 1 and 5, groups M and N are discrete and groups F and K are virtually separate from the others (Figure 3.6d). A description of each artifact group is presented below.

3.5.3.1. Previously Reported Groups

Of the 10 groups identified by Coffman and Rasic (2015), two, G and H, were given approximate geographical locations by these authors. Group G is thought to come from the Talkeetna Mountains near the headwaters of the Talkeetna River, as reported by the United States Geological Service (USGS). Group H is thought to come from an

Table 3.9. Count of artifacts in each archaeological assemblage by geochemical rhyolite groups. TM = Talkeetna Mountains; CC = Calico Creek.

		Rhyolite Group														
Assemblages by Time	**Total (%)**	**A**	**B**	**C**	**D**	**E**	**F**	**TM**	**CC**	**I**	**J**	**K**	**L**	**M**	**N**	**Una[1]**
13.5 - 12.8 ka																
Dry Creek C1	48 (7.1)	1 (0.2)			3 (0.4)	1 (0.2)	9 (1.3)	2 (0.3)						2 (0.3)	26 (3.9)	4 (0.6)
Walker Road	98 (14.5)	56 (8.3)	2 (0.3)		2 (0.3)			4 (0.6)	1 (0.2)	1 (0.2)	32 (4.7)					
Moose Creek C1	22 (3.3)	15 (2.2)	2 (0.3)							2 (0.3)	1 (0.2)					2 (0.3)
Owl Ridge C1	31 (4.6)	11 (1.6)								15 (2.2)	1 (0.2)	1 (0.2)				3 (0.4)
Eroadaway	8 (1.2)									6 (0.9)				1 (0.2)		1 (0.2)
Subtotal	207 (30.7)															
12.5 - 11.7 ka																
Moose Creek C2	14 (2.1)	9 (1.3)	2 (0.3)							1 (0.2)	1 (0.2)					1 (0.2)
Owl Ridge C2	33 (4.9)	18 (2.7)	1 (0.2)							14 (2.0)						
Panguingue C1	4 (0.6)	1 (0.2)	2 (0.3)					1 (0.2)								
Subtotal	51 (7.6)															
11.7-9 ka																
Dry Creek C2	127 (18.8)	73 (10.8)		8 (1.2)	3 (0.4)			4 (0.6)	2 (0.3)	17 (2.5)	2 (0.3)		10 (1.5)			8 (1.2)
Owl Ridge C3	33 (4.9)	17 (2.5)	3 (0.4)			1 (0.2)				2 (0.3)		2 (0.3)				8 (1.2)
Panguingue C2	52 (7.7)	4 (0.6)	18 (2.7)	1 (0.2)		2 (0.3)	2 (0.3)	5 (0.7)	16 (2.4)	1 (0.2)						3 (0.4)
Little Panguingue Creek C2	30 (4.4)	2 (0.3)				1 (0.2)		1 (0.2)		26 (3.9)						

Table 3.9 Continued

Assemblages by Time	Total (%)	A	B	C	D	E	F	TM	CC	I	J	K	L	M	N	Una[1]
Subtotal	242 (35.9)															
8 – 3.5 ka																
Houdini Creek	42 (6.2)	8 (1.2)				10 (1.5)		2 (0.3)				22 (3.3)				
Teklanika West C3	32 (4.7)	16 (2.4)	1 (0.2)	6 (0.9)			2 (0.3)			1 (0.2)				4 (0.6)		4 (0.6)
Carlo Creek C2	26 (3.9)	26 (3.9)														
Moose Creek C3	8 (1.2)	1 (0.2)	5 (0.7)					1 (0.2)								1 (0.2)
Panguingue C3	4 (0.6)	1 (0.2)	3 (0.4)													
Moose Creek C4	24 (3.6)	4 (0.6)	3 (0.4)							1 (0.2)	16 (2.4)					
Dry Creek C4	39 (5.8)	3 (0.4)		2 (0.3)			4 (0.6)		2 (0.3)	1 (0.2)				24 (3.6)		7 (1.0)
Subtotal	175 (25.9)															
Total	**675 (100)**	**266 (39.4)**	**42 (6.2)**	**17 (2.5)**	**8 (1.2)**	**15 (2.2)**	**12 (1.8)**	**20 (3.0)**	**21 (3.1)**	**88 (13.0)**	**53 (7.9)**	**25 (3.7)**	**10 (1.5)**	**30 (4.4)**	**26 (3.9)**	**42 (6.2)**

[1] Number of unassigned artifacts

Table 3.10. Statistical summaries of minimum, maximum, mean, standard deviation (St Dev), and percent standard deviation (%SD) of element concentrations (ppm) measured for each artifact rhyolite group A-N.

Rhyolite Group	Element	Min	Max	Mean	St Dev	%SD
A (N=266)	Mn	167.61	2632.84	529.55	357.28	67.47
	Fe	12018.14	53436.82	27960.76	7237.21	25.88
	Zn	76.99	542.73	188.96	70.33	37.22
	Ga	21.25	62.52	42.51	10.76	25.31
	Rb	141.10	348.59	231.57	37.54	16.21
	Sr	14.87	32.16	22.76	4.19	18.43
	Y	36.05	76.97	49.48	6.55	13.23
	Zr	128.44	236.36	179.44	22.03	12.27
	Nb	13.51	27.48	19.34	2.63	13.59
	Th	22.18	62.19	36.05	7.30	20.25
Rhyolite Group	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
B (N=42)	Mn	200.52	2624.06	662.20	618.84	93.45
	Fe	9693.97	75573.25	34981.70	16681.32	47.69
	Zn	49.50	423.30	203.85	77.32	37.93
	Ga	19.65	57.50	32.87	10.39	31.60
	Rb	120.61	205.80	151.49	26.22	17.31
	Sr	60.36	107.68	86.25	13.21	15.32
	Y	24.65	42.09	32.74	4.42	13.50
	Zr	130.06	241.38	176.34	26.82	15.21
	Nb	10.32	29.57	19.85	4.05	20.42
	Th	7.36	26.81	15.35	4.12	26.83
Rhyolite Group	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
C (N=17)	Mn	427.61	1213.79	898.38	204.21	22.73
	Fe	15376.75	44958.66	29165.56	7836.33	26.87
	Zn	51.08	112.30	67.80	14.75	21.75
	Ga	19.26	49.85	31.96	8.59	26.86
	Rb	86.92	159.82	121.69	21.27	17.48
	Sr	86.87	134.01	107.32	12.56	11.70
	Y	31.49	53.40	41.93	4.77	11.37
	Zr	212.03	321.12	262.19	30.90	11.79
	Nb	13.84	24.93	18.83	2.81	14.92
	Th	3.15	12.90	7.99	2.81	35.13

Table 3.10 Continued.

Rhyolite Group	Element	Min	Max	Mean	St Dev	%SD
D (N=8)	Mn	319.62	1456.81	561.58	348.98	62.14
	Fe	26677.44	77584.69	36458.86	16121.86	44.22
	Zn	93.65	188.10	128.85	31.35	24.33
	Ga	19.70	46.56	26.61	8.51	31.98
	Rb	82.97	119.60	100.02	12.19	12.19
	Sr	175.19	231.04	200.40	15.93	7.95
	Y	19.73	32.10	26.02	3.43	13.18
	Zr	141.19	190.07	165.96	14.78	8.91
	Nb	12.08	13.93	13.14	0.73	5.59
	Th	8.01	10.24	8.83	0.88	9.97
Rhyolite Group	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
E (N=15)	Mn	38.16	672.75	445.51	166.31	37.33
	Fe	21266.01	72755.27	36810.69	14019.00	38.08
	Zn	121.92	189.63	147.92	18.69	12.64
	Ga	19.65	41.09	30.27	6.67	22.05
	Rb	103.51	163.13	130.26	13.29	10.20
	Sr	168.60	220.66	194.24	14.63	7.53
	Y	27.86	40.39	33.02	3.53	10.70
	Zr	167.87	244.08	207.36	22.22	10.72
	Nb	16.77	19.62	18.44	1.04	5.64
	Th	9.54	17.83	14.82	2.61	17.61
Rhyolite Group	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
F (N=12)	Mn	404.04	853.67	697.26	150.43	21.57
	Fe	18920.76	35043.29	25785.28	4521.77	17.54
	Zn	75.08	150.12	102.86	23.75	23.09
	Ga	20.46	51.60	40.90	11.22	27.44
	Rb	91.81	128.05	107.10	10.75	10.04
	Sr	253.15	284.65	270.81	9.56	3.53
	Y	24.61	44.57	35.93	5.75	15.99
	Zr	162.35	308.43	264.37	54.31	20.54
	Nb	12.66	17.99	15.50	1.84	11.87
	Th	8.21	14.56	10.59	1.97	18.57
Rhyolite Group	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
G (Talkeetna Mountains) (N=20)	Mn	260.31	1647.17	793.21	438.51	55.28
	Fe	20343.63	118057.51	50268.94	28194.58	56.09
	Zn	81.74	214.23	132.14	33.45	25.31

Table 3.10 Continued.

Rhyolite Group	Element	Min	Max	Mean	St Dev	%SD
	Ga	12.26	56.95	27.30	11.04	40.43
	Rb	72.96	157.74	110.24	22.82	20.70
	Sr	112.92	165.68	144.28	13.86	9.61
	Y	22.30	40.27	29.27	4.73	16.15
	Zr	143.10	204.18	163.95	16.81	10.25
	Nb	11.33	16.55	13.47	1.29	9.56
	Th	6.85	14.37	9.91	2.18	22.03
Rhyolite Group	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
H (Calico Creek) (N=21)	Mn	160.12	1568.79	444.56	315.27	70.92
	Fe	15911.55	45849.76	26805.77	6881.30	25.67
	Zn	41.93	184.59	103.88	34.66	33.37
	Ga	11.69	33.41	22.52	5.92	26.30
	Rb	54.32	208.67	115.74	29.67	25.64
	Sr	52.26	76.98	64.88	7.03	10.83
	Y	30.64	39.59	34.63	2.96	8.54
	Zr	149.73	259.80	200.06	25.93	12.96
	Nb	9.07	19.20	14.74	2.59	17.58
	Th	2.99	22.02	11.26	3.68	32.70
Rhyolite Group	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
I (N=88)	Mn	10.64	2521.64	288.31	379.92	131.77
	Fe	3130.63	97848.56	19925.22	16254.09	81.58
	Zn	16.23	151.73	48.09	28.62	59.52
	Ga	13.43	53.68	33.86	9.64	28.46
	Rb	96.64	314.50	196.23	42.38	21.59
	Sr	18.80	43.28	30.58	5.97	19.52
	Y	17.22	41.08	27.64	4.35	15.72
	Zr	161.69	374.81	280.23	41.16	14.69
	Nb	8.58	23.73	14.04	2.89	20.59
	Th	4.91	25.29	9.63	3.28	34.02
Rhyolite Group	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
J (N= 53)	Mn	198.27	2180.51	413.82	275.58	66.59
	Fe	13199.05	38572.39	21995.97	6327.29	28.77
	Zn	99.56	428.76	206.34	63.88	30.96
	Ga	23.27	56.68	40.19	9.75	24.27
	Rb	164.03	323.25	225.54	37.87	16.79

Table 3.10 Continued.

Rhyolite Group	Element	Min	Max	Mean	St Dev	%SD
	Sr	38.91	104.55	62.87	16.04	25.51
	Y	38.36	72.30	53.86	8.06	14.96
	Zr	130.68	242.99	179.30	24.44	13.63
	Nb	14.20	26.98	20.87	3.19	15.27
	Th	24.23	65.57	36.24	8.93	24.65
Rhyolite Group	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
K (N= 25)	Mn	994.75	2446.14	1659.44	382.38	23.04
	Fe	68174.28	95913.51	83166.85	8709.30	10.47
	Zn	135.58	264.68	170.79	32.95	19.29
	Ga	25.98	53.93	39.79	8.37	21.04
	Rb	63.00	140.52	103.21	18.72	18.14
	Sr	262.35	384.52	336.05	32.64	9.71
	Y	22.57	46.93	35.19	6.66	18.93
	Zr	234.01	362.86	308.52	31.18	10.11
	Nb	24.59	36.87	30.25	3.69	12.18
	Th	5.30	14.12	10.69	2.07	19.33
Rhyolite Group	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
L (N= 10)	Mn	197.49	511.97	302.62	89.57	29.60
	Fe	10422.01	28481.93	17671.27	5104.69	28.89
	Zn	41.91	85.93	62.30	15.43	24.78
	Ga	17.67	45.95	33.85	9.02	26.66
	Rb	164.21	256.32	215.65	29.15	13.52
	Sr	15.97	23.71	19.01	2.51	13.22
	Y	45.28	58.63	52.29	4.75	9.09
	Zr	317.68	445.47	395.00	38.97	9.87
	Nb	20.18	27.66	24.58	2.68	10.89
	Th	9.34	12.98	11.55	1.21	10.44
Rhyolite Group	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
M (N=30)	Mn	552.29	1997.76	1096.03	371.57	33.90
	Fe	21355.78	74821.33	49030.37	13900.62	28.35
	Zn	39.81	153.76	92.96	33.80	36.36
	Ga	15.96	58.30	35.92	10.55	29.36
	Rb	81.07	148.18	106.53	18.51	17.38
	Sr	295.98	670.40	447.18	106.55	23.83
	Y	25.85	42.57	32.14	4.50	14.02
	Zr	189.31	348.11	248.22	36.79	14.82

Table 3.10 Continued.

Rhyolite Group	Element	Min	Max	Mean	St Dev	%SD
	Nb	8.48	18.20	12.60	2.47	19.61
	Th	2.06	12.23	7.80	2.25	28.81
Rhyolite Group	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
N (N= 26)	Mn	318.53	709.07	496.68	100.54	20.24
	Fe	8499.05	20228.21	13466.29	3135.81	23.29
	Zn	37.60	105.12	60.52	17.78	29.37
	Ga	13.65	45.33	27.71	9.02	32.54
	Rb	33.86	85.05	59.04	11.12	18.83
	Sr	617.22	1102.29	804.09	125.72	15.64
	Y	12.22	19.56	15.34	1.80	11.75
	Zr	98.59	176.08	136.58	22.24	16.28
	Nb	8.20	14.65	10.57	1.65	15.60
	Th	8.59	16.04	11.28	1.70	15.03

Table 3.11. Eigenvalue, percentage of variance, and element score for each principal component calculated from the variance-covariance matrix of concentration data (log-10 ppm) for rhyolite artifact samples.

Principal Component	Eigenvalue	% Variance	Cumulative % Variance
1	0.2663	59.09	59.09
2	0.1311	29.10	88.19
3	0.0292	6.50	94.69
4	0.0157	3.50	98.19
5	0.0081	1.81	100.00

Element	PC 1	PC 2	PC3	PC4	PC5
Rb	0.30	0.41	-0.07	-0.83	0.22
Sr	-0.93	0.29	0.07	-0.20	-0.01
Y	0.19	0.57	0.39	0.14	-0.69
Zr	-0.01	0.26	-0.92	0.14	-0.27
Nb	0.07	0.59	0.05	0.49	0.64

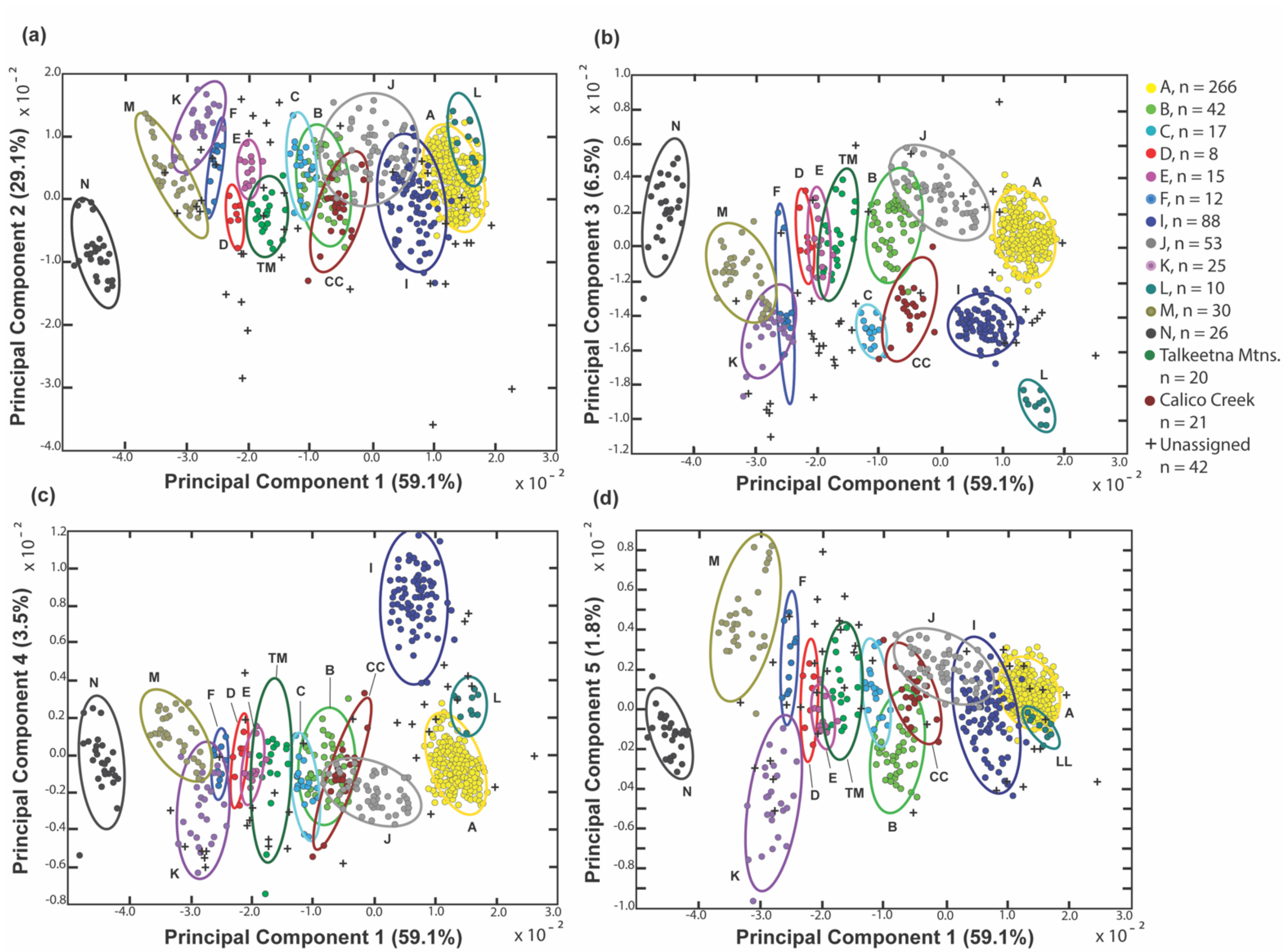


Figure 3.6. Logged (base 10) biplots of (a) rhyolite artifact samples and their assigned groups by scores of principal components 1 and 2, (b) principal components 1 and 3, (c) principal components 1 and 4, and (d) principal components 1 and 5. Unassigned artifacts denoted by black crosses in all plots. Ellipse confidence intervals drawn at 90%. TM = Talkeetna Mountains source area, formerly “group G”; CC= Calico Creek source area, formerly “group H”.

area near Calico Creek in the upper Teklanika drainage (Figure 3.1). Nevertheless, in the discussion of the artifact groups below, I note that artifacts assigned to groups G and H may have come from the Talkeetna Mountains area and upper Teklanika drainage; therefore, when presenting and discussing these further I refer to them as the Talkeetna Mountains source area and the Calico Creek source area to highlight their potential as known sources. Coffman and Rasic (2015) did not report comparative geochemical data to establish if groups G and H artifacts match geochemical signatures from Talkeetna and Teklanika rock samples, or fully characterize these source localities. A single rhyolite sample that matches Group H was encountered as an alluvial cobble in the upper Teklanika drainage, but we do not currently know the exact nature of the outcrop contributing to this alluvium (Coffman, personal comm. 2021). More work needs to be done to establish these locations as toolstone sources tied to group G and H artifacts.

Group A represents the largest group membership (39.4%) of all sampled rhyolite artifacts (Table 3.8), replicating the high numbers of this grouping observed by Coffman and Rasic (2015) in their analysis that reached outside the Nenana valley. Group A loads positively on the PC 1 axis and mostly positive on the PC 2 axis, characterized by high Rb, very low Sr, high Y, moderate Zr, and moderate Nb compared to other groups (Tables 3.9 and 3.10). Group B rhyolite comprises 6.2% of sampled artifacts and loads negatively on the PC 1 axis and mostly positive on the PC 2 axis. It is characterized by moderately high Rb, low Sr, moderately low Y, low Zr, and moderate Nb relative to other groups. Seventeen artifacts, 2.5% of the total, are assigned to Group

C. Group C loads negatively on the PC 1 axis and mostly positive on the PC 2 axis and is characterized by moderate Rb, moderate Sr, high Y, high Zr, and moderate Nb. Group D, representing 1.2% of the total, loads negatively on the PC 1 axis and mostly negative on the PC 2 axis. It is characterized by very low Rb, moderate Sr, high Y, high Zr, and moderate Nb. Group E loads negatively on the PC 1 axis and positively on the PC 2 axis, consists of 2.2% of the total, and is characterized by moderate Rb, high Sr, moderate Y, moderate Zr, and moderate Nb. Group F comprises 1.7% of sampled artifacts, loads negatively on the PC 1 axis and mostly positive on the PC 2 axis, and is characterized by moderately low Rb, high Sr, high Y, high Zr and moderate Nb. Talkeetna Mountains (Group G) rhyolite makes up 2.9% of sampled artifacts. This group loads negatively on the PC 1 axis and mostly negative on the PC 2 axis, reflecting moderately low Rb, moderate Sr, low Y, very low Zr, and low Nb. Rhyolite artifacts belonging to Calico Creek, 3.1% of the total analyzed, load negatively on the PC 1 axis and both equally positive and negative on the PC 2 axis. This group is characterized by moderate Rb, moderately low Sr, and moderate Y, Zr, and Nb. Group I makes up 13.0% of analyzed artifacts and loads positively on the PC 1 axis and equally positive and negative on the PC 2 axis. It is characterized by moderately high Rb, low Sr, low Y, high Zr, and moderately low Nb compared to other groups. Group J rhyolites, 7.8% of total, load equally positive and negative on the PC 1 axis and positive on the PC 2 axis. These rhyolite artifacts are characterized by very high Rb, low Sr, very high Y, low Zr, and high Nb (Figure 3.6; Tables 3.8-3.10).

3.5.3.2. Newly Reported Groups

This study identifies four new rhyolite groups: K, L, M, and N. Group K rhyolite comprises 3.7% of sampled artifacts, loads negatively on the PC 1 axis, and loads positively on the PC 2 axis. It is characterized by low Rb, high Sr, moderate Y, very high Zr, and high Nb compared to other groups. Group L (1.5% of total) loads positively on both PC 1 and PC 2 axes and is characterized by high Rb, very low Sr, very high Y, very high Zr, and high Nb. Group M makes up 4.4% of sampled artifacts, loads negatively on the PC 1 axis and mostly positive on the PC 2 axis. These rhyolite artifacts are characterized by low Rb, very high Sr, moderately low Y, moderate Zr, and very low Nb. Group N comprises 3.8% of the artifact sample, loads negatively on both PC 1 and PC 2 axes, and are characterized by very low Rb, very high Sr, and low Y, Zr, and Nb compared to other groups (Figure 3.6; Tables 3.9, 3.10). More sampling will be needed to further corroborate these results.

In summary, there are at minimum 14 rhyolite groups represented in the Nenana valley archaeological assemblages, increasing the diversity of rhyolites coming from potentially different sources by at least 40% beyond Coffman and Rasic's (2015) initial assessment.

3.5.4. Combining Geochemical Analyses of Geological and Archaeological Samples to Define Sources

3.5.4.1. Rhyolite Artifacts and Rhyolite Alluvium

Comparison of rhyolite artifact groups A-N (including Talkeetna Mountains and Calico Creek) with the four alluvial sample sets by PCs 1 and 2 (91.1% of the total variance) indicates separation of groups B, C, D, E, F, K, M, N, and Talkeetna Mountains rhyolite from the alluvial samples; however, five groups, A, I, J, L, and Calico Creek, overlap with several alluvial sample locations (Figure 3.7; Table 3.12). By examining just these five artifact groups and alluvial samples by PCs 1 and 3, only one California Creek sample overlapped with the Group J ellipse (Figure 3.8a). When isolating just Group J and the alluvium against PCs 3 and 5, the California Creek sample no longer falls within the Group J ellipse (Figure 3.8b). Therefore, none of the alluvial samples collected in this study clearly pairs with the artifact groups.

Considering only unassigned artifacts and alluvium in a comparison of PCs 1 and 2, only eight artifacts appear close to any alluvium sample (Figure 3.9a), but examination of PCs 1 and 3 show five of these eight artifacts plot away from their respective alluvium sample (Figure 3.9b), and PCs 1 and 4 show separation of the remaining three artifacts from the alluvium sample (Figure 3.9c). Thus, no unassigned rhyolite artifacts were paired with alluvium samples.

3.5.4.2. Rhyolite Artifacts and Outcrops

When comparing artifact rhyolite groups and unassigned rhyolite artifacts with rhyolite outcrops, PCs 1 and 2, comprising 90.1% of the total variance, illustrate artifact rhyolite groups K, M, and N separate from the outcrop ellipses (Figure 3.10a; Table 3.13). PCs 1 and 3 show Talkeetna rhyolite removed from Ferry 1; groups C, I, Talkeetna, and Calico Creek rhyolites removed from Ferry 3; groups B, C, J, Talkeetna,

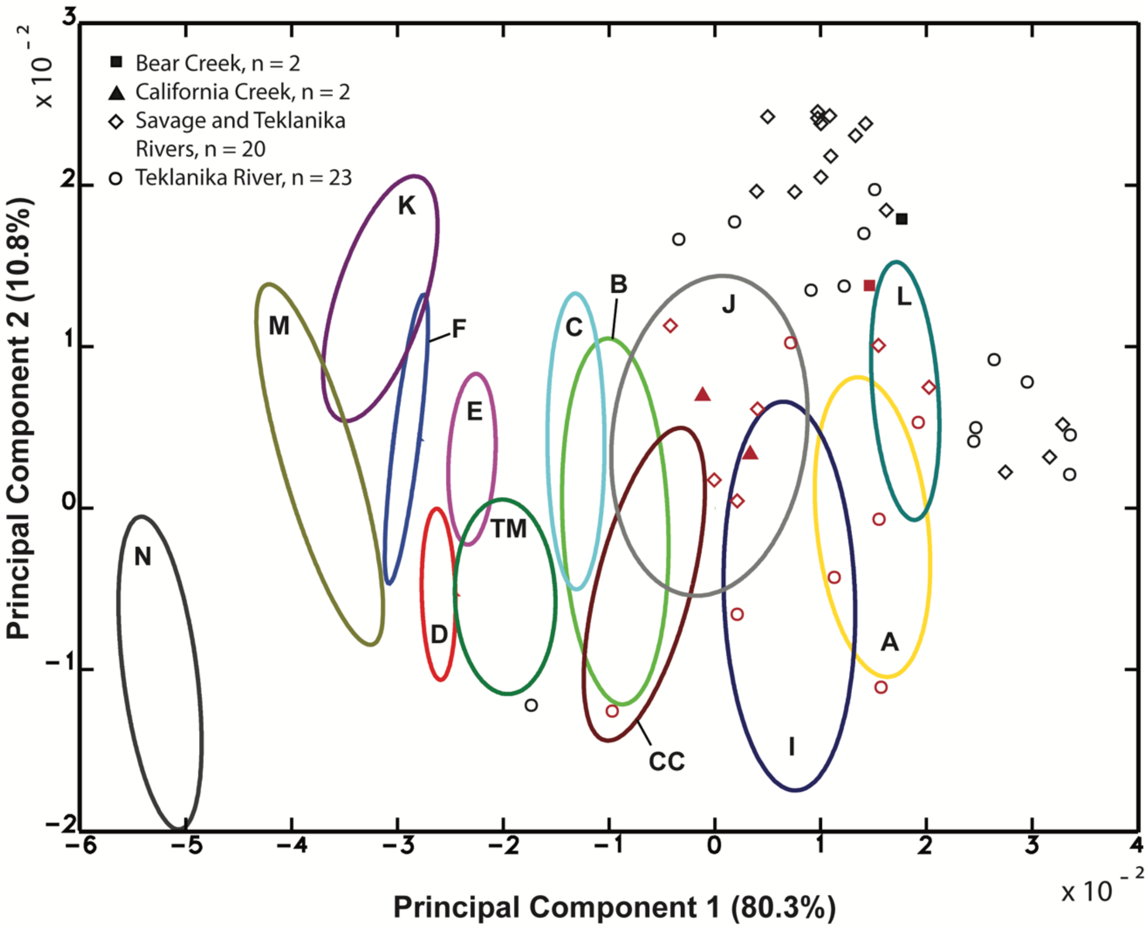


Figure 3.7. Logged (base 10) biplot comparing rhyolite artifact groups (ellipses) and unassigned artifacts with alluvial samples by scores of principal components 1 and 2. Alluvial samples overlapping with artifact rhyolite groups are highlighted in red. Ellipse confidence intervals drawn at 90%. TM = Teklanika Mountains source area; CC= Calico Creek source area.

Table 3.12. Eigenvalue, percentage of variance, and element score for each principal component calculated from the variance-covariance matrix of concentration data (log-10 ppm) for rhyolite artifact and alluvial samples.

Principal Component		Eigenvalue	% Variance	Cumulative % Variance	
1		0.2587	80.28	80.28	
2		0.0347	10.79	91.07	
3		0.0147	4.56	95.63	
4		0.0104	3.23	98.86	
5		0.0036	1.14	100.00	
Element	**PC 1**	**PC 2**	**PC3**	**PC4**	**PC5**
Rb	0.28	0.27	0.33	0.85	-0.12
Sr	-0.93	0.26	0.19	0.16	0.03
Y	0.20	0.50	0.42	-0.29	0.67
Zr	0.01	0.49	-0.82	0.20	0.23
Nb	0.10	0.61	0.08	-0.36	-0.70

Table 3.13. Eigenvalues, percentage of variance, and element scores for each principal component calculated from the variance-covariance matrix of concentration data (log-10 ppm) for rhyolite artifact and outcrop samples.

Principal Component		Eigenvalue	% Variance	Cumulative % Variance	
1		0.2664	59.70	59.70	
2		0.1358	30.44	90.14	
3		0.0236	5.29	95.43	
4		0.0127	2.85	98.28	
5		0.0077	1.72	100.00	
Element	**PC 1**	**PC 2**	**PC3**	**PC4**	**PC5**
Rb	0.27	0.55	0.32	0.69	0.20
Sr	-0.95	0.23	0.19	0.08	0.11
Y	0.15	0.46	0.12	-0.65	0.58
Zr	-0.07	0.39	-0.91	0.13	0.04
Nb	0.04	0.53	0.15	-0.29	-0.78

and Calico Creek rhyolites removed from Ferry 4; groups I and Calico Creek rhyolites removed from Ferry 5; and groups I and L removed from both Sugarloaf and Triple Lakes outcrops (Figure 3.10b). Additional rhyolite artifact groups separated from outcrops by PCs 1 and 4 are D and E removed from Ferry 1 (Figure 3.10c), and artifact

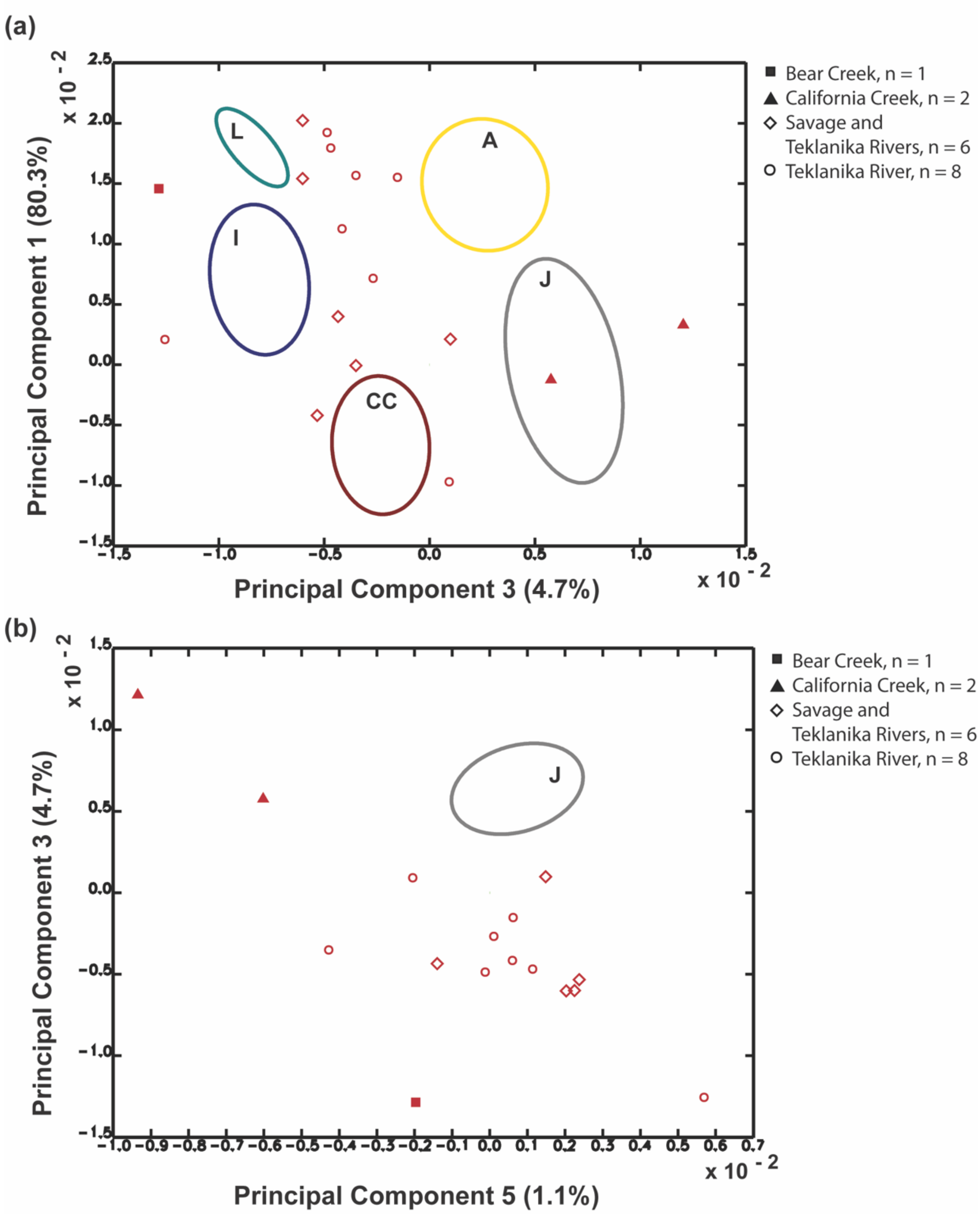


Figure 3.8. Logged (base 10) biplots comparing select rhyolite artifact groups (ellipses) with alluvial samples by scores of principal components 1 and 3 (a) and principal components 3 and 5 (b). Alluvial samples positioned within or near a group ellipse in Figure 3.7 are shown here in red. CC= Calico Creek source area. Ellipse confidence intervals drawn at 90%.

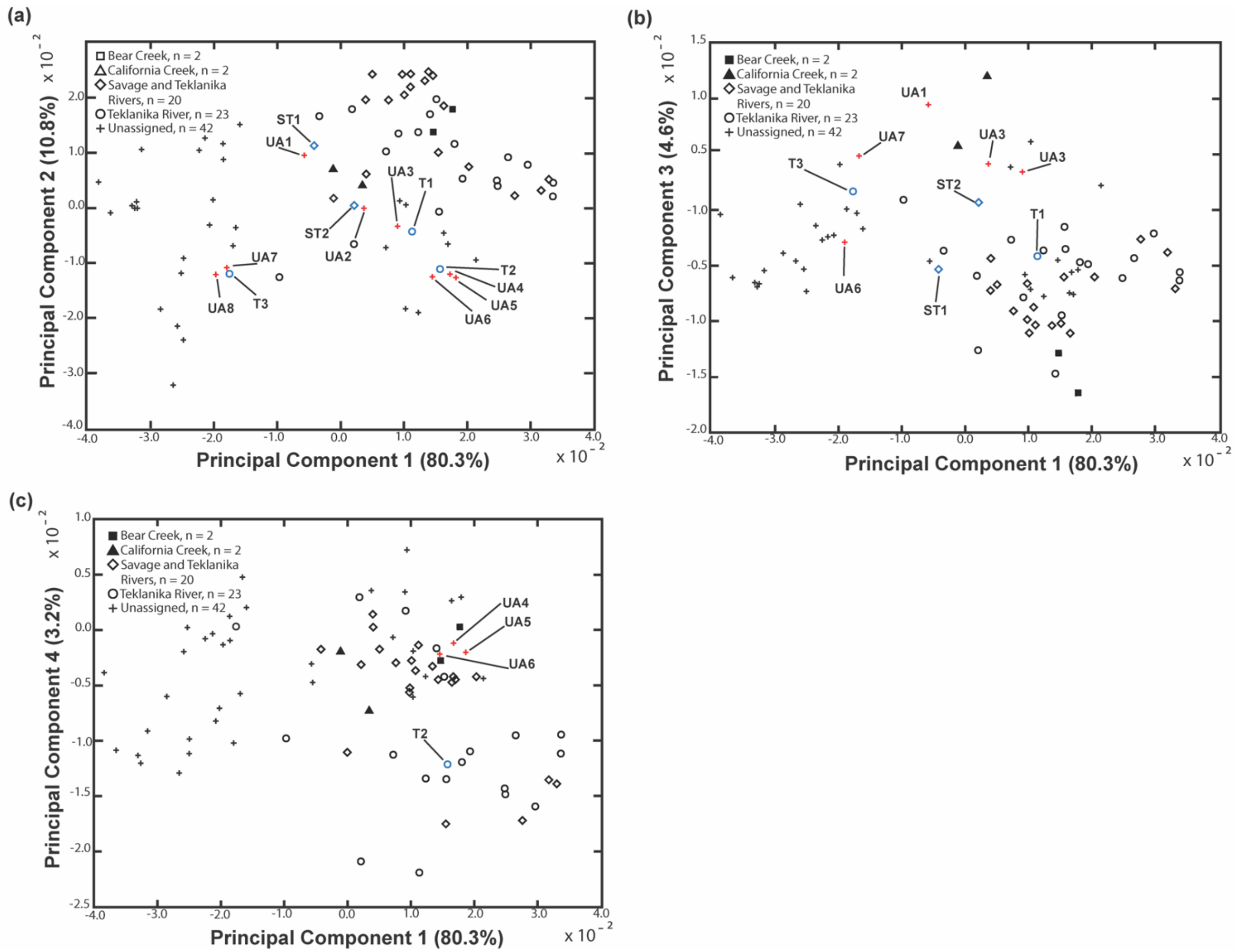


Figure 3.9. Logged (base 10) biplots comparing unassigned artifacts and alluvium by (a) principal components 1 and 2, (b) principal components 1 and 3, and (c) principal components 1 and 4. Unassigned artifacts discussed in text denoted by red crosses and the label "UA"; alluvial samples discussed in text denoted by blue alluvial symbol and labeled. ST = Savage and Teklanika Confluence sample; T = Teklanika River sample.

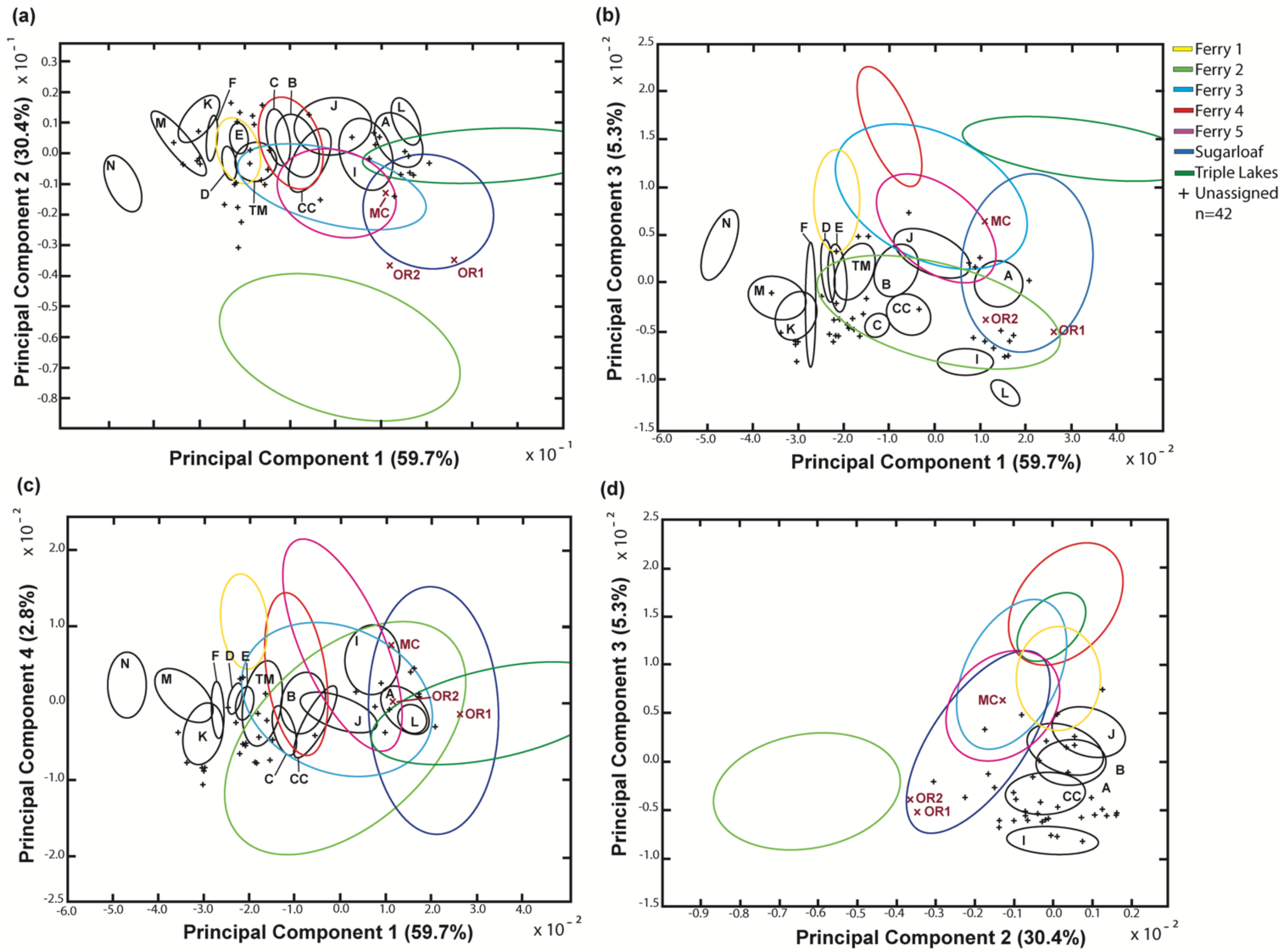


Figure 3.10. Logged (base 10) biplots comparing artifact rhyolite group ellipses, unassigned artifacts, and outcrop samples (ellipses) by (a) scores of principal components 1 and 2, (b) principal components 1 and 3, (c) principal components 1 and 4, and (d) principal components 2 and 3. Artifacts assigned to Triple Lakes denoted by red crosses and labeled according to site assemblages (Moose Creek C3 [MC]; Owl Ridge C3 [OR1 and OR2]). TM= Talkeetna source area; CC= Calico Creek source area. Ellipse confidence intervals drawn at 90%.

groups separated by PCs 2 and 3 are groups B and J from Ferry 3; Group J from Ferry 5; and Group A from Triple Lakes (Figure 3.10d). Although artifact Group B appears to overlap slightly with the Ferry 5 outcrop, a 3D plot of artifacts and outcrop samples show they are clearly separate (Figure 3.11). To summarize, no artifact groups can be unequivocally linked with the known rhyolite outcrops in the Nenana valley.

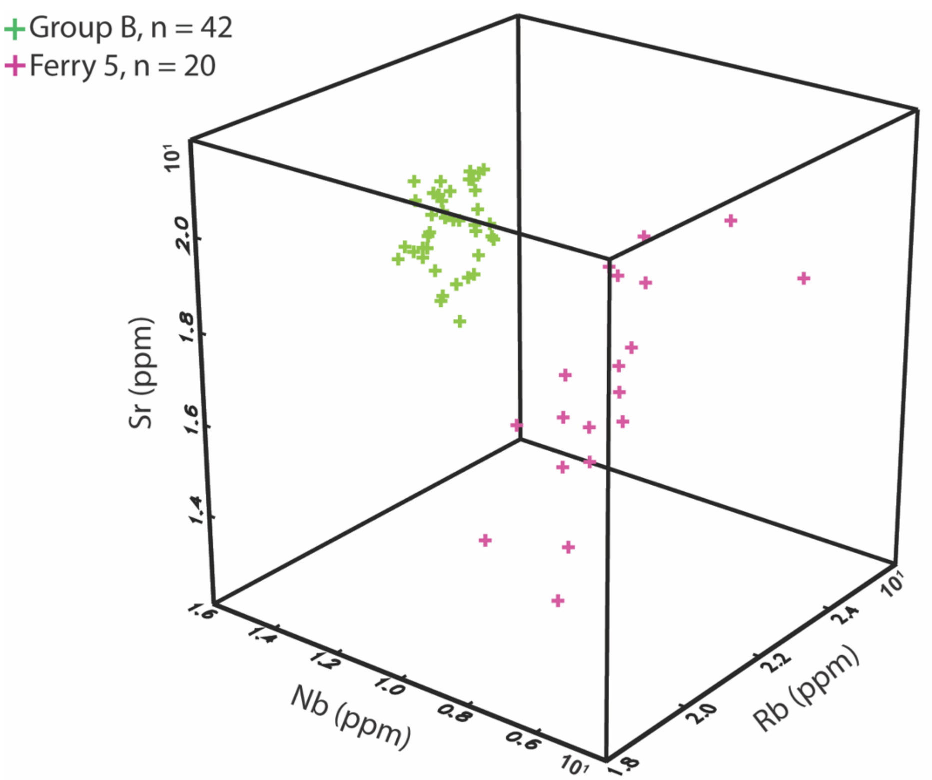


Figure 3.11. Logged (base 10) 3D plot of rhyolite outcrops sampled in this study, comparing Sr, Nb, and Rb (ppm) values of Group B artifacts and Ferry 5 outcrop samples.

3.5.4.3. Triple Lakes: A New Source

Three of the 42 rhyolite artifacts unassignable to an artifact group appear to match one of the outcrops presented above, Triple Lakes. These three artifacts are labeled OR1, OR2, and MC in Figure 3.10a-d, where they repeatedly fall within (or adjacent to) the space of the same confidence ellipse representing that source's variation. These artifacts consist of one flake fragment and one secondary cortical spall from Owl Ridge C3 (~11.3-11.2 ka) and a lanceolate bifacial point from Moose Creek C3 (~6.5 ka). The Moose Creek C3 biface falls within the 90% confidence interval ellipses of the Triple Lakes outcrop sample when comparing the first four PCs in this analysis. It also, however, lies within the ellipses of the Ferry 3 outcrop sample when comparing these same PCs, and within the ellipses of the Ferry 5 outcrop sample when comparing PCs 1-3 (Figure 3.10a-d). Group membership probabilities based on MD calculations predict this biface belongs to the Triple Lakes sample at 68% probability versus 0.006 % probability it belongs to Ferry 3 and 32% probability of it belonging to Ferry 5 (Table 3.14). Given these probabilities and the lack of overlap between this artifact and the Ferry 5 ellipses in two of the four PC comparisons, this artifact is assigned to Triple Lakes. The two artifacts from Owl Ridge C3, a flake (OR1) and cortical spall (OR2), are consistently positioned within the PC 1-4 ellipses of Triple Lakes (Figure 3.10a-d). Artifact OR2, however, lies just outside the confidence ellipse for Triple Lakes rhyolite in the biplot comparing PC 1 and PC 2. MD calculations predict this piece belongs to Triple Lakes at 31% probability, but because it is from the same site and cultural component as the other Owl Ridge sample (OR1), assignment to Triple Lakes cannot be confidently ruled out. Increased sampling of rhyolites from Nenana valley assemblages and outcrop sources are needed to confirm these results. There are two interesting observations to mention. Given the age of Owl Ridge C3, the Triple Lakes source has been used since the early Holocene. If the assignment of the OR2 artifact is maintained

Table 3.14. Group probabilities of artifact membership in each rhyolite outcrop group based on Mahalanobis distance calculations.

Artifact	Rhyolite Outcrop Group Membership Probabilities		
	Ferry 3	*Ferry 5*	*Triple Lakes*
MC	0.006	32.306	68.241
OR2	0.001	0.373	31.569

by future analyses, then it is quite interesting that it expresses cortex ~50 km from its source.

None of the remaining outcrop or alluvium geological samples presented here match the artifact groups. As mentioned above, however, artifact groups G and H have tentatively been attributed to the Talkeetna Mountains and upper Teklanika river drainage, respectively, and 41 artifacts in the archaeological sample have been attributed to these sources. Though we do not yet know the exact locations of these two groups and more work needs to be done to confirm that general locations given for them are appropriate, we attribute artifacts of groups G and H to these areas in discussion below. This leaves a minimum of 12 geographically unknown rhyolite groups used by prehistoric peoples from the Nenana valley: A, B, C, D, E, F, I, J, K, L, M, and N.

3.5.5. Rhyolite Transport, Provisioning Strategies, and Diversity

3.5.5.1. Rhyolite Transport

Based on the geochemical results presented above, there are 44 artifacts that can be tied to on-the-ground source locations for which a specific transport distance can be ascertained. Above, I defined a new known source, Triple Lakes, that accounts for three artifacts. In addition, there are 20 artifacts tied to the Talkeetna Mountains source area and 21 artifacts from the Calico Creek source area. Artifacts from Triple Lakes moved 47 km from southeast to northwest when taken to the Owl Ridge site and 41 km from south to north when taken to Moose Creek (Figure 3.1). Artifacts from the Talkeetna source area moved from south to north over 200 km into the Nenana valley and were discarded at Dry Creek (200 km), Panguingue Creek (202 km), Houdini Creek (205 km), Little Panguingue Creek (206 km), Walker Road (210 km), and Moose Creek (220 km). Rhyolite from the Calico Creek area moved as much as 41 km from southwest to northeast to Panguingue Creek, 42 km to Dry Creek, and 50 km to Walker Road. Keeping in mind that these are all straight-line distances between source areas and sites, it is important to note that at distances > 40 km, following the parameters outlined at the outset of this study, they would all be considered nonlocal raw materials, given that they have not yet been encountered in alluvium closer to the sites.

Another, more indirect means of measuring rhyolite transport is to consider frequencies of artifact groups and cortex present in each artifact group through time. A total of 207 artifacts came from Allerød assemblages, 51 from YD assemblages, 242 from early Holocene assemblages, and 175 from middle Holocene assemblages (Table 3.9). The total number of rhyolite groups varies within each time period: there are a minimum of 12 groups present during the Allerød, five during the YD, 13 during the early Holocene, and 12 during the middle Holocene (Table 3.15). Table 3.15 shows that Nenana valley folks maintained the use of at least five varieties of rhyolite from the late Pleistocene through the middle Holocene. A Kruskal-Wallis test showed that use of specific rhyolite groups in each time period differs significantly: $H(3) = 18.96$, $p <$

Table 3.15. Total number of artifact rhyolite groups used during each time period and the mean and median of artifact rhyolite groups used at each site within the time period.

Time Period	Total Number of Rhyolite Groups	μ	M
13.5 – 12. 8 ka	12	5.0	5.0
12.5 - 11.7 ka	5	3.3	3.0
11.7 – 9.0 ka	13	5.2	6.0
8.0 – 3.5 ka	12	3.9	4.0

A Kruskal-Wallis H test confirms that the differences in overall number of rhyolite groups at sites is statistically significant between these time periods (H= 18.96, df=3, p <0.001).

0.001 (Table 3.15). A post hoc multiple comparison test revealed significant differences between the Allerød and YD, the YD and middle Holocene, and the early and middle Holocene. However, there was no significant difference between the Allerød and early Holocene, Allerød and middle Holocene, or YD and early Holocene (Kruskal-Wallis multiple comparison testing, p= > 0.05). Several rhyolite groups have high frequencies among the total sampled population and site occurrence. Group A rhyolite comprises 39.4% of all artifacts and is present in 95% of all site assemblages in the valley (Table 3.9; Figure 3.12). This rhyolite was continuously used through time (Figure 3.13a). Group I is the second-most common rhyolite group sampled in both total sample number (13%) and assemblage frequency (68.4%), being present at nearly every site in the valley (Table 3.9; Figure 3.12). Group I rhyolite is represented in all time periods (Figure 3.13a). Two other rhyolite groups have high total sample frequencies but are distributed variably in site assemblages, site locations, and time periods. For example, Group J is third-most common in total sample number (7.8%) and occurs in six assemblages (31.5% of total) at four site locations and in all time periods except the early Holocene

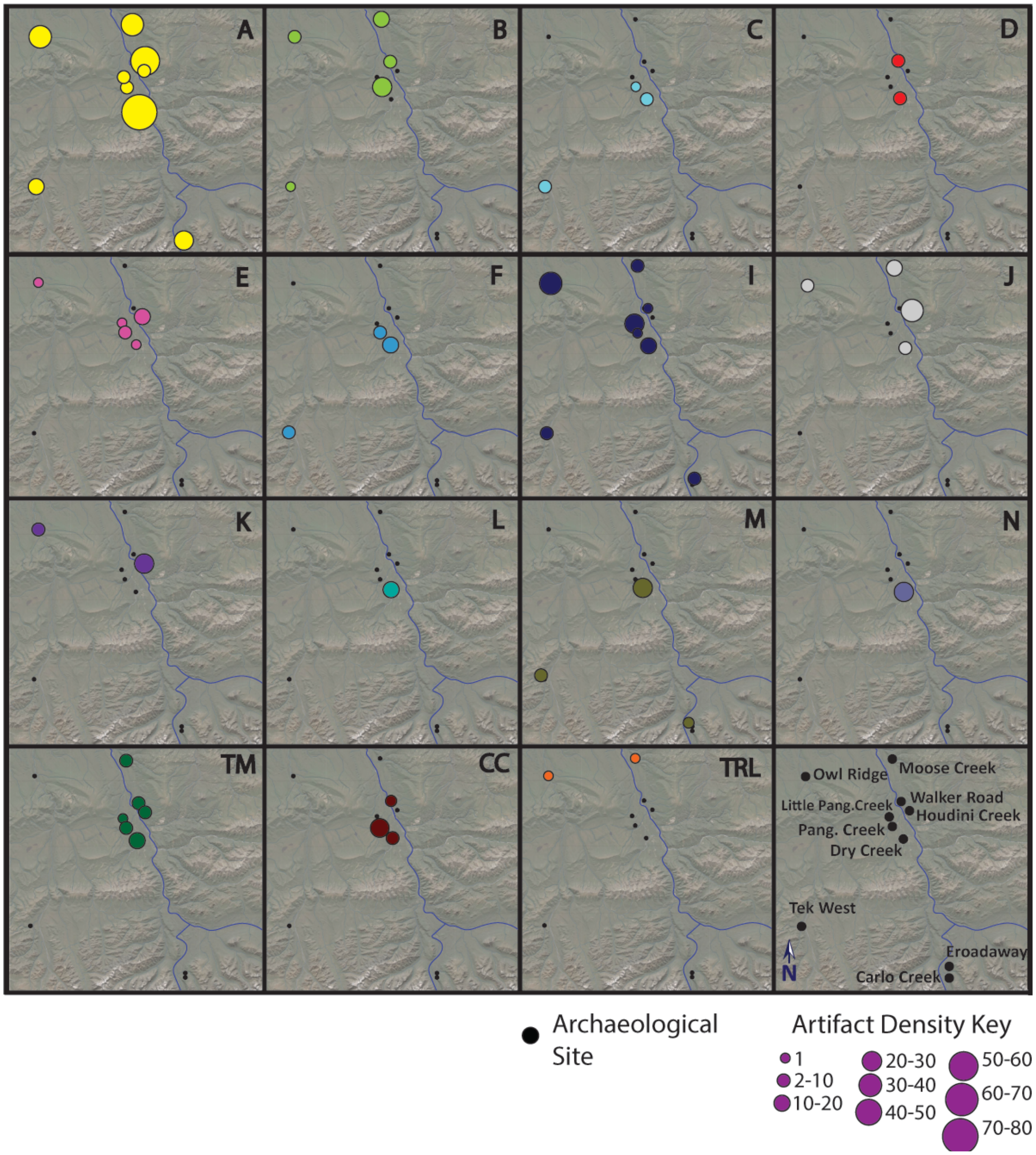
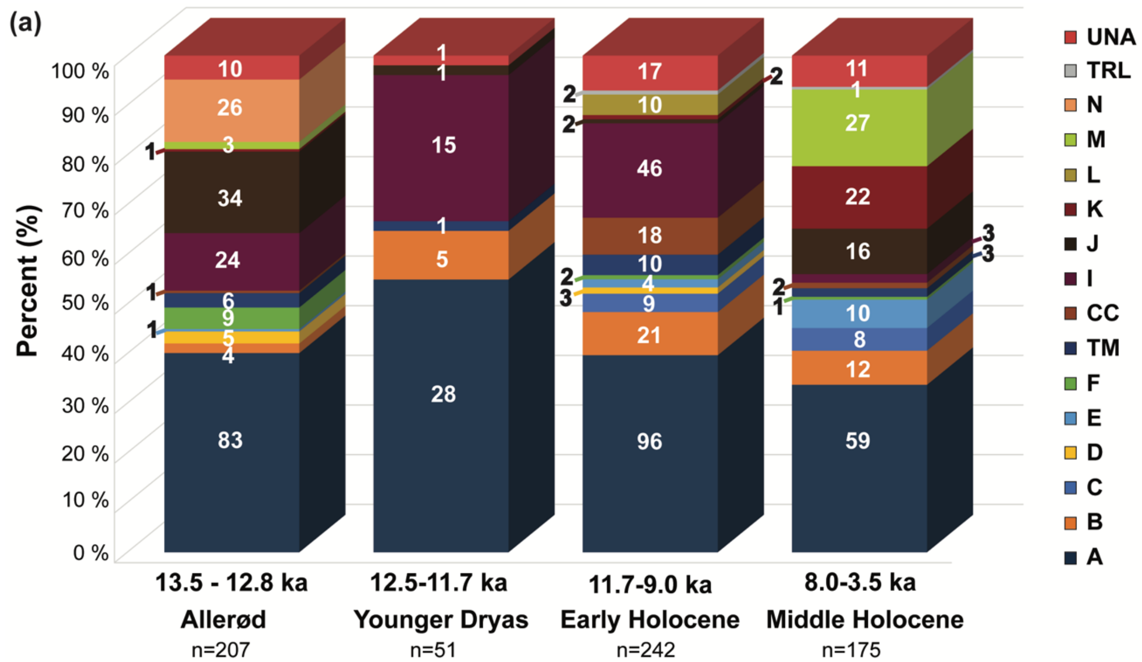


Figure 3.12. Spatial distribution and proportion of rhyolite artifact groups in the Nenana valley.

(Table 3.9; Figures 3.12, 3.13a). Artifacts from Group B are 6.2% of the total sample and occur in 11 assemblages (57.7% of total) at four site locations in all time periods (Table 3.9; Figures 3.12, 3.13a). These four represent the mostly widely used groups in the Nenana valley.

By contrast, most of the other rhyolite groups, C, D, E, F, K, L, M, N and Calico Creek rhyolite, were found in very low overall frequencies (≤ 4.4%) and/or in few sites (≤ 5) and site assemblages (≤ 26.5%) (Table 3.9; Figures 3.12, 3.13a). Further, these low-incident rhyolite groups occur sporadically through time (Table 3.9). The Triple Lakes source is also a low-occurrence rhyolite, represented by only three artifacts (0.4%) from two sites, three site assemblages (10.5%), and in only two time periods (early-middle Holocene). Talkeetna rhyolite is exceptional because though it is also present in low total sample frequencies (2.9%), it occurs in more assemblages (42.1%), site locations (eight), and in all time periods compared to other low-frequency rhyolite groups (Table 3.9; Figures 3.12, 3.13).

Cortex amount varies among rhyolite groups (Table 3.16; Figure 3.13b). Group A possesses the most cortical pieces out of all groups (23.1%). These pieces are present in every time period in nine assemblages (47.7%). Group B exhibits the second-highest incidence of cortex (19.2%) distributed among four site assemblages (21%) and three time periods (Allerød-early Holocene), and Group I exhibits the third-highest incidence of cortex (15.4%), present in three site assemblages (15.8% of total) and three time periods (Allerød, YD, and middle Holocene).



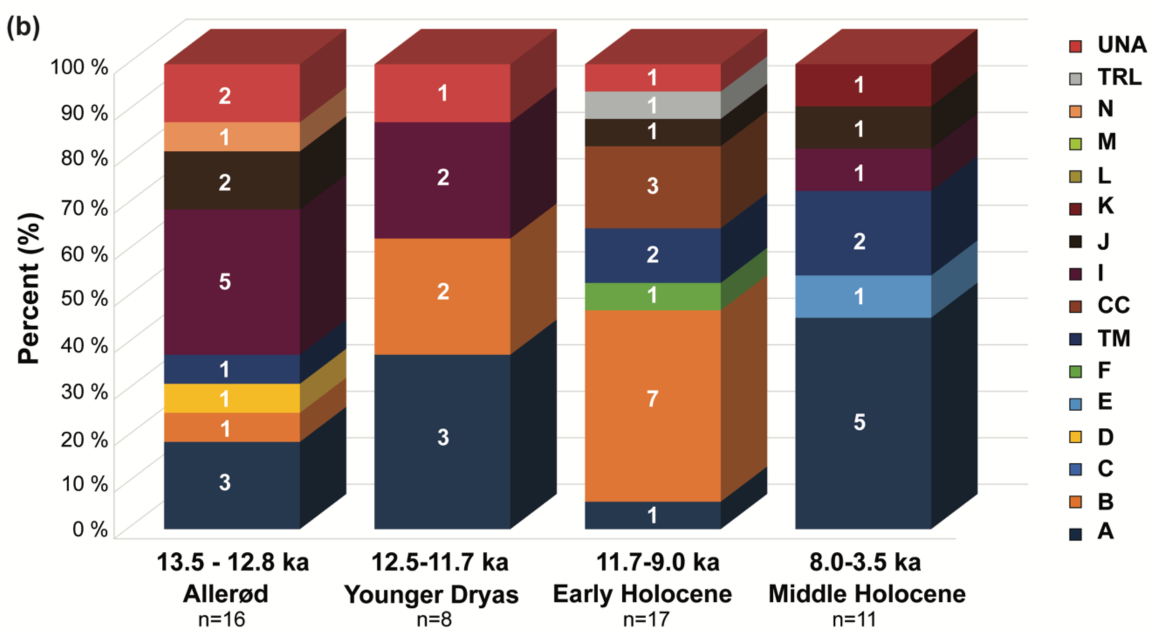


Figure 3.13. Stacked bar charts showing (a) proportions and numbers of rhyolite artifact groups by time, and (b) cortex amount by group by time. CC = Calico Creek artifacts; TM= Talkeetna Mountain artifacts; TRL = Triple Lakes artifacts; UNA= unassigned artifacts. Raw counts are given within each bar section, and percentages are measured along the y-axis.

Talkeetna, Group J, and Calico Creek rhyolites have moderately low amounts of cortex, 9.6%, 7.7%, and 5.8% of total, respectively. These groups occur in a handful of assemblages, 21.1%, 15.8%, and 5.3%, respectively, and are represented in three time periods (Allerød and early-middle Holocene for Group J and Talkeetna rhyolite, and only the early Holocene for Calico Creek rhyolite). Very low cortex amounts are observed in the D, E, F, K, and N rhyolite groups, each containing just one artifact with cortex (1.9% each) in the Allerød (groups D and N), early Holocene (Group F), and middle Holocene (groups E and K). Cortical pieces are completely absent in rhyolite groups C, L, and M (Table 3.16; Figure 3.13b).

Unknown artifact groups A, I, and B are found in high sample and assemblage frequencies with moderate-to-high amounts of cortex. Conversely, unknown groups C, D, E, F, K, L, M, and N exhibit low sample frequencies, low assemblage distribution, sporadic use through time, and low-to-absent cortex frequencies. Learning from the cortical piece of Triple Lakes rhyolite found at Owl Ridge, small amounts of artifacts with cortex can travel significant distances (> 40 km) so that we cannot simply use the presence or absence of cortex as a reliable determinant of transport distance. Instead, relative amounts of cortex are used to infer degrees of transport. Although Group J rhyolite is present in high total sample frequency, over half (60%) of the total group sample is located at just one Allerød site, Walker Road (7.9% of total) with low assemblage distribution and low cortex amounts. Sample frequency, assemblage distribution, and cortex frequencies indicate unknown groups A, B, and I are probably

Table 3.16. Count and percentage of artifacts with cortex in each archaeological assemblage and their assigned artifact rhyolite group.

		Rhyolite Group															
Assemblages by Time	**Total (%)**	**A**	**B**	**C**	**D**	**E**	**F**	**TM**	**CC**	**I**	**J**	**K**	**L**	**M**	**N**	**TRL**	**Una[1]**
13.5-12.8 ka																	
Dry Creek C1	1 (1.9)														1 (1.9)		
Walker Road	7 (13.4)	2 (3.9)	1 (1.9)		1 (1.9)			1 (1.9)			2 (3.9)						
Moose Creek C1	2 (3.9)	1 (1.9)															1 (1.9)
Owl Ridge C1	6 (11.5)									5 (9.6)							1 (1.9)
Eroadaway	0 (0.0)																
Subtotal	16 (30.8)																
12.5-11.7 ka																	
Moose Creek C2	5 (9.6)	2 (5.7)	1 (1.9)							1 (1.9)							1 (1.9)
Owl Ridge C2	2 (3.9)	1 (1.9)								1 (1.9)							
Panguingue C1	1 (1.9)		1 (1.9)														
Subtotal	8 (15.4)																
11.7-9 ka																	
Dry Creek C2	4 (7.7)	1 (1.9)						1 (1.9)	1 (1.9)		1 (1.9)						
Owl Ridge C3	1 (1.9)															1 (1.9)	
Panguingue C2	12 (23.0)		7 (13.4)				1 (1.9)	1 (1.9)	2 (3.9)								1 (1.9)

Table 3.16 Continued.

Assemblages by Time	Total (%)	A	B	C	D	E	F	TM	CC	I	J	K	L	M	N	TRL	Una[1]
Little Panguingue Creek C2	0 (0.0)																
Subtotal	17 (32.7)																
8-3.5 ka																	
Houdini Creek	4 (7.7)					1 (1.9)		2 (3.9)				1 (1.9)					
Tek West C3	1 (1.9)	1 (1.9)															
Carlo Creek C2	2 (3.9)	2 (3.9)															
Moose Creek C3	0 (0.0)																
Panguingue C3	1 (1.9)	1 (1.9)															
Moose Creek C4	3 (5.8)	1 (1.9)								1 (1.9)	1 (1.9)						
Dry Creek C4	0 (0.0)																
Subtotal	11 (21.2)																
Total (%)	**52 (100)**	**12 (23.1)**	**10 (19.2)**	**0 (0.0)**	**1 (1.9)**	**1 (1.9)**	**1 (1.9)**	**5 (9.6)**	**3 (5.8)**	**8 (15.4)**	**4 (7.7)**	**1 (1.9)**	**0 (0.0)**	**0 (0.0)**	**1 (1.9)**	**1 (1.9)**	**4 (7.7)**

[1] Number of unassigned artifacts.

local to the Nenana valley, while unknown groups C, D, E, F, J, K, L, M, and N represent rhyolites likely procured from nonlocal sources, perhaps outside the study area.

3.5.5.2. Rhyolite Provisioning Strategies

Figure 3.14 presents proportions of local and nonlocal rhyolites within each assemblage based on the transport determinations determined from presence/absence of cortex and transport distances presented above. Allerød assemblages Walker Road, Moose Creek C1, Owl Ridge C1, and Eroadaway are dominated by local rhyolites (60%, 95%, 98%, and 86%, respectively), but Dry Creek C1 rhyolites are nearly all nonlocal rhyolites (98%). All YD assemblages are dominated by local rhyolites (92% at Moose Creek C2, 100% at Owl Ridge C2, and 75% at Panguingue Creek C1). During the early Holocene, Owl Ridge C3, Dry Creek C2, and Little Panguingue Creek are dominated by local rhyolite (96%, 76%, and 93%, respectively), while Panguingue Creek C2 has more nonlocal rhyolite (53%). Four middle Holocene assemblages are dominated by local rhyolite (Teklanika West C3 [64%], Carlo Creek C2 [100%], Moose Creek C3 [75%], and Panguingue Creek C3 [100%]), with three assemblages dominated by nonlocal rhyolites (Houdini Creek [81%], Moose Creek C4 [67%], and Dry Creek C4 [87%]) (Figure 3.14; Table 3.17).

In sum, among the Allerød-aged assemblages, these data suggest people provisioned individuals with nonlocal rhyolites at Dry Creek C1 but chose to provision-place with local rhyolites at Walker Road, Moose Creek C1, Owl Ridge C1, and Eroadaway. It is noteworthy that Walker Road also contains a significant amount (40%) of nonlocal rhyolite because it may represent a base camp where we would expect both

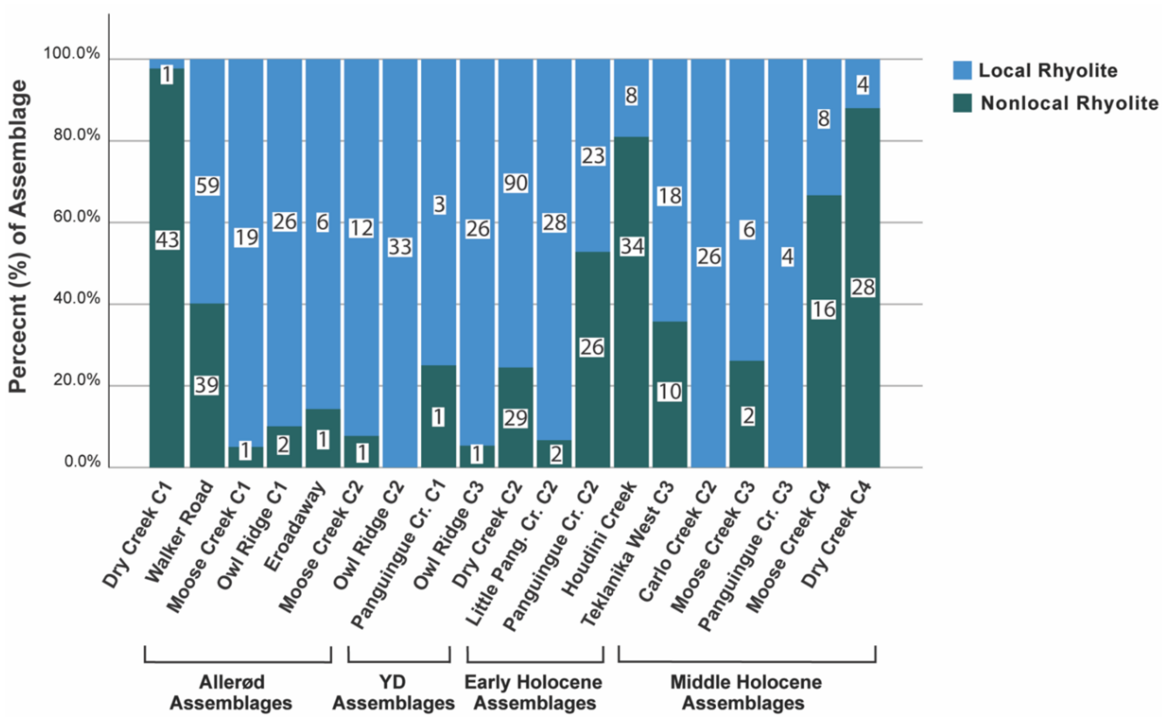


Figure 3.14. Stacked bar chart showing proportions and numbers of local and nonlocal rhyolites within each assemblage. Assemblages proceed chronologically, oldest to youngest, from left to right. Raw counts are given in each bar section, and percentages are measured along the y-axis.

local and nonlocal toolstones to be discarded. During the YD, foragers all chose to provision-place with local rhyolites, as was the case during the early Holocene, apart from Panguingue Creek C2 where people shifted towards provisioning individuals with more nonlocal rhyolites. During the middle Holocene, there is a mixture of provisioning strategies, with Houdini Creek, Moose Creek C4, and Dry Creek C4 expressing a provisioning-individuals pattern of mostly nonlocal rhyolites used, while Teklanika West C3, Carlo Creek C2, Moose Creek C3, and Panguingue Creek C3 express a provisioning-place pattern of mostly local rhyolites (Table 3.17). Below, these results are placed into a broader discussion of changing provisioning strategies through time.

Table 3.17. Summary of local rhyolite transport, nonlocal rhyolite transport, and dominant provisioning strategy within each assemblage, organized by time period.

	Local Rhyolite Transport	*Nonlocal Rhyolite Transport*	*Dominant Provisioning Strategy*
Allerød			
Dry Creek C1	Low	High	Individuals
Walker Road	High	Moderate	Place
Owl Ridge C1	High	Low	Place
Moose Creek C1	High	Low	Place
Eroadaway	High	Low	Place
YD			
Panguingue Creek C1	High	Low	Place
Moose Creek C2	High	Low	Place
Owl Ridge C2	High	Low	Place
Early Holocene			
Little Panguingue Creek C2	High	Low	Place
Owl Ridge C3	High	Low	Place
Panguingue Creek C2	High	Low	Place
Dry Creek C2	High	Low	Place
Middle Holocene			
Houdini Creek	Low	High	Individuals
Teklanika West C3	High	Moderate	Place
Moose Creek C3	High	Low	Place
Carlo Creek	High	Low	Place
Panguingue Creek C3	High	Low	Place
Moose Creek C4	Low	High	Individuals
Dry Creek C4	Low	High	Individuals

3.5.5.3. Rhyolite Diversity

To assess rhyolite diversity, Table 3.18 presents the ratio of the number of rhyolite groups and sources found in each assemblage to the total number of rhyolite groups and sources found among all assemblages within the Nenana valley. These ratios

Table 3.18. Comparison of number of artifact rhyolite groups and sources represented in each assemblage with the total number of groups and sources found in Nenana valley site assemblages.

Assemblage	Total*	*n* Groups/15 Total Groups	(%)
Allerød Assemblages			
Dry Creek C1	44	7/15	(0.47)
Walker Road	98	7/15	(0.47)
Moose Creek C1	20	4/15	(0.27)
Owl Ridge C1	28	4/15	(0.27)
Eroadaway	7	2/15	(0.13)
Subtotal	197	12/15	(0.80)
Younger Dryas Assemblages			
Moose Creek C2	13	4/15	(0.27)
Owl Ridge C2	33	3/15	(0.20)
Panguingue C1	4	3/15	(0.20)
Subtotal	50	5/15	(0.33)
Early Holocene Assemblages			
Dry Creek C2	119	8/15	(0.53)
Owl Ridge C3	27	6/15	(0.40)
Panguingue C2	49	8/15	(0.53)
Little Panguingue Creek C2	30	4/15	(0.27)
Subtotal	225	13/15	(0.87)
Middle Holocene Assemblages			
Houdini Creek	42	4/15	(0.27)
Teklanika West C3	28	6/15	(0.40)
Carlo Creek C2	26	1/15	(0.07)
Moose Creek C3	8	4/15	(0.27)
Panguingue C3	4	2/15	(0.13)
Moose Creek C4	24	4/15	(0.27)
Dry Creek C4	32	6/15	(0.40)
Subtotal	164	12/15	(0.80)
Sum of Artifacts	**636**		
** 39 unassigned artifacts excluded.*			

are high for the Allerød, early Holocene, and middle Holocene time periods (0.80, 0.87, and 0.80, respectively), reflecting higher overall diversity of rhyolites in these assemblages, whereas the total ratio for the YD period is low (0.33), reflecting low overall rhyolite diversity. Interestingly, if we examine these ratios a little more closely, there is quite a bit of variability within the time periods that tells a more complicated story. For example, when comparing the average ratio values between the YD (0.22) and the Allerød (0.32), it becomes clear that the Allerød period has as many low-diversity sites as the YD (3), showing similar low-diversity signals. Though overall diversity seems less for the YD, this might be related more to the amount of YD sites than to the fact that these sites are less diverse in their rhyolite-use pattern. Alternatively, it may also be a result of similar site function, occupation duration (with low-diversity sites being short-term occupations while Dry Creek C1 and Walker Road were longer-term occupations), or sampling. Early Holocene assemblages show an overall high diversity signal while a closer look at middle Holocene assemblages reveals an average diversity of just (0.26) with the highest number of least-diverse sites.

To further assess rhyolite group diversity, the number of rhyolite groups used at each site was compared with the total number of rhyolite artifacts studied by logging (base 10) the numbers to control for small and variable sample sizes (e.g., Dry Creek C2 sample is 119 and Panguingue Creek C3 is 4) (Figure 3.15). Linear regression evaluates diversity among assemblages by assuming that as a site's rhyolite assemblage size increases, the diversity of identified rhyolite groups should increase. The Carlo Creek C2 assemblage was omitted from this analysis because it is an outlier with only one rhyolite group present. The scatterplot shows a strong linear relationship between the number of rhyolite groups and the total number of rhyolites sampled (Pearson's R = 0.824; $p <$

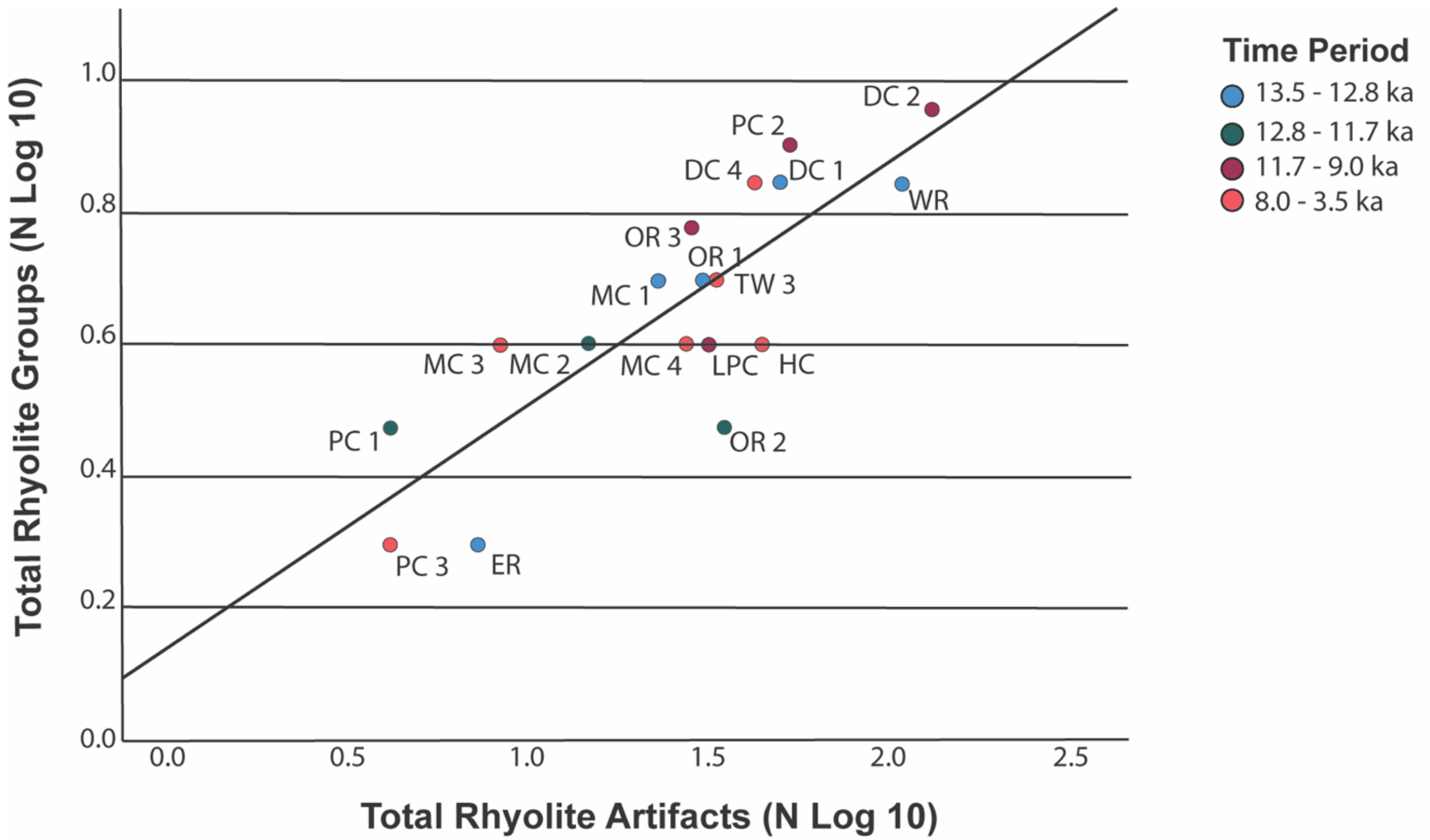


Figure 3.15. Linear regression graph comparing number of rhyolite groups (y-axis; log base 10) with total number of rhyolite artifacts sampled (x-axis; log base 10). The slope coefficient is 0.369; the intercept coefficient is 0.336; Pearson's correlation coefficient (R) is 0.824; the R^2 value is 0.659. Assemblages are color coded by time period. WR is Walker Road; DC 1, DC 2, and DC 4 are Dry Creek C1, Dry Creek C2, and Dry Creek C4, respectively; MC 1, MC 2, MC 3, and MC 4 are Moose Creek C1, Moose Creek C2, Moose Creek C3, and Moose Creek C4, respectively; OR 1, OR 2, and OR 3 are Owl Ridge C1, Owl Ridge C2, and Owl Ridge C3, respectively; PC 1, PC 2, and PC 3 are Panguingue Creek C1, Panguingue Creek C2, and Panguingue Creek C1, respectively; ER is Eroadaway; TW 3 is Teklanika West C3; HOU is Houdini Creek; and LPC is Little Panguingue Creek C2.

0.001) with randomly patterned standardized residuals (Figure 3.16) indicating this positive correlation is a reliable fit to the data. The slope coefficient for the rhyolite sample is 0.369 so the number of rhyolite groups increases by this amount for each additional artifact sampled. The adjusted R^2 value is 0.659, indicating that 66% of the variation in rhyolite groups can be explained by the number of artifacts sampled for each site.

Examining the best-fit line (Figure 3.15), nine site assemblages have more-than-expected rhyolite groups relative to the total number of rhyolite artifacts sampled, indicating greater rhyolite diversity among these assemblages. These rhyolite-diverse assemblages include Dry Creek C1, C2, and C4; Moose Creek C1, C2, and C3; Panguingue Creek C1 and C2; and Owl Ridge C3. In contrast, seven site assemblages have less-than-expected rhyolite diversity, including Walker Road, Eroadaway, Owl Ridge C2, Little Panguingue Creek, Houdini Creek, Moose Creek C4, and Panguingue Creek C3. The Owl Ridge C1 and Teklanika West C3 assemblages lie on the best-fit line with the Owl Ridge assemblage slightly more diverse than expected and the Teklanika West assemblage slightly less diverse than expected.

In sum, there are some interesting temporal patterns. Among the more diverse assemblages, the majority (60%) are terminal Pleistocene in age, with four dating to the Allerød and two dating to the YD. The reverse is true for the less-diverse assemblages, where less than 40% date to the terminal Pleistocene: two dating to the Allerød and one to the YD. Fifty percent of the less diverse assemblages are middle Holocene in age

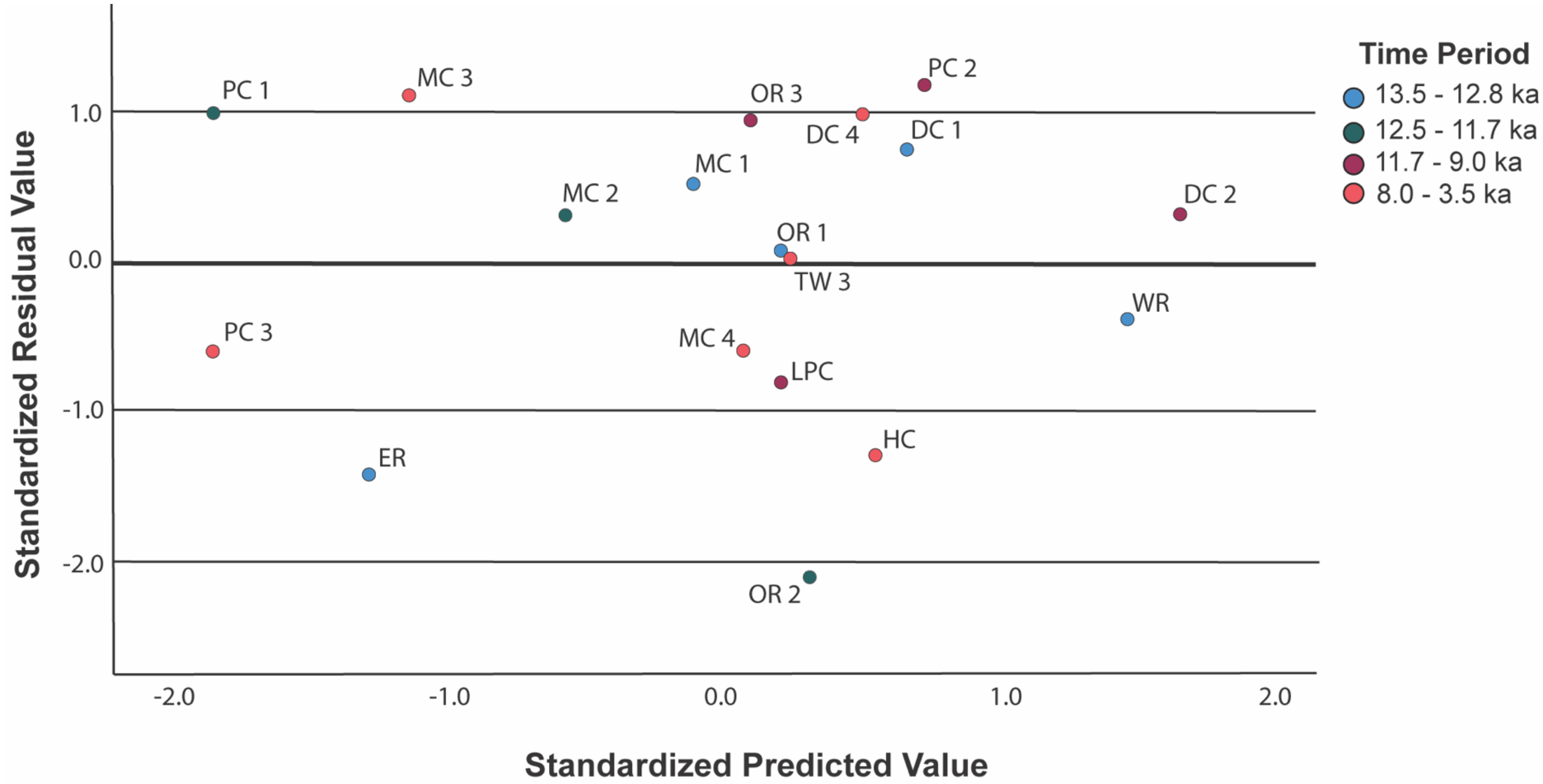


Figure 3.16. Bar chart showing mean standardized residuals (y-axis) for each archaeological assemblage (x-axis), color coded by time period. WR is Walker Road; DC 1, DC 2, and DC 4 are Dry Creek C1, Dry Creek C2, and Dry Creek C4, respectively; MC 1, MC 2, MC 3, and MC4 are Moose Creek C1, Moose Creek C2, Moose Creek C3, and Moose Creek C4, respectively; OR 1, OR 2, and OR 3 are Owl Ridge C1, Owl Ridge C2, and Owl Ridge C3, respectively; PC 1, PC 2, and PC 3 are Panguingue Creek C1, Panguingue Creek C2, and Panguingue Creek C3, respectively; ER is Eroadaway; TW 3 is Teklanika West C3; HOU is Houdini Creek; and LPC is Little Panguingue Creek.

(Figure 3.15). For each Nenana valley assemblage, Figure 3.17 compares the relative frequencies of total number of rhyolite artifacts with the number of rhyolite groups represented. Through time, there is a trend in decreasing diversity of rhyolite types relative to the total amount of rhyolite in each assemblage, especially after the early Holocene. There are also interesting spatial patterns in these diversity data (Figures 3.1 and 3.15). With regards to the position of sites relative to the river, there is an equal number of less-diverse assemblages located on either side of the river; however, it is interesting that 70% of the more-diverse assemblages are located west of the river. Perhaps more rhyolite groups are physically located in the hills between the Nenana and Teklanika rivers. Of the three sources that are now known, two of them are indeed found west of the river.

3.6. Discussion

Composition of the lithic landscape and environmental conditions shape mobile strategies that in turn influence how humans provisioned themselves (Andrefsky 1994a, 2009; Kuhn 1995). Therefore, study of the lithic landscape is critical when interpreting adaptive behaviors and provisioning strategies. Study survey results show the Nenana valley is extremely limited in high-quality, easily knappable materials (e.g., rhyolites), comprised mostly of hard-to-knap, low-quality quartzes, schists, and quartzites. Despite limited availability in outcrops and alluvium, geochemical analysis coupled with geological survey to search for usable rhyolite has resulted in the discovery of one new rhyolite source, Triple Lakes, found within Denali National Park and Preserve boundaries and reported here for the first time. Further, this study confirms two

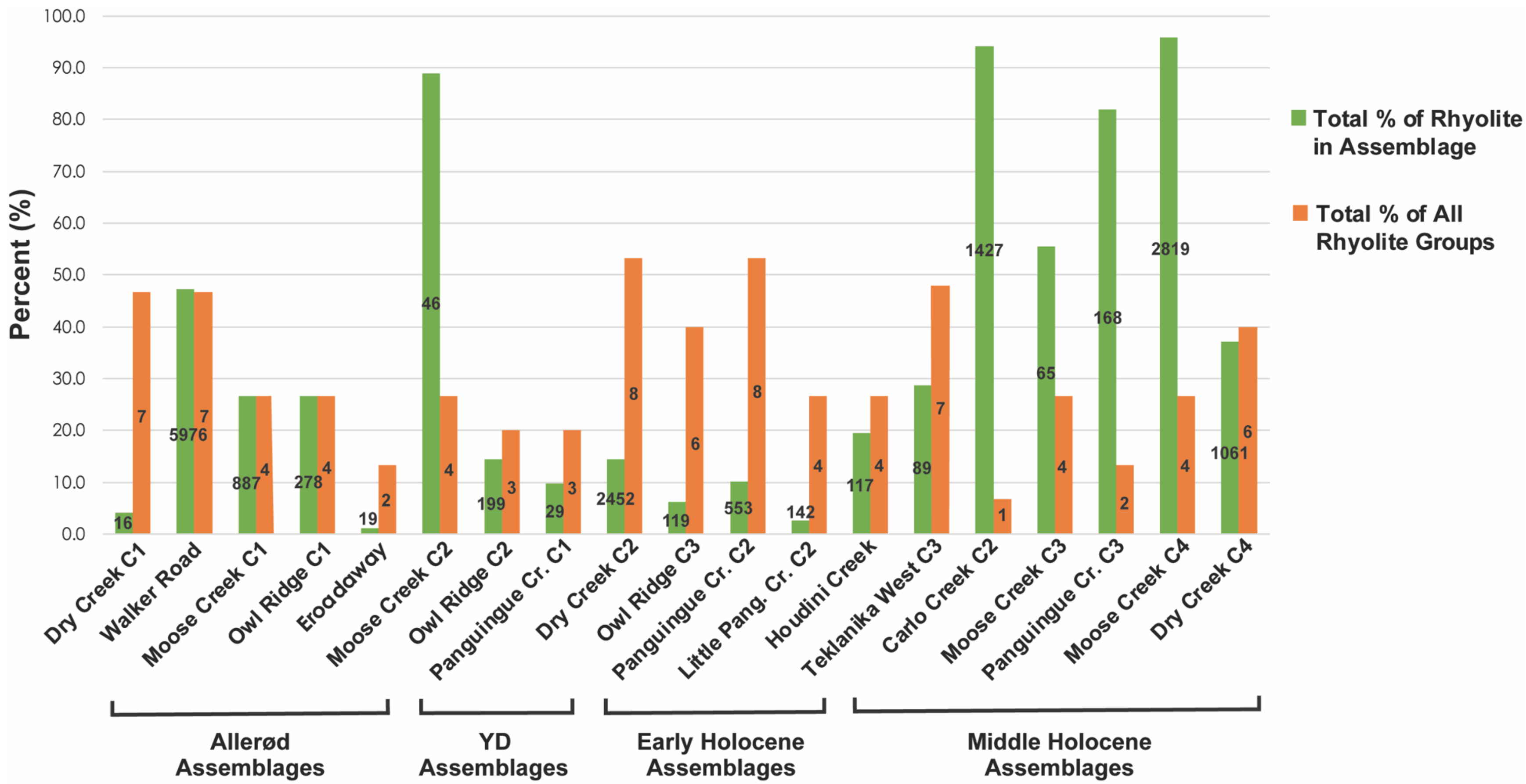


Figure 3.17. Bar chart showing proportion and numbers of rhyolite toolstone in each assemblage compared with the proportion and number of rhyolite groups within each assemblage, presented I chronological order from left to right; percentages measured along the y axis.

previously reported source areas, Calico Creek and Talkeetna Mountains, following Coffman and Rasic (2015), and demonstrates their presence in archaeological assemblages of the Nenana valley. It also confirms eight previously reported geographically unknown rhyolite artifact groups (Coffman and Rasic 2015) and reports an additional four unknown rhyolite groups that remain unknown. Discovery of a new geographically known source, additional unknown rhyolite groups, and confirmation of previously reported source areas and unknown groups are important because they provide more specific descriptions about rhyolite transport, provisioning, and landscape knowledge.

3.6.1. Rhyolite Transport

The overarching chronological patterns recognized here suggest continuous reliance on transporting local rhyolite groups (A in particular) from the initial occupation of the valley onward, but that most rhyolite outcrops in the valley, Sugarloaf Mountain, Ferry Group, and Triple Lakes, were not very desirable to any foragers no matter when or where they were operating within the region. Nenana valley occupants in all time periods chose to supplement local groups (A, B, and I) with nonlocal rhyolites. Rhyolite from the Talkeetna Mountains source area was transported over 200 km to the Nenana valley, Calico Creek transported ~40-50 km, in addition to groups C, D, E, F, J, K, L, M, and N, which were presumably transported from unknown sources outside of the valley.

Examining distributions of concentrations of each rhyolite artifact group may reveal information regarding source location (Figure 3.12). Group A cortical pieces are concentrated in far northern sites and may have originated from a northern source location, confirming an observation offered by Coffman and Rasic (2015). Group B artifacts and cortical pieces are similarly concentrated in the foothills and northern sites, and may also originate from the north, broadly consistent with a source origin in the central Alaska Range posited by Coffman and Rasic 2015. Like groups A and B, Group I has a wide distribution among all sites in the valley, but rhyolite artifact numbers and cortex values are highest at Owl Ridge, perhaps indicating a western source origin. Group J artifacts and cortical pieces are concentrated towards the east (Moose Creek C1, C2, C4, and Walker Road), supporting a possible source location east of the Nenana River, perhaps in the eastern Alaska Range or middle Tanana valley. Overall, spatial patterns show slightly more rhyolite groups found in assemblages on the west side of the Nenana River, suggesting more rhyolite sources occur to the west. For example, groups C, F, L, M, and N are absent in assemblages east of the Nenana River. Similarly, Coffman and Rasic (2015) suggested a western origin in the Kuskokwim Mountains for Group C (2015). Spatial trends of known sources may also reveal patterns of movement. Pieces of Triple Lakes rhyolite are few, but this rhyolite is found at just two archaeological sites 40-50 km north of the source outcrop, perhaps indicative of movement of this rhyolite from south to north (or extensive but rare occurrence in the region's alluvium). Rhyolite from the Talkeetna Mountains source area also seems to have been carried in a south-to-north direction because it was found in six sites in this study, Moose Creek, Walker Road, Dry Creek, Little Panguingue Creek, Panguingue Creek, and Houdini Creek. Peculiarly, it is missing from the two most southern sites in the Nenana valley, more proximate to the Talkeetna Mountains.

Interestingly, transport expectations are only partially met when we focus on the sourced raw materials. For example, regarding the expectation of increased frequency of a rhyolite source in nearby site assemblages, we expected the Triple Lakes and Calico Creek sources to be used more in the Nenana valley compared with use of the more distant Talkeetna Mountains source area; however, neither Triple Lakes nor Calico Creek sources are prevalent in Nenana valley assemblages. Artifacts on Triple Lakes rhyolite number just three and are found in only two sites, Owl Ridge and Moose Creek. Calico Creek rhyolite numbers 23 artifacts from just four sites (see Coffman and Rasic 2015; Table 3.8). Though Talkeetna Mountains rhyolite occurs in low frequencies, it is distributed in six different site assemblages. Nevertheless, none of these three nonlocal sources were used in every site nor in the frequencies documented for groups A, B, and I. Regarding expectations of finding low frequencies of cortex on distant, or nonlocal toolstones, Triple Lakes provides an interesting case. Although considered a nonlocal source, it preserves cortex on a single artifact at Owl Ridge despite being located at nearly the opposite end of the valley from this site. Perhaps more confounding and counter to the expectations laid out here is the distribution of cortical pieces for the Calico Creek and Talkeetna Mountains rhyolites. Sites in the Nenana valley with cortex on these source materials are concentrated in the north, and therefore traveled the farthest. These observations rely on simple distance measures, not on specific pathways (e.g., least cost pathways [Anderson and Gillam 2000; Taliafero et al. 2010]) and cannot account for nuanced decisions made by users of these toolstones. Directional trends discussed here remain somewhat speculative and warrant further testing by increasing the sample size to include interregional comparisons.

3.6.2. Rhyolite Provisioning Strategies

This study used relative measures of local and nonlocal rhyolites to inform on overall provisioning strategies. Expectations are that humans choosing to provision place would leave behind assemblages with a preponderance of local materials alongside nonlocal materials, while humans engaging in provisioning individuals would leave behind assemblages of mostly nonlocal rhyolites. There are variable patterns in rhyolite provisioning strategies in the Nenana valley through time, and these are discussed below.

During the Allerød, most site assemblages appear to have relied on local rhyolites (mostly A and I), except for Walker Road and Dry Creek (Figure 3.14; Table 3.8). Dry Creek (C1) has only one artifact belonging to Group A, the only local group represented in the assemblage, while the remainder (98%) represents nonlocal rhyolite groups, indicative of provisioning individuals. This interpretation runs counter to previous analyses describing this assemblage as representing a more place-oriented provisioning strategy (Graf and Goebel 2009); however, it is important to note Graf and Goebel (2009) were basing this interpretation on the technologies and raw material make-up of the entire assemblage, and they did not have the benefit of geochemical analyses to aid in detecting the presence of different and varied rhyolite types. Walker Road is described as a base-camp occupation with an assemblage produced on mostly local materials (Goebel 2011). Rhyolites make up nearly 50% of assemblage's toolstones (Figure 3.17), and nearly 40% of these consist of nonlocal materials (Figure 3.14). Because it is suspected to be a base camp, Walker Road should have a mixture of local and nonlocal rhyolites, and the local rhyolites should have relatively high cortex values. The former expectation of an assemblage with both local and non-local rhyolite groups is met, but the latter expectation of local rhyolites exhibiting high cortex values is not. Neither local nor nonlocal rhyolites express many cortical pieces. Further, local groups B and I were not selected by Walker Road inhabitants. The Dry Creek C1 and Walker Road assemblages contain the most nonlocal rhyolites of all Allerød-aged sites, reflecting more of a provisioning-individuals pattern for these two earliest sites. The Allerød occupations of Moose Creek C1, Owl Ridge C1, and Eroadaway are described as camps where occupants used primarily local toolstones, supported by geochemical results of the rhyolites reported here (Gore 2021; Gore and Graf 2018; Holmes et al. 2018; Pearson 1999). These results indicate a change to more of a provisioning-place strategy near the end of the Allerød.

During the YD, the percent of nonlocal rhyolites in assemblages decreases compared to Allerød sites. The Moose Creek C2 and Panguingue Creek C1 assemblages are small, but nevertheless contain mostly local rhyolites, while rhyolites at Owl Ridge C2 are exclusively local, indicative of a continuation of a provisioning-place strategy with ever-increasing familiarity of the rhyolite landscape. Previous descriptions of YD technological organization, however, suggest YD populations may have been provisioning individuals because site toolkits were highly standardized, well-planned as part of a mobile land-use system (Gore and Graf 2018; Graf and Bigelow 2011). It is important to consider that Gore and Graf (2018) studied the complete array of raw materials and technological strategies represented at a single site in the foraging system, a short-term, special-task site, but here the focus is solely on rhyolite use at all sites in the region. The two studies represent two scales of the research, and continued work will be geared toward bringing these varied lines of inquiry together for a more holistic view. For example, we may expect individuals operating in a provisioning-place system to still gear up when undertaking task-specific forays at resource extraction sites, especially if there were known local sources of toolstone near the camp. In addition to the presumed local rhyolites in the Owl Ridge assemblage, andesite, too, was used and readily available in the alluvial cobbles within 1 km of the site (Gore and Graf 2018).

During the early Holocene, foragers at Owl Ridge C3, Dry Creek C2, and Little Panguingue Creek continued to utilize predominantly local rhyolites, while at Panguingue Creek C2 the opposite pattern is true. This would seem to indicate humans provisioned place at Owl Ridge, Dry Creek, and Little Panguingue Creek, but provisioned individuals at Panguingue Creek. While place provisioning was likely employed at Owl Ridge (Gore and Graf 2018) and Little Panguingue Creek (Gómez-Coutouly et al. 2019), previous analyses of the Dry Creek C2 assemblage note that overall toolstone procurement was both local and nonlocal with formal, planned technologies, reflecting a logistically-organized mobility strategy (Graf and Goebel 2009; Powers et al. 2017). Therefore, on the spectrum between provisioning individuals and provisioning place, together these early Holocene assemblages express a provisioning-place pattern with some individual provisioning at Dry Creek and Panguingue Creek, a similar pattern to the one described for the YD interval.

Middle Holocene assemblages exhibit a clear shift back to incorporating more nonlocal rhyolites in their toolkits. Three assemblages, Houdini Creek, Moose Creek C3, and Dry Creek C4, are dominated by nonlocal rhyolites, expressing the provisioning of individual foragers. The remaining sites are dominated by local rhyolites, representing provisioning place. Overall, this pattern resembles that identified for the earliest few hundred years of human occupation in the Nenana valley.

3.6.3. Rhyolite Diversity

Rhyolite group diversity helps us estimate degree of landscape knowledge. This is based on the assumption that landscape novices will procure fewer local rhyolite groups because they are unfamiliar with where to find these resources, and they will bring more nonlocal rhyolites with them to reduce the risk of not finding adequate toolstone (i.e., not arriving empty handed) (Kelly 2003; Kelly and Todd 1988; Meltzer 2001, 2003, 2004a; Rockman 2003; Steele and Rockman 2003). As foragers learn the landscape, they will encounter new, local resources and gradually include these into their toolkits, ultimately resulting in less-diverse assemblages because they have learned where reliable rhyolites are located and can concentrate on procuring only those as needed. Broadly speaking, diversity patterns vary within time periods so that we expect to find assemblages within each that are diverse and assemblages that are not so diverse. Much of this variability likely reflects different site types because base camps will always accumulate more diversity in artifact and raw material types, whereas special-task sites will express less diverse assemblages (Graf 2010). In this study of rhyolite use, there are two important trends to highlight. First, the majority of more-diverse-than-expected Nenana valley assemblages date to the terminal Pleistocene, especially the Allerød interstadial (Figures 3.15-3.17). This pattern is expected from landscape novices or learners. Second, the majority of assemblages less diverse than expected are Holocene in age, a pattern especially true of middle Holocene sites. The Terminal Pleistocene foragers in the Nenana valley were engaged in landscape learning, with Holocene foragers increasingly becoming landscape experts so that during the middle Holocene they were experts.

3.6.3.1. Landscape Learning

Together, rhyolite transport, provisioning, and diversity can elucidate patterns in landscape learning processes through time. Expectations of this study are that landscape learners would have provisioned individuals with mostly nonlocal rhyolites because they did not yet know where to find local rhyolites, while landscape experts would have known where to obtain local materials and provisioned place with mostly local rhyolites (Table 3.2). Given the discussion above, the picture through time is complicated; however, there are some interesting patterns and salient points to make. First, in the two oldest sites of the Allerød interstadial, Dry Creek C1 (~13.5 ka) and Walker Road (~14-13.3 ka)[2], there is more non-local rhyolite than expected meaning that these earliest inhabitants of the Nenana valley were bringing rhyolite materials to the valley. Both

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[2] According to Goebel (personal communication May 2022), newly produced radiocarbon ages for the Nenana complex occupation at Walker Road an age for the assemblage as early as 13.5 ka.

early sites express mixed patterns of provisioning, yet there is a strong current of provisioning individuals. Diversity within the Dry Creek C1 assemblage is among the highest of all sites. For example, Group N is only found in the Dry Creek C1 assemblage and in none of the other sites or time periods. Though the Walker Road assemblage falls below the regression line in Figure 3.15, because of its large sample size, it still expresses a considerable amount of diversity in rhyolite groups compared to many other site assemblages in the valley. Interestingly, despite this diversity, local rhyolite groups A, B, and I were virtually unused and unknown, while these earliest foragers were using the Talkeetna Mountains source, located ~200 km away. Together, these data suggest the Dry Creek C1 and Walker Road assemblages represent landscape novices to the Nenana valley. Keeping in mind their occupations occurred several hundred years prior to the other Allerød-aged sites, according to expectations, they do appear the most landscape naïve.

After 13.3 ka, foragers in the Nenana valley began using more local raw materials and started practicing a provisioning-place strategy. They appear to be more knowledgeable than before, so it would seem they rapidly learned where to find good-quality local rhyolites. This pattern continued through the YD, though they completely drop the use of distant rhyolites except for Talkeetna Mountains and Group J. Importantly, data gathered so far indicates the C, L, and Triple Lakes groups remained unknown until the early Holocene, indicating humans were still learning where regional rhyolites were located and how they could incorporate them into their toolkits, and thus were not yet rhyolite landscape experts; alternatively, groups C and L may have been located high in the mountains and remained under glacial cover. Until this time. During the early Holocene, transport was still predominantly local, and people were provisioning place, but more nonlocal sources were being used than during the late Allerød and YD. It is interesting that each rhyolite group was used at this time except for M and N, which were recognized and used by the earliest people to enter the Nenana valley. Either early Holocene foragers had discovered enough relatively local materials that they did not need to procure groups M and N, or they were simply not using those locations anymore. During the middle Holocene, however, these patterns changed.

By 8 ka, people began using a greater amount of nonlocal rhyolites, but they depended on fewer nonlocal types with the diversity of nonlocal rhyolites falling precipitously. This suggests these hunter-gatherers were selectively provisioning individuals, coupling this strategy with provisioning of place when needed. I argue middle Holocene foragers had become landscape experts, familiar enough with the regional rhyolite sources to deftly practice a strategy relying on gearing up for special tasks and provisioning place as needed.

3.6.4. Paleoenvironment and Human Settlement of the Nenana Valley

This examination of rhyolite procurement and use in the Nenana valley shows a pattern of initial landscape learning and settling-in, followed by a quick accumulation of expert rhyolite knowledge. Learning a landscape is achieved through the gathering of environmental information (Rockman 2003, 2009); therefore, we can contextualize this process by considering how fluctuating climate regimes shaped the region's environments and influenced human behavioral response. The earliest Allerød assemblages (~14-13.3 ka) reflect humans subsisting in an environment transitioning from a treeless, xeric herb-tundra to a more mesic shrub-tundra. During the latter climatic regime there was an increase in archaeological visibility, representing human expansion into the Alaskan interior. The Allerød landscape supported a variety of large- and small-game resources procured by humans (e.g., bison, wapiti, and waterfowl) and perhaps provided more woody vegetation for fueling fires used for cooking and warmth compared with the herb-tundra of pre-Allerød times (Hoffecker and Elias 2007). If the expansion of shrub-tundra brought about increased fuel opportunities while supporting plentiful ungulate populations, this environmental transition may have been key in enabling humans to expand, explore, and successfully establish themselves in the region. This, in addition to the high surface visibility offered by a shrub-tundra landscape, initial valley occupants successfully accumulated specific locational knowledge of toolstone sources beyond the largest, most visible ones. It seems initial humans arriving in the Nenana valley during the early Allerød arrived with high-quality rhyolite (and obsidian [Reuther et al. 2011]) from outside the area, but they were less schooled in knowing where to find local rhyolites in the valley. Through the end of the Allerød and into the YD, visitors to the valley had gained enough local knowledge to map onto several local rhyolite toolstones.

By contrast, Holocene rhyolite use suggests a more complete knowledge of the local and regional lithic landscape, but there is a general decrease in diversity among Holocene assemblages compared to late Pleistocene assemblages. The arrival of the Holocene thermal maximum is marked by transition from a shrub-tundra to boreal-forest biome with warmer and more mesic conditions, peatland, conifer expansion, and range restriction of both small and large fauna (Jones and Yu 2010; Kaufman et al. 2016; Mason and Bigelow 2008). While wood-fuel would have been plentiful, gregarious animals (e.g., caribou) would have been accessed seasonally in uplands, with more solitary species (e.g., moose and bear) being more common throughout the region. In response, human diet breadth decreased, land-use patterns changed, and technologies shifted (Doering 2021; Esdale 2008; Potter 2008a, 2008b; Potter 2016). Given this, perhaps some rhyolites were no longer cost-effective to procure due to changes in subsistence practices of hunting solitary game and seasonally-scheduled caribou, despite persisting knowledge of source locations. In addition, a decrease in rhyolite diversity could indicate that some sources were less visible or accessible due to boreal-forest cover, more months with snow cover, difficulty crossing glacially-fed streams and rivers during warmer summers, or limited accessibility due to increased glacio-fluvial erosion, especially during the early Holocene. Regardless, these environmental conditions did not completely prohibit access to all high-quality rhyolites because many continued to be used in the Nenana valley.

3.7. Conclusions

The overarching goal of this study was to contribute to the nascent body of raw material studies in eastern Beringia by seeking to establish the local lithic landscape of the Nenana valley and more specifically investigating rhyolite use through a geochemical and behavioral approach. Raw material surveys completed to date show that high-quality raw materials are limited in quantity, availability, and even distribution within the region. In the case of rhyolites, several outcrops are available within the valley, but geochemical comparison indicates most of these geological sources were not utilized by prehistoric humans. Only a few known sources were used sporadically, one being the newly identified Triple Lakes source. It seems these were never compelling sources of toolstone for Alaskans. Work reported here provides compelling support for most rhyolite procurement elsewhere, perhaps deeper within upland settings of the Alaska Range as posited by Coffman and Rasic (2015). Clearly the use of the Talkeetna Mountains source area is a good example of use of an upland source. Perhaps groups A, B, and I will be located in a similar upland contexts.

Several interesting patterns in rhyolite use are evident from the incorporation of pXRF geochemistry and lithic analyses. First, a broad number of rhyolites were used from the earliest visible occupation of the Nenana valley through the middle Holocene. Ancient Alaskans inhabiting the valley during the Allerød provisioned their sites with a wide variety of local and nonlocal materials, showing that they had sufficient knowledge of raw material locations in the greater, interior region of Alaska (Blong 2018; Goebel 2011; Gore 2021; Graf and Goebel 2009; Reuther et al. 2011). All geochemically identified rhyolites appearing within Allerød assemblages, except one, continue to be used by humans within the Nenana valley into the Holocene, further suggesting humans at this time were already engaged in learning the local lithic landscape. However, the absence of rhyolites that are seen later in Holocene assemblages indicates their knowledge was incomplete. As the shrub-tundra transitioned to a boreal-forest regime in interior Alaska, landscape knowledge appears to have increased as new local rhyolites were procured by Nenana valley inhabitants. By 8 ka, the Indigenous peoples of interior Alaska had become rhyolite experts. During this time there is an increase in the use of nonlocal rhyolites and a concurrent decrease in rhyolite diversity, perhaps because the warm temperatures and boreal cover of the Holocene Thermal Maximum brought about different constraints and opportunities, such as decreased rhyolite visibility and accessibility and/or seasonal focus on caribou hunting which likely led to a need for traveling greater distances to social aggregation sites during the caribou hunting season. This may have brought about the opportunity to easily embed procurement of distant rhyolites (i.e., Talkeetna Mountains source) (Binford 1979; Mason et al. 2001; Smith 2020).

This study shows that locations of high-quality rhyolites in interior Alaska were understood and valued as significant raw material sources from the earliest occupation of the Nenana valley throughout the Holocene, implying that the process of landscape learning happened quickly upon arrival. Questions remain, however, about the degree to which the complexity of this landscape knowledge was affected by environmental constraints, provisioning strategies, and/or settlement patterns. Continued research will be necessary to answer these questions.

The incorporation of additional assemblage-wide analyses will no doubt help test the above hypotheses. Geographically identifying and geochemically characterizing new rhyolite sources in interior Alaska will help anchor rhyolite groups to known source locations, providing further insight into mobility patterns. Eventually such legwork will untangle questions of technological provisioning and use, including full characterization of lithic landscapes, landscape knowledge, technological needs, mobility strategies, seasonal landscape use, climate regimes, social interaction, trade, and exchange. Likely all of these factors influenced the makeup of ancient Alaskan toolkits to some degree, raising several remaining questions. Are other toolstones (e.g., basalts, cherts, quartzites, etc.) procured according to the same patterns as rhyolite, or are these patterns unique? How did regional toolstone availability shape technologies?

The limited archaeological record and scope of this study permitted discussion of just a few aspects of human behavior. To unravel the complexities of these behaviors as reflected in the lithic record, further studies incorporating toolstone sourcing and assemblage studies at the local and regional level must be conducted to clarify the behavioral strategies underlying patterns described here. Doing so will elucidate a more holistic picture of the complex behaviors that contributed to lithic provisioning, mobility, and behavioral adaptation in prehistoric Alaska. Although survey results did not reveal sources for any previously reported rhyolite groups, incorporation of geochemical results of this study with lithic technological analysis provides insight into rhyolite transport patterns.

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4. BASALT PROCUREMENT AND USE IN THE NENANA VALLEY, CENTRAL ALASKA

4.1. Introduction

The Eastern Beringian record is critical to studies of human dispersals in the Americas. Paleogenomic studies point to an Asian origin of the founding population of eastern Beringia, but beyond this agreement about the timing and nature of this dispersal event is complicated by a variable and complex archaeological record (Dillehay 2021; Flegontov et al. 2019; Fu et al. 2013; Graf and Buvit 2017; He et al. 2012; Hoffecker et al. 2014; Moreno-Mayar et al. 2018a, 2018b; Raff and Bolnick 2014; Raghavan et al. 2014; Reich et al. 2012; Sikora et al. 2019; Skoglund et al. 2015; Wells et al. 2001). The central Alaskan record preserves the earliest well-dated sites in eastern Beringia, dating to 14,200–12,000 years ago (ka). These late Pleistocene sites are highly variable, prompting continued debates and disagreements regarding explanations of this diversity (Goebel and Buvit 2011; Gore and Graf 2018; Graf and Bigelow 2011; Hoffecker 2001; Holmes 2011; Mason et al. 2001; Odess and Rasic 2007; Potter 2007, 2008; Potter et al. 2014; West 1996; Wygal 2011). Likewise, the Holocene record of interior Alaska exhibits similar technological variability and lack of scholarly consensus (Ackerman 2004, 2011; Esdale 2008, 2009; Mason et al. 2001; Mason and Bigelow 2008). To date, we know little about the colonization, behavioral adaptations, and learning processes of the earliest Beringians inhabiting the central Alaskan landscape, or how they responded to the marked and dynamic environmental fluctuations following the end of the late glacial.

The Nenana River valley (hereafter, Nenana valley), located in central Alaska, preserves well-dated archaeological sites spanning the late glacial to middle Holocene. The lithic assemblages of this region provide an opportunity to explore how raw material distribution across the landscape shaped procurement and selection habits of early Beringians, and in turn, whether these toolstone strategies reflect human responses to landscape learning and shifting environmental regimes. This paper focuses on integrating geochemical characterization of natural basalt rocks with basalt artifacts to assess four questions: in the Nenana valley, (1) were local basalts being used as sources by past humans, (2) how did early occupants transport basalt transport, (3) how did people provision themselves with basalt, and (4) how did basalt transport and provisioning affect landscape learning, and vice versa?

4.2. Background

4.2.1. The Beringian Archaeological Record

Interior Alaska preserves a rich archaeological record spanning the late glacial to middle Holocene (West 1996). The earliest unequivocal archaeological evidence of humans in eastern Beringia occurs at Swan Point in central Alaska, where a 14.2 ka occupation found in the lowest cultural zone (CZ4) contains wedge-shaped microblade cores used as components of composite osseous tools (Gómez Coutouly and Holmes 2018; Hirasawa and Holmes 2017; Holmes 2011). This eastern Beringian site marks the expansion of humans into Alaska following 19,000 years of human absence from the

Beringian record; after humans lived at Yana RHS in northwestern Beringia around 33 ka, harsh climates of the last glacial maximum (LGM) constrained arctic and subarctic settlements until ameliorating conditions of the Allerød chronozone allowed humans to expand north and east into North America (Buvit et al. 2016; Clark 2009; Graf 2009, Graf and Buvit 2017; Hoffecker and Elias 2007; Tallavaara et al. 2015; Wren and Burke 2019; but see Hoffecker et al. 2016).

Humans who re-settled Beringia at 14.2 – 13 ka brought variable lithic technologies with them, making interpretations of this early record difficult. For example, the lowest archaeological layers at Berelekh, Nikita Lake, and Ushki Lake in western Beringia exhibit bifaces, blades, waisted bifaces, and small, diminutive teardrop-shaped, triangular-shaped, or stemmed projectile points produced on flakes (Goebel et al. 1991, 2003, 2010; Gore and Graf 2018; Graf et al. 2015, 2017, 2020; Graf and Bigelow 2011; Holmes and Hirasawa 2017; Pearson 1999; Pitulko et al. 2014, 2017; Potter et al. 2014; Younie and Gillispie 2016). These distinct bifacial "Chindadn" points are similar to those found in Allerød-aged sites to the east in central Alaska (e.g., Dry Creek, Moose Creek, Owl Ridge, and Walker Road), but are absent from the oldest cultural occupation at Swan Point. No site with well-defined stratigraphy is found in western or eastern Beringia where Chindadn points and microblades co-occur (Goebel et al. 1991, 2003, 2010; Gore and Graf 2018; Graf et al. 2015, 2017, 2020; Graf and Bigelow 2011; Holmes and Hirasawa 2017; Pearson 1999; Pitulko et al. 2014, 2017; Potter et al. 2014; Younie and Gillispie 2016).

Technological variability continues to characterize the archaeological record of eastern Beringia during the Younger Dryas (YD) and Holocene. During the YD (12.8-11.7 ka), biface-based assemblages similar to those of the Allerød interval persist in some assemblages, but in others large lanceolate bifacial projectiles begin to appear, and wedge-shaped microblade technologies re-emerge, followed by the appearance of Paleoindian fluted bifaces at the onset of the Holocene Thermal Maximum (HTM) at 11.7 ka (Ackerman 2011; Buvit et al. 2019; Dikov 1968; Goebel et al. 1991, 2003, 2010, 2013; Gore and Graf 2018; Graf et al. 2015, 2020; Graf and Bigelow 2011; Kunz and Reanier 1995; Pearson 1999; Smith et al. 2014). Toolkit variability continues into the Holocene, with the emergence of notched projectile points found variably alongside burins, *tci-tho* scrapers, knives, microblade technologies, and a variety of biface forms (e.g., stemmed, concave-based, and lanceolate points) (Esdale 2008, 2009; Hare et al. 2004, 2012; Rasic 2011). Further, many Holocene-aged assemblages are often under-reported and/or understudied (but see Esdale 2008, 2009), limiting behavioral explanations gleaned from this time period in the record).

Interpretations of the rich late Pleistocene and Holocene records of Beringia are hampered by technological variability, understudied time periods and/or regions, and disagreement about the environmental, economic, behavioral, and cultural factors that shaped Beringian lithic technologies (Goebel and Buvit 2011; Graf and Buvit 2017). Because the Alaskan record is mostly lithic, we can attempt to elucidate human behavior using technological organization approaches (Graf and Goebel 2009, Gore and Graf 2018; Kuhn 1995, 2004; Nelson 1991). One aspect of technological organization, toolstone procurement, is employed in this study to explain lithic variability and human adaptive behaviors evident in the regional archaeological record of the Nenana valley, central Alaska.

4.2.2. Toolstone Procurement and the Lithic Landscape

Ancient toolstone economies have long been an avenue of interest and investigation for researchers engaged in lithic studies of hunter-gatherers because quality raw materials were a critical resource that shaped human behaviors and decision-making (Andrefsky 1994a; Braun 2005; Elston 2013; Gould and Saggers 1985; Surovell 2009). Their location and distribution were important, remembered, and transmitted through the cultural landscape of ancient Alaskans, clearly demonstrated in ethnographic data, oral history, and surviving place names (Kari 1999; Nelson 1986; Reimer 2014, 2018). Toolstone procurement strategies influenced, and were influenced by, technological goals, mobility strategies, the quality, accessibility and distribution of raw materials, territoriality, and other social factors, often leaving measurable and observable behavioral signatures in the lithic record (Andrefsky 1994a; Bettinger 1982; Binford 1979, 1980; Blades 1999; Blumenschine et al. 2008; Ford 2011, 2012; Kuhn 1995, 2004, 2020; Odell 1996; Rockman 2003; Surovell 2009). In this study, lithic raw material source distribution and geographic location are used, when available, as proxies to inform mobile strategies (Binford 1980). Thus, learning from where, why, and how humans acquired these materials is critical for understanding technological organization. Studies focusing on raw material procurement and landscape use are few in central Alaska, with most focusing on archaeological obsidians despite the rarity of these pieces in most assemblages (Goebel et al. 2008; Gómez Coutouly 2017; Reuther et al. 2011; Slobodina et al. 2009; West 1996; but see Gore 2021). By contrast, other fine-grained volcanic materials comprise a large portion of central Alaskan assemblages, but their exact geographic locations, distribution, and quality are not well studied (Gore 2021; Gore and Graf 2018; Graf and Goebel 2009). Rhyolites, dacites, and cherts have been minimally investigated (Coffman and Rasic 2015; Gore 2021; Malyk-Selivanonva et al. 2008), but foundational knowledge of the nature of mafic materials within archaeological assemblages and their local geological availability limits interpretations of their acquisition and use in the record. Basalts, for example, were used as a toolstone in a variety of contexts, for example in the production of scrapers, planes, choppers, and bifaces during the late Pleistocene and as processing and hunting tools during the Holocene, but little else is known about patterns of acquisition and use of this material (Gore and Graf 2018; Graf et al. 2015, 2020; Goebel 2011). Geochemical analyses of raw materials offer potential answers to questions of toolstone provisioning, yet these studies are few in eastern Beringia (Coffman and Rasic 2015; Gore 2021; Lawler 2019; Rains 2014).

Geochemical sourcing techniques are valuable aids in identifying which toolstone resources were used in the past and from where they came. X-Ray fluorescence spectrometry (pXRF) is a particularly valuable technique used in archaeological provenance studies because it is cost- and time-efficient, non-destructive compared to other techniques (e.g., NAA), and requires minimal sample preparation (Shackley 2011). Although pXRF studies in North America have focused mostly on obsidian, studies in other areas of the world have applied geochemical methods, including pXRF geochemistry, to successfully source mafic materials (Fertelmes and Glascock 2018; Grave et al. 2012; Lundblad et al. 2008, 2009; McAlister and Allen 2017; Mills et al. 2010; Page and Duke 2015; Palumbo et al. 2015; Scharlotta and Quach 2015). Despite its prevalence in the record, geochemical studies of mafics in interior Alaska are limited (but see Rains 2014; Handley 2013). Further, recent studies have questioned models of toolstone conveyance and procurement based solely on obsidian sourcing, noting that incorporation of non-obsidian materials often provides a significantly different pattern of scale within a system than more common toolstones within the same assemblage (Newlander 2015, 2019; Newlander and Lin 2017). Therefore, applying geochemical techniques like pXRF to archaeological basalts in central Alaska should provide a more informed, holistic, and complete reflection of diachronic provisioning behaviors.

Although regional geochemical studies of basalts and other non-obsidian, fine-grained volcanic materials have been successful (McAlister and Allan 2017), several factors can complicate geochemical sourcing of this material. Geochemical heterogeneity in single formations can potentially occur depending on magma chamber conditions, solidification rates, variable contributions of petrogenic materials, metamorphism, and weathering processes (Fertelmes and Glascock 2018; Grave et al. 2012; Kienle and Nye 1990; Lundblad 2011). In addition, the paleoenvironmental setting of the Nenana valley and nearby Alaska Range must be considered as a potential complicating factor. Millennia of glacial processes have affected the surface geology of the region (Hoffecker et al. 1988; Ritter and Ten Brink 1986; Thorson 1986), potentially transporting cobbles of basalts from numerous unknown and re-worked sources in the valley's alluvial deposits, increasing the potential for geochemical variability within samples from secondary alluvial contexts (e.g., cobbles from streambed alluvium or exposures). Sampling of rocks in these contexts is often overlooked, even in obsidian studies, despite warnings that their exclusion from geochemical studies cloud behavioral interpretations (Shackley 2008; Rorabaugh and McNabb 2014). In some cases, the need to extensively sample materials in alluvial contexts can be reduced if regional quarries at basalt outcrops are known, the spatial extent of an outcrop's contribution to secondary contexts is well-defined, and/or archaeological materials show no evidence of procurement from alluvial sources (e.g., no cobble-cortex present) (Fertelmes and Glascock 2018; Shackley 2008). None of these situations apply to the Nenana valley study area because no physical evidence of prehistoric quarrying of any material has ever been documented, no systematic studies of regional basalt sources or their geochemistry have been completed, and evidence of raw materials exploited from alluvial contexts have been demonstrated in several lithic analyses of assemblages in the region (Goebel 2011; Gore and Graf 2018; Gore 2021; Gómez Coutouly et al. 2019; Graf and Goebel 2009; Powers et al. 2017).

In combination with limited geological information, conclusions about provenance and provisioning strategies focusing on basaltic materials are hampered. No systematic study integrating knowledge of the local lithic landscape with geochemical results has yet been conducted for basalts in eastern Beringia. This situation leaves us with questions. How did people procure and use this material? Did those patterns of procurement and use change as humans learned the landscape and coped with environmental fluctuations that potentially reordered and redistributed resources upon the landscape? This paper seeks to inform these questions. Specifically, the goals are to investigate and describe the distribution of basalts on the landscape, characterize them geochemically and compare them to the Nenana valley's artifact sample to assess their relationship with each other. Recently, efforts to map and define the lithic landscape have contributed to our knowledge of toolstone distribution within the Nenana valley (Gore 2021). Significantly, the current study builds on this research to map basalt availability from an archaeological perspective and is the first to assess usefulness of pXRF geochemistry applied to basalts in this region. Here, basalt refers to mafic rocks of igneous origin, generally aphanitic in texture but may range from fine-grained to coarse-grained depending on the nature of its geological formation (Andrefsky 2009).

4.3. Materials

4.3.1. Geology of the Nenana River Valley

The Nenana River bisects the central Alaska Range and then flows northward as a tributary to the Tanana River. Biomes in the valley include upland tundra vegetation in the mountainous portions of the valley to the south and boreal forest in the foothills of the north of the valley (Figure 4.1). During the 1950's, railroad construction and mining activities in the region spurred geological explorations; however, areas beyond the railroad corridor and valley mines have been only generally described in the geological literature because these areas are very remote (Cameron et al. 2015; Csejtey et al. 1986;

Wahrhaftig 1953, 1970a, 1970b, 1970c, 1987; Wahrhaftig et al. 1969; but see Albanese 1980). Despite these limitations, descriptions of the region depict a diverse and complex geological landscape (Csejtey et al. 1986; Wahrhaftig 1953, 1970a, 1970b, 1970c; Wahrhaftig et al. 1969).

Bedrock formations within the Nenana valley include the Nenana Gravel formation, an early Pleistocene-aged formation composed of granites, shist, sandstones, conglomerates, and intrusive rocks commonly found throughout the Alaska Range (Sortor et al. 2021; Wahrhaftig 1958, Wahrhaftig et al. 1969). The Middle Devonian-aged Totatlanika Schist formation composed of metavolcanics, schists, and gneisses characterizes the northern valley geology (Csejtey et al. 1986, 1992), while the Keevy Peak formation runs east to west in the central portion of the valley, composed of Paleozoic-aged, meta-sedimentary and meta-igneous rocks including quartz, quartzites, slates, interbedded marble, and schist (Athey et al. 2006; Csejtey et al. 1992; Frost et al. 2002; Wahrhaftig 1968). The Cantwell formation runs east to west in the south of the valley and is composed of Paleocene and late Cretaceous mudstones, conglomerates, coals, sandstones, andesites, basalts, and rhyolites (Csejtey et al. 1992, 1986; Gilbert et al. 1976; Wolfe and Wahrhaftig 1970). The Paleozoic Birch Creek Schist formation is mapped in areas of the south, west, and north of the region and is comprised of schists, quartzites, and quartz-sericite schists (Csejtey et al. 1992; Wahrhaftig 1953, 1970a, 1970b, 1970c).

Diverse igneous-rock types characterize the surface geography in the valley. The geological literature broadly describes several igneous formations and intrusions

(Clautice et al. 1999; Csejtey et al. 1986, 1992; Nye 1978; Wahrhaftig 1953, 1970a, 1970b, 1970c; Wahrhaftig et al. 1969; Wilson et al. 1998), though most are not mapped or described in detail (Albanese and Turner 1980; Csejtey et al. 1992; Robinson 1990; Wahrhaftig et al. 1953). Several specific basalt outcrops are mapped in the Alaska Range uplands, within the Birch Creek formation (Albanese 1980; Wahrhaftig 1970a, 1970b, 1970c). These are on the western slope of Mt. Healy, eastern and western slopes of Dora Peak, a slope immediately south of Carlo Creek, and at other localities outside of the valley (e.g., Wyoming Hills and the Yukon-Tanana Uplands located north and east of Fairbanks) (Albanese 1980; Albanese and Turner 1980; Csejtey et al. 1992; Wahrhaftig 1970a, 1970b, 1970c).

Pleistocene-aged glaciofluvial outwash terraces and Holocene-aged alluvium deposits of the Nenana River and its tributary waterways cover the landscape of the valley downstream from mountain and foothills slopes, representative of the valley's diverse geology (Thorson and Hamilton 1977, Wahrhaftig 1958). Toolstones are available in cobble form from these surface deposits (Gore and Graf 2018; Gore 2021; Graf and Goebel 2009). Previous raw material surveys in the valley sought to define the local lithic landscape of the valley based on these materials (Gore 2021) and are expanded upon in this study.

For this study, I analyzed a total of 925 geological samples: 140 were collected from geological basalt outcrops and 785 were collected from alluvial locations in the Nenana valley (Figure 4.1).

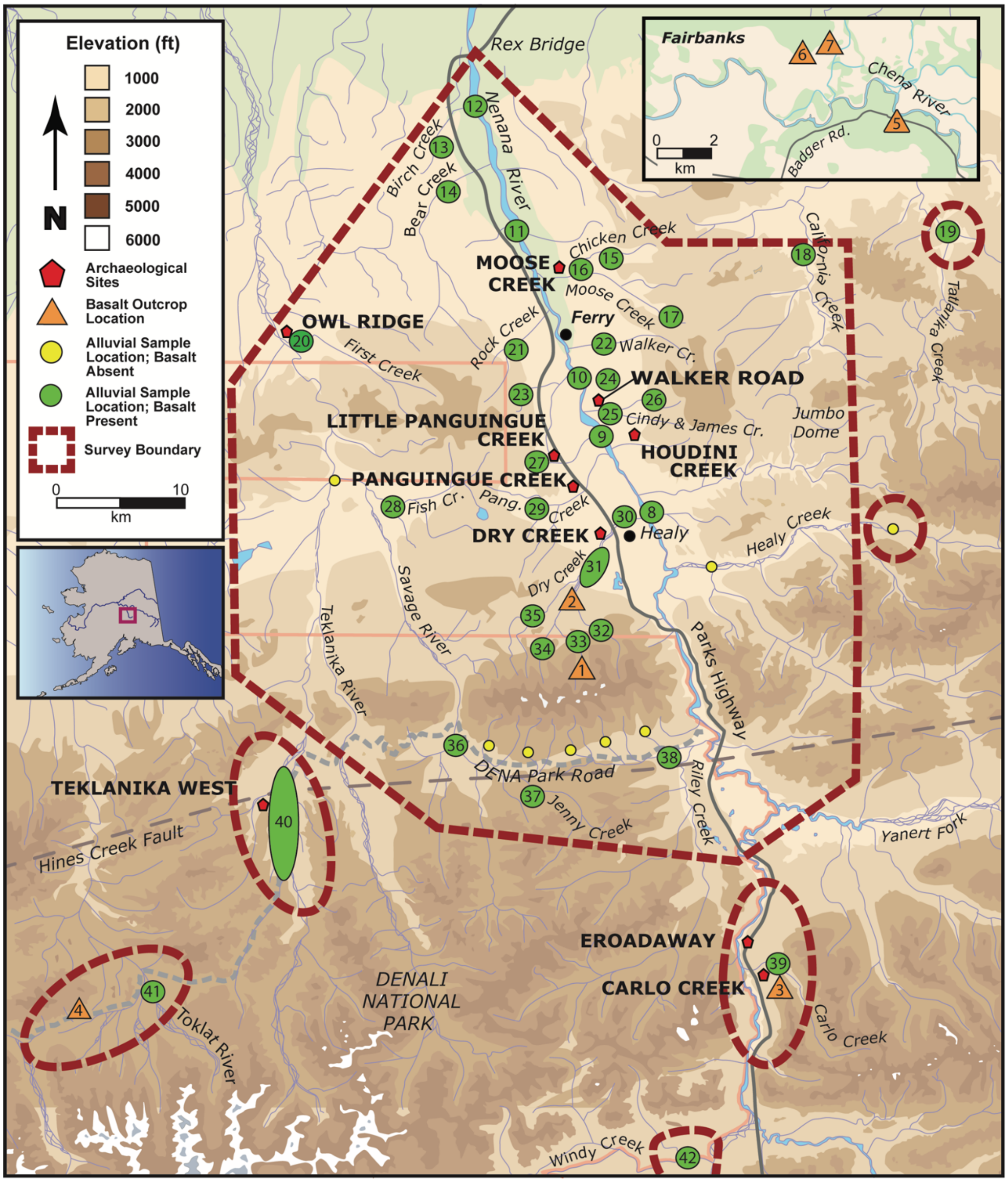

Figure 4.1. Map of archaeological sites, sample locations, and survey boundaries in the Nenana River Valley. Basalt Outcrops: 1: Dry Creek 1; 2: Dry Creek 2; 3: Carlo Creek; 4: Polychrome Pass; 5: Brown's Hill Quarry; 6: Sage Hill 1; 7: Sage Hill 2.Basalt Alluvial Samples: 8-12: Nenana River 1-5, respectively; 13: Birch Creek; 14:Bear Creek; 15: Chicken Creek; 16: Lower Moose Creek; 17: Upper Moose Creek; 18: California Creek; 19: Tatlanika Creek; 20: First Creek; 21: Rock Creek; 22: Walker Creek; 23: Slate Creek; 24: Cottonwood Creek; 25: Lower Cindy and James Creek; 26: Upper Cindy and James Creek; 27:Little Panguingue Creek; 28: Fish Creek; 29: Panguingue Creek; 30-35: Dry Creek Alluvium 1-6 respectively; 36: Savage River; 37: Jenny Creek; 38: Riley Creek; 39: Carlo Creek; 40: Teklanika River; 41: Toklat River; 42: Windy Creek. Adapted from Gore and Graf 2018.

4.3.2. Archaeological Sites in the Nenana River Valley

The Nenana valley provides a particularly suitable region to investigate lithic resource procurement questions because this area preserves many well-stratified archaeological sites and assemblages dating from the late Pleistocene through the Holocene (West 1996). Archaeological sites here are primarily positioned on south-facing slopes in the foothills zone 10-30 km north of the Alaska Range front. Sites are typically preserved within a series of loess and aeolian deposits situated on top of glacial outwash terrace margins adjacent to side streams flowing into the Nenana River, many with two or more stratigraphically separate occupations (Powers and Hoffecker 1989; Ritter 1982; Thorson and Hamilton 1977; Wahrhaftig 1958).

For this study, I analyzed a sample of 742 basalt artifacts from the 10 archaeological sites in the valley known to contain basalt lithic raw material. These artifacts came from a total of 18 different cultural component assemblages, representing different periods of use of the sites (see Table 4.1 for a list of site assemblages, dates associated with these assemblages, and the number of basalt artifacts analyzed here). The goal is to evaluate basalt provenance, transport, and use by comparing the geochemical signatures of these artifacts with samples collected from both natural basalt outcrops and basalt cobbles from valley streambeds.

4.4. Methodology

4.4.1. Rock Survey and Collection of Geological and Archaeological Samples

4.4.1.1. Field Survey

Table 4.1. Radiocarbon dates for site assemblages from the Nenana valley used in this study.

Site Assemblage	Artifact Sample (n = 742)	Calibrated Date (thousand years BP)[1]	Radiocarbon Dates	Reference
Dry Creek C1	92	13.5-13.3 ka	11,510 ± 40 (UCIAMS-135114) 11,530 ± 50 (BETA-315411) 11,580 ± 40 (UCIAMS-135113) 11,635 ± 40 (UCIAMS- 135112)	Graf et al. 2015
Walker Road	98	14.1-13.3 ka	11,820 ± 200 (BETA-11254) 11,010 ± 230 (AA-1683) 11,170 ± 180 (AA-1683) 11,300 ± 120 (AA-2264)	Goebel et al. 1996; Hamilton and Goebel 1999
Moose Creek C1	27	13.2-13.0 ka	11,190 ± 60 (BETA-96627)	Pearson 1999
Owl Ridge C1	34	13.3-12.8 ka	11,060 ± 60 (AA86969)	Graf et al. 2020
Eroadaway	59	12.9-12.8 ka	10,890 ± 40 (BETA-24155) 10,570 ± 50 (BETA-368365)	Holmes et al. 2018
Moose Creek C2	1	12.7-12.5 ka	10,500 ± 60 (BETA-106040)	Pearson 1999
Owl Ridge C2	16	12.5-11.4 ka	10,485 ± 25 (UCIAMS-71261) 10,420 ± 60 (AA-86960) 10,340 ± 75 (AA-86963) 10,020 ± 40 (BETA-289382)	Graf et al. 2020[2]
Panguingue Creek C1	10	12.2-11.4 ka	10,180 ± 130 (AA-1686) 9,836 ± 62 (GX-17457)	Goebel and Bigelow 1992
Carlo Creek C1	55	11.3-11.2 ka	10,035 ± 50 (AA-75052) 9,872 ± 65 (AA75049) 9,763 ± 50 (AA75051) 9,647 ± 60 (AA-75050)	Bowers 1980 Bowers; Reuther 2008[3]
Owl Ridge C3	32	11.3-11.2 ka	9,880 ± 40 (BETA-330172) 9,790 ± 40 (BETA-289379)	Graf et al. 2020
Dry Creek C2	136	11.1-10.4 ka	9,480 ± 35 (UCIAMS-135115) 9,460 ± 40 (BETA-315410)	Graf et al. 2015
Little Panguingue Creek C2	13	9.6 ka	8,620 ± 40 (Beta-431673)	Gómez-Coutouly et al. 2019
Panguingue Creek C2	41	9 - 8.4 ka	7,850 ± 180 (BETA-15093) 7,130 ± 180 (BETA-15094) 7,430 ± 270 (AA-1688) 7,595 ± 405 (GX-13012)	Powers and Maxwell 1986; Goebel and Bigelow 1996
Houdini Creek	34	8.8 ka	7,880 ± 60 (Beta-74737)	Potter et al. 2007
Teklanika West C3	34	7.7 - 7.5 ka	6,770 ± 50 (BETA-276455) 7,030 ± 40 (BETA-292107) 7,330 ± 40 (GX-18518)	Coffman 2011; Goebel 1996
Moose Creek C3	2	6.6 - 6.4 ka	5,680 ± 50 (BETA-106041)	Pearson 1999
Panguingue Creek C3	3	6.4 ka	4,510 ± 95 (GX-13011) 5,620 ± 65 (SI-3237)	Powers and Maxwell 1986

Table 4.1 Continued.

Site Assemblage	Artifact Sample (n = 742)	Calibrated Date (thousand years BP)[1]	Radiocarbon Dates	Reference
Dry Creek C4	55	3.9 - 3.5 ka	3,430 ± 75 (SI-2332) 3,655 ± 60 (SI-1934) 4,670 ± 95 (SI-1937)	Powers et al. 2017

[1]Radiocarbon date ranges calibrated using Reimer (2020) calibration curve in OxCal online software.
[2,3] Representative dates selected; for full list of all dates, see Graf et al. (2020) and Bowers and Reuther (2008).

Until recently, no systematic survey of raw materials within the Nenana valley had been conducted, leaving our locational knowledge of knappable basalts informed only by preliminary studies (Gore 2021; Gore and Graf 2018; Graf and Goebel 2009) and limited geological descriptions (Csejtey et al. 1992; Gilbert et al. 1977; Wahrhaftig 1970a, b, c). For this reason, I conducted a multi-year systematic survey of raw material to locate and sample knappable toolstone materials within the region, including basalts, to establish a comparative map of the local lithic landscape (Gore *in prep*). The survey area extended from Rex Bridge in the north to Windy Creek in the south and is bounded by the Toklat River in the west and Carlo Creek in the east (Figure 4.1). Several previous studies have suggested alluvium from creeks, rivers, and glacial outwash as an important potential toolstone resource easily acquired by ancient Alaskans camped nearby (Graf and Goebel 2009; see also Shackley 1998c, 2005). Therefore, local basalts could have been procured from two contexts: (1) a geological outcrop location, or (2) as alluvial materials obtained from local waterways or exposed glacial outwash. Here, an outcrop collection location is defined as a lithic deposit occurring in an *in situ* outcrop, and an alluvial collection location is defined as re-deposited lithic materials such as glacial till, outwash, or cobbles from active river or creek floodplains. Specific alluvial material makeup and geographical extent are only minimally addressed in geological reports; therefore, my toolstone survey efforts focused on sampling every major drainage within the region to record the location and quality of toolstones found there in addition to locating and sampling basalt outcrops. This adds significant knowledge of the availability of basalts within the valley, particularly within the region's various alluvial settings.

Sampling locations were informed by geological maps of the valley as well as proximity to known archaeological sites included in this study. At each collection location, at least twenty (n = 20) samples were collected via rock hammer or sledge from either outcrop or alluvium for pXRF analysis (following Glascock et al. 1998; Shackley 2008). Four outcrops were sampled within the survey area, and three outcrops from the Fairbanks area were sampled to provide control for comparisons with the expectation that, at ~150 km outside the survey area, these distant Fairbanks outcrops would not share geochemical affinity with those local to the Nenana River valley. Thirty-five alluvial locations were sampled in the valley, except where mafic materials were limited in sample size (e.g., Chicken Creek, Tatlanika Creek, and Dry Creek Alluvium 3 and 4). At each alluvial collection location, a 1-x-1-m square was measured, and each rock greater than 1 cm in size found inside the square was tallied to record the total number of rock types represented at each location to provide a quantitative measure of toolstones available. In addition, a 100-m transect was walked north and south of each 1-x-1-m location to record and collect knappable materials including fine-grained volcanic toolstones.

4.4.1.2. Artifact Sample Selection

The basalt artifact sample selected for geochemical comparison with geological samples numbered 675 specimens. Basalt artifacts were selected from 18 lithic assemblages. Each artifact sample was chosen based on size (> 3 mm in maximum linear dimension), thickness (> 3 mm), and artifact class. I included blades, flakes, cortical spalls, and resharpening chips along with cores and tools to provide an array of technological variability to not bias transport results (Eerkens et al. 2008). Sample numbers fell below 20 in two instances, when either basalt densities were low at Little Panguingue Creek (Gómez Coutouly et al. 2019) and Owl Ridge C2 (Gore and Graf 2018) or artifact provenance information was missing (e.g., Panguingue Creek C1 and C3 [Powers and Maxwell 1986] and Moose Creek C2 and C3 [Pearson 1999]).

4.4.2. Geochemical Analysis

4.4.2.1. Collecting the Geochemical Data

Rock outcrop, alluvium, and archaeological samples from the sites listed above were analyzed with a portable, non-destructive, X-ray fluorescence (pXRF) instrument. Each sample was analyzed using a Bruker Tracer III-V portable X-ray analyzer with rhodium tube and SiPIN detector, resolution of ca. 170 eV FHWM for 5.9 keV X-rays (at 1000 counts per second) in an area of 7 mm^2. Each sample was run at a live count time of 180 seconds to maximize both chemical counts and the number of total samples obtained (following Fertelmes 2014). Several studies demonstrate that chemical weathering causes minimal changes in the geochemistry of mid-Z trace elements analyzed here (Gauthier and Burke 2011; Lundblad et al. 2008, 2011), but precautions were taken to minimize variability due to surface textural and mineral irregularities, sample thickness, and surficial weathering (Shackley 2011). Geological samples were freshly broken in field or before pXRF analysis, enabling unweathered surface exposure, and all artifacts were analyzed on the surface exhibiting the most homogeneous, flat, unweathered and non-cortical surface of the specimen. All samples exceeded 5 mm in thickness and maximum dimension. All sample analyses were conducted at 40 keV using a 6mil copper, 12mil aluminum, and 1mil titanium filter in the X-ray path. Because all samples are volcanic, mid-Z elements useful in characterizing different petrogenic groups, including Rubidium (Rb), Strontium (Sr), Yttrium (Y), Zirconium (Zr), and Niobium (Nb), were selected for measurement and statistical analyses. Iron (Fe), Gallium (Ga), Thorium (Th), and Zinc (Zn) were measured but excluded from statistical analyses because the instrument filter used here is not optimized for these elements and their measurements are thus subject to wider error (Charleux et al. 2014; Grave et al. 2012; Lundblad et al. 2011; McAlister 2019). Peak intensities for these elements were calculated as ratios to the Compton peak of Rhodium (Rh) and converted to elemental weight concentrations using linear regressions provided by MURR, derived from the analysis of 40 rock standards cross-checked by neutron activation analysis (NAA) and inductively coupled plasma-mass spectrometry (ICP-MS) (Glascock and Ferguson 2012; Glascock et al. 1998) in Bruker's S1CalProcess program.

4.4.2.2. Analyzing the Geochemical Data

Groupings of geological and archaeological samples were identified using exploratory approaches following Glascock et al. (1998, 2020). Elemental measurements with zero values were replaced with a constant value 65% of the detection limit of the given element, then log-transformed and subjected to further comparisons and multivariate analyses (Glascock et al. 1998; Lubbe et al. 2021). These procedures (e.g., principal component analysis [PCA], scatter plot matrices, and elemental biplots) were run in GAUSS and IBM SPSS statistical programs (GAUSS is an open-source program available at http://archaeometry.missouri.edu/datasets/GAUSS_download.html). First, geochemical groupings were explored by submitting geochemical data to a principal components analysis (PCA) using the variance-covariance matrix of the data. Preliminary groupings were tested by observing biplots of all PCA loading combinations employing a 90% confidence interval drawn at a constant Mahalanobis distance (MD) from each preliminary group center. Each geological or artifact sample was tested against these preliminary reference groups one by one, and those that fell within the 90% confidence interval in all combinations of PCA loadings of biplots were admitted to the group. This process was repeated and cross-validated using biplots of parts-per-million element values to confirm PCA results. If element values did not reflect sample overlap or inclusion in a given group, that sample was excluded from membership. If a sample's inclusion within a group was ambiguous, probability scores for that specimen's membership within the constructed reference group were calculated based on the MD measure of that sample to the reference samples (see Chapter 3 methods for more details). A non-parametric Kruskal-Wallis H test was run comparing group means for elements Rb-Nb for all outcrop samples to provide a quantitative measure of significant differences. A post-hoc Dunn's test with Bonferroni adjustment was run on all pairwise comparisons of outcrop samples to assess which of the mean differences were statistically significant.

The geochemical data in this study were examined in several stages. First, samples from outcrop locations were compared with each other to explore variability within and between collection locations. Then, outcrop and alluvial samples were compared to each other to assess geochemical relatedness. Alluvial samples that did not match outcrops were further analyzed to see if any of them shared geochemical signatures, forming clusters or basalt alluvial groups. Likewise, artifacts were examined to determine if discrete geochemical clusters or artifact groups could be observed. Lastly, artifact groups were compared to geological samples to search for matches between them to establish whether any of the sampled basalts were used as sources (Chapter 3).

4.4.3. Basalt Transport and Provisioning Strategies

The ultimate goal of this paper is to map the basalt lithic landscape and explore its use within the Nenana valley. A review of methodological theories and expectations related to assessing basalt transport, provisioning behaviors, and patterns of landscape learning is presented here, closely following the methods presented in Chapter 3 of this dissertation (Table 4.2).

4.4.3.1. Basalt Transport

Basalt toolstone transport is defined as the distance and direction of artifact movement between its procurement and final discard location. Both distance and direction are measured if basalt source and discard locations are known, but in cases

Table 4.2. Expectations of basalt transport and technological provisioning.

Variables	**Transport Expectations**	
	Local	***Non-Local***
Frequency of Basalt Groups	High	Low
Cortex Presence in Basalt Groups	High	Low
	Provisioning Strategy Expectations	
	Place	***Individuals***
Local Basalt Transport	High	Low
Non-Local Basalt Transport	Low	High

where only artifact groups are identified, relative distance and direction measures are estimated by examining basalt group frequencies and cortex frequencies within site assemblages (Table 4.2; Chapter 3).

4.4.3.2. Provisioning Strategies

Prehistoric Alaskans used their technologies and toolkits to live and subsist successfully within their environment; therefore, the Alaskan lithic record informs on aspects of human behavior (Kelly 2001; Kuhn 1995). Provisioning strategies, or the spectrum of human behavioral strategies between "provisioning individuals" and "provisioning places", are observable in the lithic record and guide the expectations and interpretations of this study (Kuhn 1995; 2005). Provisioning individuals is chosen when mobile populations engage in "gearing up" with flexible, portable toolkits to prepare for few encounters with known or high-quality lithic resources; while provisioning place is chosen when populations place themselves at or near the resources they need (Binford 1977, 1978, 1979; Graf 2010; Kelly and Todd 1988; Kuhn 1991, 1995, 2004; Parry and

Kelly 1987). Basalt transport is used as a variable to understand provisioning behaviors (Table 4.2; Chapter 3).

4.4.3.3. Landscape Learners

Landscape learning occurs as humans enter an unknown region. At first, humans will not know where to procure all of their animal, plant, and toolstone resources, but as time passes, they will learn the full range of high-quality resources locally available (Fitzhugh 2004; Gore and Graf 2018; Graf and Goebel 2009; Meltzer 2002, 2003; Rockman 2003; Steele and Rockman 2009). Therefore, patterns of basalt transport and provisioning strategies summarized above are used as variables to assess landscape learning in this study (Table 4.3; Chapter 3).

Table 4.3. Expectations of landscape learning.

Variables	**Landscape Learning Expectations**	
	Learners	***Experts***
Basalt Transport	Mostly non-Local	Mostly Local
Basalt Provisioning Strategy	Individuals	Place

4.5. Results

4.5.1. Raw Material Survey

Mafic materials such as basalts are readily available in many outcrop and alluvial contexts in the study area, though they are not uniformly distributed in waterways across the valley (Figure 4.1). Survey of 42 waterways within the survey-area boundaries shows that valley alluvium is dominated by schist, quartz, quartzite, and other non-knappable rocks of low utility to humans. Traditionally, the literature reporting certain lithic raw material types represented by pieces ranging from black to dark gray in color and fine- to medium-grained in texture were called “degraded quartzite” (Powers et al. 2017; see also see Graf and Goebel 2009); however, these rock types represent materials on the mafic spectrum (e.g., basalts composed of 40-50% SiO^2; rich in magnesium and iron; and rich in pyroxene, plagioclase and/or olivine minerals). Across the Nenana valley, basalts comprise less than 37% of the alluvial makeup of most waterways in which they are present, except for Windy Creek, where they comprise 85% of the alluvium (see Table 3.4 in Chapter 3). Basalts in all alluvial locations are minimally weathered, grade from aphanitic to phaneritic, and are found in package sizes ranging from < 1 cm in diameter to large boulders.

Basalt outcrops are accessible in at least four places within the Nenana valley region: the headwaters of Dry Creek along the north face of Mt. Healy, headwaters of Moody Creek along the eastern and western slopes of Dora Peak, .25 km northeast of the Carlo Creek archaeological site, and within the Denali National Park and Preserve (hereafter ‘Denali Park’) at Polychrome Pass (Figure 4.1). Some outcrops mapped on the north face of Mt. Healy on geological maps (Wahrhaftig 1970c) could not be re-located, and the outcrops mapped on the slopes of Dora Peak could not be reached during survey given limited research time and budget constraints. A total of six basalt outcrops were sampled for this study, four from the Nenana valley region, including Carlo Creek, Dry Creek 1, Dry Creek 2, and Polychrome Pass outcrops, and two from ~140 km northeast of the valley near Fairbanks in the Yukon-Tanana Uplands, including two exposures of the Sage Hill outcrop, called Sage Hill 1 and Sage Hill 2, and Brown’s Hill Quarry (a commercial quarry) (UTM coordinates for each are provided in Table 4.4). Because basalts are so prevalent in the alluvium of the Nenana valley's drainages, I sampled these locations outside the valley to provide a set of control groups for comparison.

Table 4.4. Table showing UTM coordinates of each basalt outcrop source sample location**.**

Basalt Outcrop Source Sample	**UTM Coordinates**	
	Easting	***Northing***
Dry Creek 1	60396784.00	7075614.00
Dry Creek 2	60396507.00	7077281.00
Carlo Creek	60410317.00	7050298.00
Polychrome Pass	60359965.00	7048500.00
Sage Hill 1	60473665.00	7192021.00
Sage Hill 2	60474925.00	7192491.00
Brown's Hill Quarry	60477686.00	7189584.00

4.5.1.1. Dry Creek Basalts

The Dry Creek 1 outcrop is located at the headwaters of Dry Creek, 370 m south of the Denali Park boundary on the northern slope of Mt. Healy. This exposure is approximately 120 m long and 50 m wide, downcut by the tributary stream flowing into Dry Creek. Its exposure is approximately 45 m above the creek bed. Basalt from this outcrop is eroding in blocky nodules, ranging from dark brownish gray to dark gray in color, iron-stained, and finely aphanitic in texture. The Dry Creek 2 outcrop is also located at the headwaters of Dry Creek, approximately 1 km north of the Denali Park boundary, and approximately 1.25 km northwest of the Dry Creek 1 outcrop. This exposure is narrow, approximately 40 m wide, rises 60 m from the creek bed, and has been exposed by the downcutting of Dry Creek. Like Dry Creek 1, basalt from this outcrop is eroding in blocky nodules, ranging from dark brownish gray to dark gray in color, is iron-stained, and finely aphanitic in texture.

4.5.1.2. Carlo Creek Basalt

The Carlo Creek outcrop is located 0.25 km northeast of the Carlo Creek site near the southern end of the valley. This outcrop is approximately 100 m wide and 15 m tall. Rocks in this exposure are strongly weathered, blocky, dark gray in color and have aphanitic (fine-to-medium) texture.

4.5.1.3. Polychrome Pass Basalt

Basalt was collected from a roadcut exposure at Polychrome Pass (mile 46 along the park road, approximately) in Denali Park. The exposure is 15 m high and 10 m wide. Rocks from this outcrop are brittle pillow basalts, dark brown in color, and vesicular in texture.

4.5.1.4. Sage Hill Basalts

The Sage Hill 1 and 2 outcrop samples came from two basalt exposures of a singular formation located on the north end of Fort Wainwright, near Fairbanks. These exposures are two points near the ends of a small ridge rising approximately 75 m in elevation above the floodplain of the Chena River and measuring 2 km long (east-west) by 0.3 km wide (north-south). The two collection points are from road-clearing exposures, located about 1.25 km apart. The Sage Hill 1 exposure is approximately 77 m wide and 30 m long, while the Sage Hill 2 exposure is approximately 250 m wide and 60-75 m long. The basalt from both locations is weathered, blocky, finely aphanitic, and brownish gray in color. Though these samples were collected from what appears to be the same basalt flow, in the geochemical analyses below I treat them separately to test the hypothesis that they share the same geochemistry.

4.5.1.5. Brown's Hill Quarry Basalt

This location is a currently active, commercial rock quarry south of the Chena River in the Fairbanks area. Its artificial exposure measures approximately 0.5 km east-west and 0.3 km north-south, rising 53 m above the surrounding terrain. Nodules were collected from the north end of this outcrop. These nodules are blocky, aphanitic (fine to medium), weathered, hard, and dark brownish gray to dark gray in color.

4.5.2. Geochemical Analysis of Basalt Outcrops and Alluvial Sample Locations

4.5.2.1. Basalt Outcrops

Outcrops of basalt were analyzed to explore their geochemical variability and ascertain whether they could be distinguished from one another. Statistical summaries (sample minimum, maximum, mean, standard deviation, and percent standard deviation) of each outcrop's geochemistry are listed in Table 4.5. A 3D plot of principal components (PCs) 1, 2, and 3 is shown in Figure 4.2, comprising 97.6% of the total variance with cumulative eigenvalues, variances, and factor loadings for each principal component listed in Table 4.6. A Kruskal Wallis test with Dunn-Bonferroni pairwise comparisons show a significant difference in the distribution of the means of Rb, Sr, Y, Zr, and Nb across all outcrops (Rb: H = 94.527, 6 df, $p \leq 0.001$; Sr: H = 51.140, 6 df, $p \leq 0.001$; Y: H = 84.253, 6 df, $p \leq 0.001$; Zr: H = 82.914, 6 df, $p \leq 0.001$; and Nb: H = 103.392, 6 df, $p \leq 0.001$ [Table 4.6]).

Table 4.5. Statistical summaries (ppm) of minimum, maximum, mean, standard deviation (St Dev), and percent standard deviation (%SD) of element concentrations measured from basalt outcrop sample locations.

Location	Element	Min	Max	Mean	St Dev	%SD
Brown's Hill Quarry (N = 20)	Mn	696.01	1547.40	1200.12	229.40	19.11
	Fe	57501.68	86062.95	69675.59	7844.40	11.26
	Zn	71.33	108.26	89.05	9.30	10.44
	Ga	18.29	29.94	23.97	3.53	14.72
	Rb	16.31	55.34	37.92	12.57	33.14
	Sr	252.69	348.42	299.46	26.22	8.76
	Y	25.73	35.11	31.09	3.13	10.08
	Zr	156.58	225.89	187.19	19.76	10.56
	Nb	9.10	17.11	13.37	1.60	11.96
	Th	2.18	6.28	4.30	1.00	23.31
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Carlo Creek Outcrop (N = 20)	Mn	587.61	1500.03	991.55	244.86	24.69
	Fe	28583.83	93585.09	46375.85	17024.77	36.71
	Zn	59.75	244.78	120.69	43.46	36.01
	Ga	12.81	28.37	21.39	3.81	17.80
	Rb	57.70	106.81	76.14	12.27	16.11
	Sr	61.74	279.42	176.06	43.42	24.66
	Y	17.88	35.91	23.30	4.40	18.87
	Zr	121.60	150.62	137.07	7.70	5.62
	Nb	8.23	13.29	10.93	1.25	11.40
	Th	5.65	9.95	7.18	1.40	19.57
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Dry Creek Outcrop 1 (N = 20)	Mn	1036.28	2129.83	1361.34	295.84	21.73
	Fe	53402.29	75742.30	62626.27	5781.59	9.23
	Zn	87.59	123.10	100.83	10.01	9.93
	Ga	17.79	30.79	24.64	3.14	12.75
	Rb	10.68	63.14	33.29	19.17	57.59
	Sr	117.78	408.32	297.55	66.65	22.40
	Y	29.47	39.43	33.57	2.45	7.29
	Zr	191.87	257.89	228.71	14.85	6.49
	Nb	15.12	21.86	18.22	1.78	9.77
	Th	3.84	6.86	5.29	0.98	18.61
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Dry Creek Outcrop 2 (N = 20)	Mn	607.67	2555.03	1674.83	483.81	28.89
	Fe	61902.72	104062.63	78471.55	9393.77	11.97

Table 4.5 Continued.

Location	Element	Min	Max	Mean	St Dev	%SD
	Zn	104.01	193.25	138.43	18.86	13.62
	Ga	22.00	31.31	26.97	2.70	9.99
	Rb	12.46	53.25	24.31	14.13	58.11
	Sr	118.39	410.70	278.32	97.27	34.95
	Y	35.42	44.96	38.81	2.47	6.37
	Zr	171.13	218.85	194.89	10.05	5.16
	Nb	15.27	22.84	18.48	1.84	9.97
	Th	4.05	8.55	5.96	1.31	22.03
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Polychrome Pass (N = 20)	Mn	994.95	3270.18	1609.28	677.70	42.11
	Fe	36700.35	90449.80	58072.28	13338.84	22.97
	Zn	68.19	131.44	90.14	17.23	19.12
	Ga	18.91	34.07	24.05	3.30	13.70
	Rb	27.08	49.25	39.37	6.18	15.69
	Sr	254.78	394.69	335.39	39.58	11.80
	Y	26.11	34.28	29.95	2.61	8.70
	Zr	154.25	216.06	188.66	17.30	9.17
	Nb	11.78	17.69	14.41	1.66	11.54
	Th	2.06	6.51	4.65	1.17	25.07
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Sage Hill 1 (N = 20)	Mn	822.23	1650.76	1211.17	180.73	14.92
	Fe	54513.87	74465.10	63813.32	5300.88	8.31
	Zn	77.73	118.84	94.99	10.32	10.86
	Ga	18.92	29.78	25.31	2.68	10.59
	Rb	41.47	59.48	55.40	4.24	7.66
	Sr	276.72	357.04	327.43	23.78	7.26
	Y	29.43	35.41	32.87	1.80	5.47
	Zr	170.67	214.71	194.30	10.32	5.31
	Nb	12.75	15.96	14.38	0.86	5.99
	Th	4.36	7.24	5.46	0.83	15.24
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Sage Hill 2 (N = 20)	Mn	926.75	1478.55	1254.71	126.44	10.08
	Fe	57085.43	73009.96	67141.85	3723.55	5.55
	Zn	82.98	106.95	97.42	6.87	7.05
	Ga	21.01	33.06	25.75	2.99	11.62
	Rb	43.08	61.03	52.21	5.57	10.67
	Sr	288.78	352.75	316.13	17.92	5.67
	Y	30.73	37.25	33.16	1.92	5.78

Table 4.5 Continued.

Location	Element	Min	Max	Mean	St Dev	%SD
	Zr	182.86	214.69	197.71	9.68	4.90
	Nb	13.64	16.48	14.74	0.88	5.97
	Th	2.86	7.60	4.45	1.19	26.84

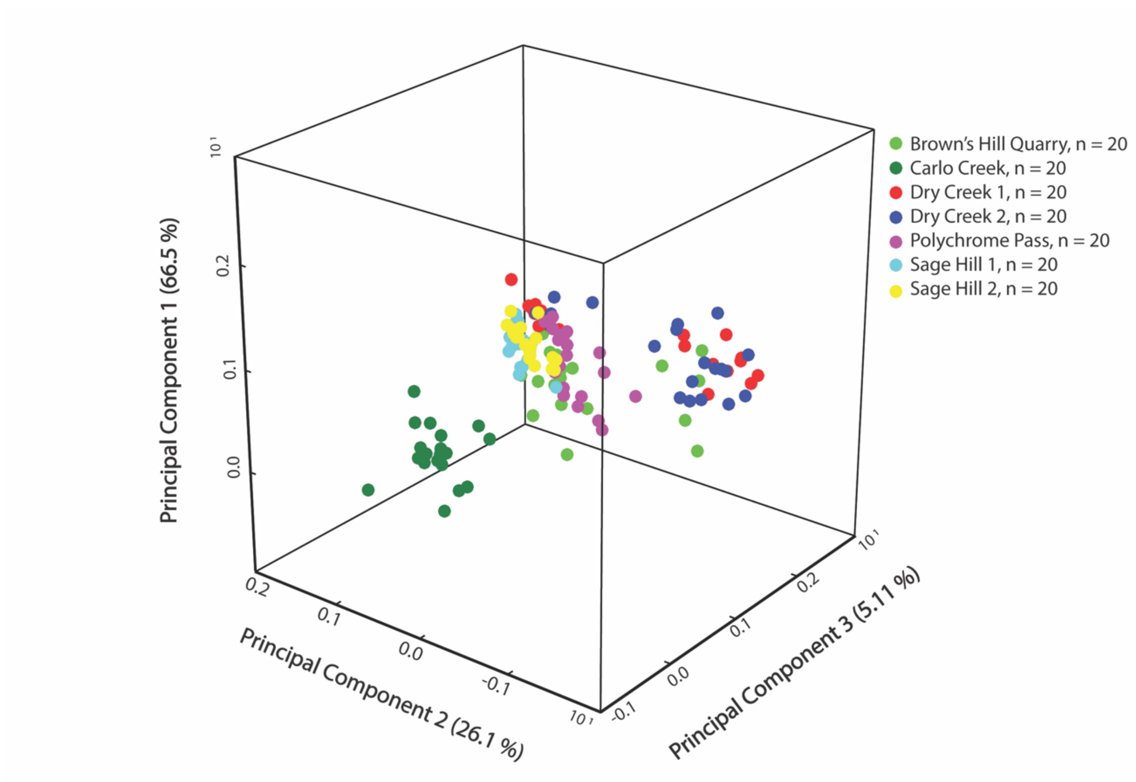

Figure 4.2. Logged (base 10) 3D plot of principal-component 1, 2, and 3 scores for basalts sampled from seven outcrop locations in this study.

Some basalt outcrops could be differentiated from each other while others could not. The most variant and distinct outcrop is Carlo Creek. It is unequivocally differentiated from all other outcrops by the first three principal components. This reflects its higher mean values of Rb and lower mean values of Sr, Y, Nb, and Zr (Table 4.5). The Dunn-Bonferroni pairwise comparison of means confirms this pattern. Except for Y values in the Polychrome Pass samples, all comparisons of element means between Carlo Creek and Nenana valley outcrop samples are statistically significant (Table 4.7). Carlo Creek is also differentiated from all Fairbanks outcrops by four or more elements in each individual comparison (Tables 4.6, 4.7).

Table 4.6. Eigenvalues and percentages of variance explained by principal components calculated from the variance-covariance matrix of concentration data (log-10 ppm) for basalt outcrop data, along with principal-component scores for each element.

Principal Component	Eigenvalue	% Variance	Cumulative % Variance
1	0.0646	66.49	66.49
2	0.0253	26.05	92.54
3	0.0050	5.11	97.64
4	0.0016	1.62	99.26
5	0.0007	0.74	100.00

Element	PC 1	PC 2	PC3	PC4	PC5
Rb	-0.93	0.18	0.32	0.07	-0.05
Sr	0.02	0.89	-0.44	-0.10	-0.07
Y	0.20	0.22	0.62	-0.73	0.06
Zr	0.17	0.28	0.35	0.49	0.72
Nb	0.27	0.21	0.46	0.46	-0.68

Samples from the Fairbanks area (Brown's Hill Quarry, Sage Hill 1 and 2 outcrops) could not be differentiated from each other. The only Fairbanks outcrop pair to exhibit a statistically significant difference in a single element mean (Rb) is Brown's Hill Quarry and Sage Hill 1. This difference was not enough to discriminate between these two outcrops (Tables 4.5, 4.7; Figure 4.2).

Further exploration of PCA plots cross-checked with plots of element concentrations revealed additional patterns of differentiation between basalt outcrop samples not apparent in Figure 4.2, beginning with outcrops located within the Nenana valley.

Table 4.7. Results of post-hoc Dunn-Bonferroni pairwise comparison tests of all basalt outcrop samples for elements Rb, Sr, Y, Zr, and Nb. Sig.= Significance (p-value); Adj. Sig.= Adjusted Significance (adjusted p-value). Significant p-values are bolded.

Pairwise Comparison	**Rb**			**Sr**			**Y**			**Zr**			**Nb**		
	Test Statistic	***Sig.***	***Adj. Sig.***	***Test Statistic***	***Sig.***	***Adj. Sig.***	***Test Statistic***	***Sig.***	***Adj. Sig.***	***Test Statistic***	***Sig.***	***Adj. Sig.***	***Test Statistic***	***Sig.***	***Adj. Sig.***
Carlo Creek – Dry Creek 1	79.47	**<.001**	**0.00**	-56.53	**<.001**	**0.00**	-63.94	**<.001**	**0.00**	-115.29	**0.00**	**0.00**	-103.07	**<.001**	**0.00**
Carlo Creek – Dry Creek 2	100.15	**<.001**	**0.00**	-49.25	**<.001**	**0.00**	-108.55	**0.00**	**0.00**	-63.90	**<.001**	**0.00**	-105.75	**0.00**	**0.00**
Carlo Creek – Polychrome Pass	82.05	**<.001**	**0.00**	-79.60	**<.001**	**0.00**	-27.38	0.03	0.66	-54.30	**<.001**	**0.00**	-51.60	**<.001**	**0.00**
Carlo Creek- Brown's Hill Quarry	-78.68	**<.001**	**0.00**	47.80	**<.001**	**0.00**	41.90	**0.00**	**0.02**	52.65	**<.001**	**0.00**	31.33	0.01	0.29
Carlo Creek -Sage Hill 2	42.03	**<.001**	**0.02**	-62.65	**<.001**	**0.00**	-59.65	**<.001**	**0.00**	-70.60	**<.001**	**0.00**	-57.10	**<.001**	**0.00**
Carlo Creek- Sage Hill 1	29.23	0.02	0.46	-75.00	**<.001**	**0.00**	-57.63	**<.001**	**0.00**	-62.55	**<.001**	**0.00**	-49.68	**<.001**	**0.00**
Dry Creek 1- Dry Creek 2	20.68	0.11	1.00	7.28	0.57	1.00	-44.61	**<.001**	**0.01**	51.39	**<.001**	**0.00**	-2.68	0.84	1.00
Dry Creek 1 Polychrome Pass-	2.58	0.84	1.00	-23.07	0.07	1.00	36.56	0.01	0.10	60.99	**<.001**	**0.00**	51.47	**<.001**	**0.00**
Dry Creek 1- Brown's Hill Quarry	0.79	0.95	1.00	-8.73	0.50	1.00	-22.04	0.09	1.00	-62.64	**<.001**	**0.00**	-71.75	**<.001**	**0.00**
Dry Creek 1-Sage Hill 2	-37.44	0.00	0.08	-6.12	0.64	1.00	4.29	0.74	1.00	44.69	**<.001**	**0.01**	45.97	**<.001**	**0.01**
Dry Creek 1-Sage Hill 1	-50.24	**<.001**	**0.00**	-18.47	0.15	1.00	6.31	0.63	1.00	52.74	**<.001**	**0.00**	53.40	**<.001**	**0.00**
Dry Creek 2- Polychrome Pass	-18.10	0.16	1.00	-30.35	0.02	0.36	81.18	**<.001**	**0.00**	9.60	0.45	1.00	54.15	**<.001**	**0.00**
Dry Creek 2- Brown's Hill Quarry	21.48	0.09	1.00	-1.45	0.91	1.00	-66.65	**<.001**	**0.00**	-11.25	0.38	1.00	-74.43	**<.001**	**0.00**
Dry Creek 2-Sage Hill 2	-58.13	**<.001**	**0.00**	-13.40	0.29	1.00	48.90	**<.001**	**0.00**	44.69	**<.001**	**0.01**	48.65	**<.001**	**0.00**

Table 4.7 Continued

	Rb			**Sr**			**Y**			**Zr**			**Nb**		
	Test Statistic	***Sig.***	***Adj. Sig.***	***Test Statistic***	***Sig.***	***Adj. Sig.***	***Test Statistic***	***Sig.***	***Adj. Sig.***	***Test Statistic***	***Sig.***	***Adj. Sig.***	***Test Statistic***	***Sig.***	***Adj. Sig.***
Dry Creek 2-Sage Hill 1	-70.93	**<.001**	**0.00**	-25.75	0.04	0.91	50.93	**<.001**	**0.00**	1.35	0.92	1.00	56.08	**<.001**	**0.00**
Polychrome Pass-Brown's Hill Quarry	3.38	0.79	1.00	-31.80	0.01	0.26	14.53	0.25	1.00	-1.65	0.90	1.00	-20.28	0.11	1.00
Polychrome Pass-Sage Hill 2	-40.03	**0.00**	**0.04**	16.95	0.18	1.00	-32.28	0.01	0.24	-16.30	0.20	1.00	-5.50	0.67	1.00
Polychrome Pass-Sage Hill 1	-52.83	**<.001**	**0.00**	4.60	0.72	1.00	-30.25	0.02	0.37	-8.25	0.52	1.00	1.93	0.88	1.00
Brown's Hill Quarry-Sage Hill 2	-36.65	.004	.084	-14.85	0.24	1.00	-17.75	0.16	1.00	-17.95	0.16	1.00	-25.78	0.04	0.90
Brown's Hill Quarry-Sage Hill 1	-49.45	**<.001**	**0.02**	-27.20	0.03	0.69	-15.73	0.22	1.00	-9.90	0.44	1.00	-18.35	0.15	1.00
Sage Hill 2-Sage Hill 1	12.80	0.32	1.00	12.35	0.33	1.00	-2.03	0.87	1.00	-8.05	0.53	1.00	-7.43	0.56	1.00

The significance level is 0.050. Adjusted significance levels calculated using the Bonferroni correction for multiple tests.

Within the Nenana valley, the Dry Creek 1 and 2 outcrops are differentiated from each other by the elements Y and Zr. Dry Creek 1 has lower mean concentrations of Y and higher mean concentrations of Zr (Table 4.5), and this pattern is verified by statistically significant differences in means (Table 4.7; Figure 4.3a). In addition, Dry Creek 2 material can be differentiated from Polychrome Pass by higher mean concentrations of the elements Y and Nb (Table 4.5; Figure 4.3b), and these elements also show statistically significant results in the Dunn-Bonferroni pairwise comparison (Table 4.7). Dry Creek 1 and Polychrome Pass also have statistically significant differences in mean concentrations of Zr and Nb (Table 4.7); however, plots visualizing these significant elemental differences still exhibit partial overlap with each other (Table 4.5; Figures 4.3c, d).

When comparing the Nenana valley outcrops to Fairbanks outcrops, Polychrome Pass has statistically significant lower means of Rb when compared to Sage Hill 1 and 2 (Tables 4.5, 4.7). While Sage Hill 1 can be differentiated from Polychrome Pass in plots representing this difference, there is partial overlap between the Polychrome Pass and Sage Hill 2 outcrops (Figures 4.4a, b). Polychrome Pass cannot be geochemically differentiated from Brown's Hill Quarry by any element (Tables 4.5, 4.7), confirming patterns shown in Figure 4.2. Dry Creek 2 can be differentiated from Brown's Hill Quarry by significantly higher mean concentrations of Y and Nb (Tables 4.5, 4.7; Figure 4.4c). Dry Creek 2 is differentiated from Sage Hill 1 and 2 by statistically significant differences in means of Rb, Y, and Nb (Tables 4.5, 4.7; Figure 4.4d).

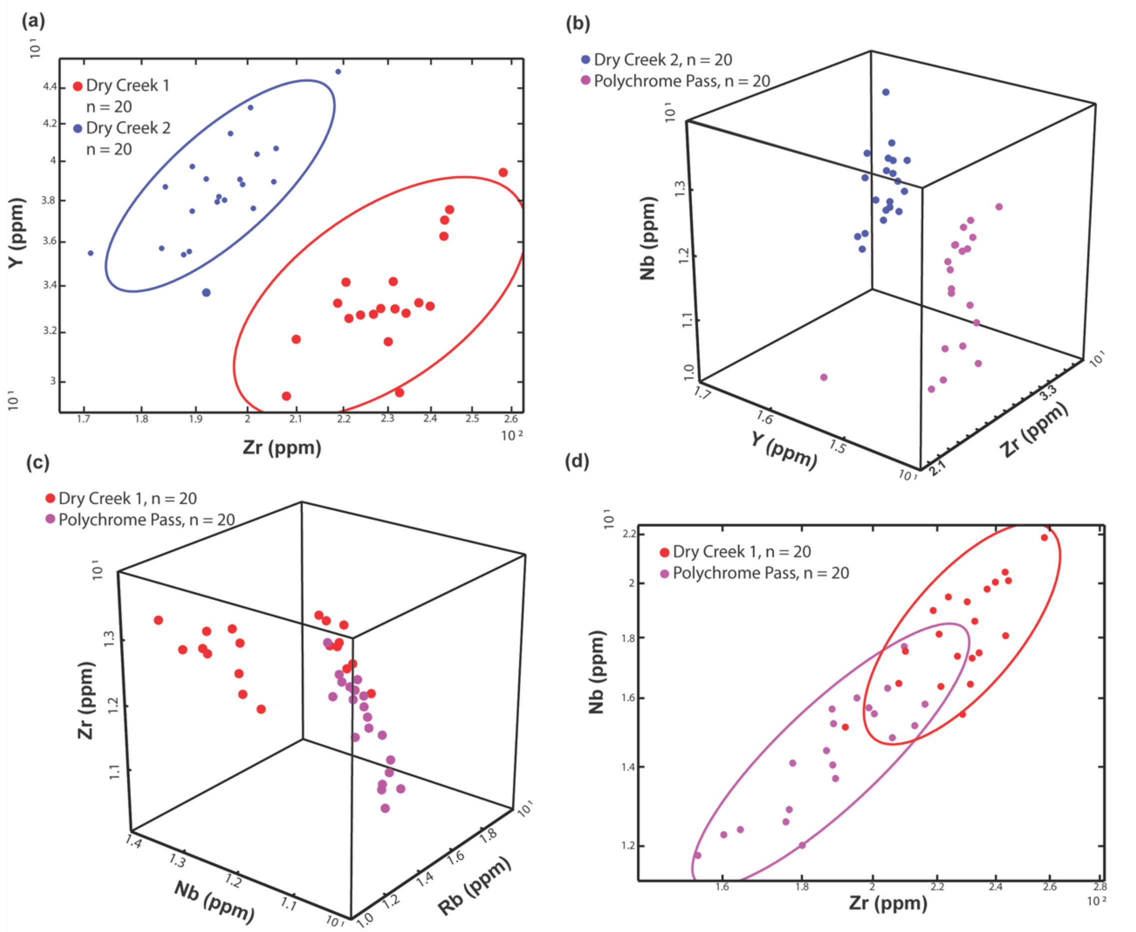

Figure 4.3. Logged (base 10) biplots and 3D plots of select basalt outcrop samples: (a) biplot of Zr and Y values of Dry Creek 1 and Dry Creek 2 outcrop samples; (b) 3D plot of Nb, Y, and Zr values of Dry Creek 2 and Polychrome Pass outcrop samples; (c) biplot of PC 1 and PC 4 scores for Polychrome Pass and Sage Hill 2 outcrop samples; (d) 3D plot of Nb, Y, and Zr values of Brown's Hill Quarry and Dry Creek 2 samples. Ellipse confidence intervals drawn at 90%.

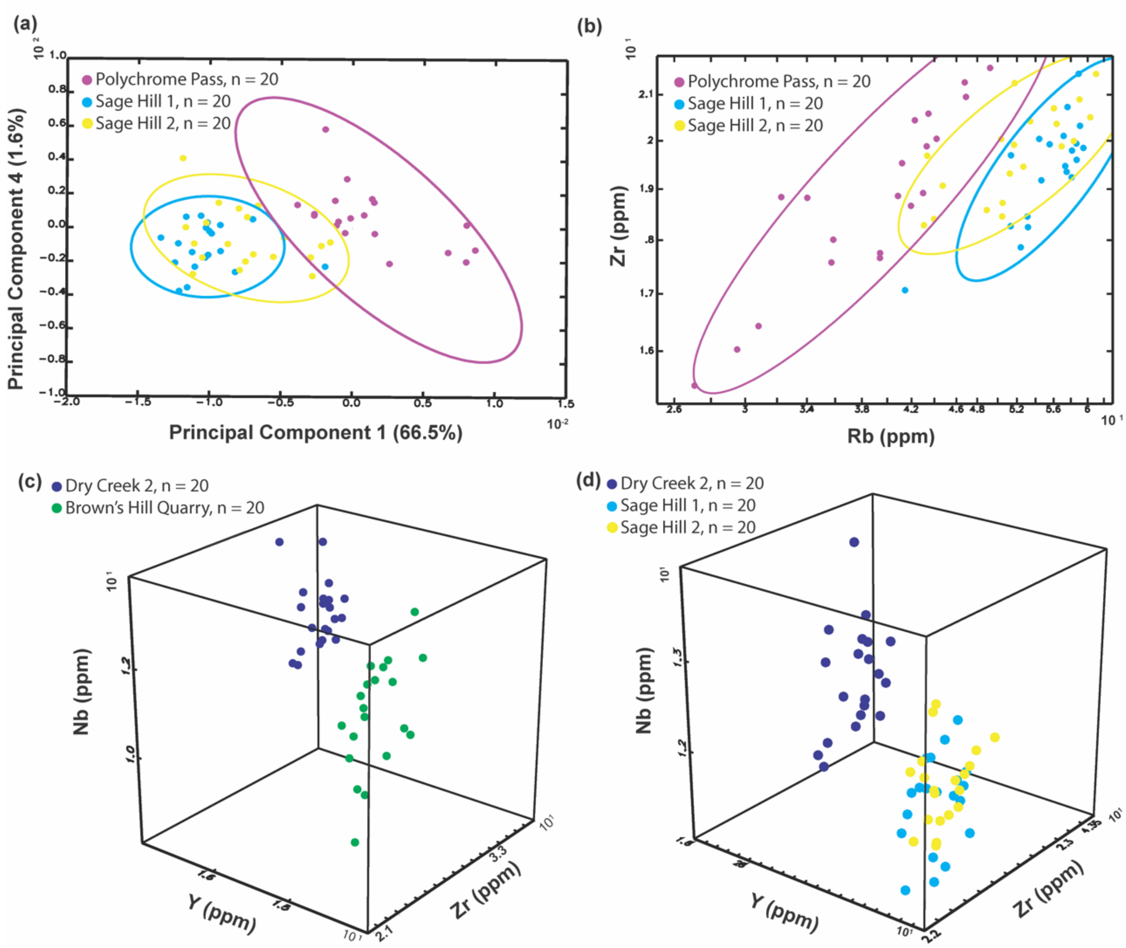

Figure 4.4. Logged (base 10) biplots and 3D plots of select basalt outcrop samples: (a) biplot of principal component 1 and 4 scores of Polychrome Pass and Sage Hill 1/2 samples; (b) biplot of Rb and Zr values of Polychrome Pass and Sage Hill 1/2 samples; (c) 3D plot of Nb, Y, and Zr values Dry Creek 2 and Brown's Hill Quarry samples; (d) 3D plot of Nb, Y and Zr values of Dry Creek 2 and Sage Hill 1/2 samples. Ellipse confidence intervals drawn at 90%.

Dry Creek 1 has statistically significant differences in means of Zr and Nb when compared to Brown's Hill Quarry and Sage Hill 1 and 2, as well as Rb when compared with just Sage Hill 1; however, additional visual plots of element values still show slight overlap between these outcrops despite the statistically significant differences in mean values of several elements (Tables 4.5, 4.7; Figure 4.5a, b, c).

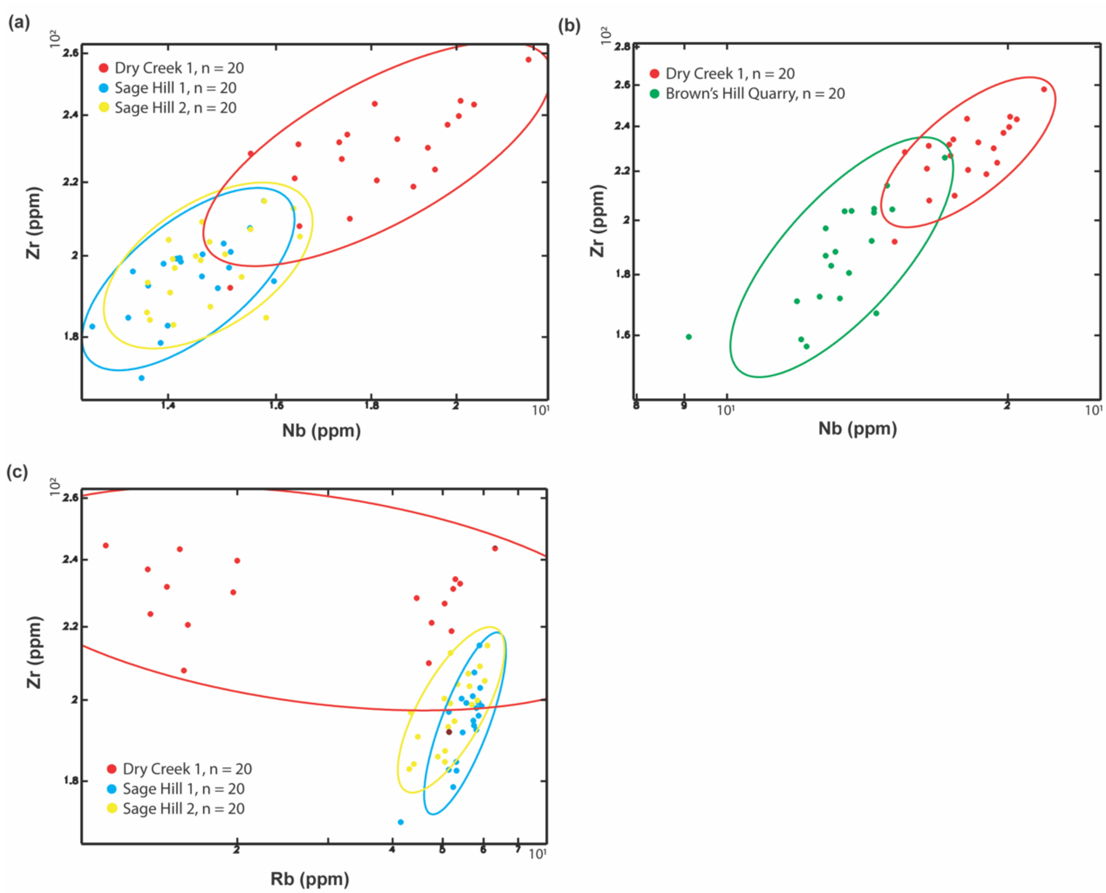

Figure 4.5. Logged (base 10) biplots of select basalt outcrop samples: (a) biplot of Zr and Nb Dry Creek 1 and Sage Hill 1/2 samples; (b) biplot of Nb and Zr values of Dry Creek 1 and Brown's Hill Quarry samples; (c) biplot of Zr and Rb values for Dry Creek 1 and Sage Hill 1/2 samples. Ellipse confidence intervals drawn at 90%.

Table 4.8 summarizes the results described above, showing which outcrop-sample locations could be differentiated from each other by principal components and which comparisons have statistically significant differences in mean element values. There are important observations to highlight in summarizing these data. The first, and perhaps most obvious, is the Carlo Creek outcrop appears to be unique and discernable from the other basalt outcrops sampled in this study, representing a discrete source location if found to match basalt artifacts. Second, the two Dry Creek outcrops appear to have significantly different concentrations of Y and Zr, suggesting that though they are found in close proximity to each other and share some similarity in chemical composition, they may have resulted from two separate flow events. Dry Creek 1, however, overlaps partially with the Fairbanks outcrops, located nearly 140 km from Dry Creek. Unlike Dry Creek 1, Dry Creek 2 appears to be isolatable as a possible source location. The Polychrome Pass basalt outcrop also partially overlaps with Dry Creek 1 and the Fairbanks outcrops, making it a poor candidate for sourcing. It is noteworthy that this rock was vesicular in texture and of "low" quality for flintknapping and toolstone use. With regards to the Fairbanks outcrops, the Sage Hill 1 and 2 samples are not significantly different from each other and physically located on the same outcrop feature; therefore, they should be considered part of the same flow. From here, I will refer to these as a single outcrop sample, "Sage Hill 1/2." Finally, Brown's Hill Quarry is not entirely geochemically distinct from Sage Hill 1/2, Polychrome Pass, and Dry Creek 1 outcrops. Its geochemical signature is highly variable and not well constrained (Tables 4.5, 4.7; Figures 4.2, 4.4, 4.5). In sum, results show that only two of these outcrops appear to be discrete from the others, Carlo Creek and Dry Creek 2. Despite the geographical distance of ≥ 140 km between the Nenana valley and Fairbanks outcrops, most share geochemical affinity with each other.

Table 4.8. Summary table of basalt outcrop-sample locations showing which could be discriminated from each other based on principal components and statistically significant mean element values. Dashes represent comparisons where significant differentiation was not achieved.

Primary Sample Location	***Dry Creek 1***	***Dry Creek 2***	***Carlo Creek***	***Polychrome Pass***	***Brown's Hill Quarry***	***Sage Hill 1***	***Sage Hill 2***
Dry Creek 1		Y, Zr	PCs 1,2,3 Rb, Zr, Y, Sr, Nb	Zr, Nb	-	Rb	-
Dry Creek 2	Y, Zr		PCs 1,2,3 Rb, Zr, Y, Sr, Nb	Y, Nb	Y, Nb	Rb, Y, Nb	Rb, Y, Nb
Carlo Creek	PCs 1,2,3 Rb, Zr, Y, Sr, Nb	PCs 1,2,3 Rb, Zr, Y, Sr, Nb		PCs 1,2,3 Rb, Zr, Sr, Nb	PCs 1,2,3 Rb, Zr, Y, Sr, Nb	PCs 1,2,3 Rb, Zr, Y, Sr, Nb	PCs 1,2,3 Rb, Zr, Y, Sr, Nb
Polychrome Pass	Zr, Nb[1]	Y, Nb	PCs 1,2,3 Rb, Zr, Sr, Nb		-	PC 1 vs 4	-
Brown's Hill Quarry	-	Y, Nb	Rb, Zr, Y, Sr, Nb	-		Rb	-
Sage Hill 1	Rb	Rb, Y, Nb	PCs 1,2,3	PC 1 vs 4 Rb	Rb		-
Sage Hill 2	-	Rb, Y, Nb	Rb, Zr, Y, Sr, Nb	-	-	-	

4.5.2.2. Alluvial Samples

Alluvial samples were compared to outcrop samples to assess if geochemical signatures of the outcrops occurred in the streambeds. A total of 785 basalt samples were collected from four rivers and 20 creeks and drainages within the valley (Figure 4.1; Tables 4.9 and 4.10).

Results show some outcrop signatures occur within alluvial samples. Several plots of PC 1, PC 2, and PC 3 scores (representing 96% variance) compare individual alluvial samples with all outcrop samples (Figures 4.6-4.14). Geochemical signatures of just three outcrops, Dry Creek 1, Carlo Creek, and Brown's Hill Quarry, occur in Nenana valley alluvial samples, but these are represented by just a handful (1-9) of cobbles collected from each sample location. Except for two Dry Creek alluvial samples (Dry Creek Alluvium 4 and Dry Creek Alluvium 6), matches between alluvial sample locations and outcrops are very low, with just ≤ 30% of each alluvial sample correlating to an outcrop. Dry Creek Alluvium 4 and 6 match the Dry Creek 1 and Dry Creek 1 and Carlo Creek outcrop samples, respectively. The majority of alluvial samples do not express geochemical affinity with the known Nenana valley basalt outcrops (Table 4.10).

Only one alluvial sample from the headwaters of Dry Creek corresponds to the Brown's Hill Quarry cluster. Aside from this outlier, Fairbanks outcrops do not occur within NRV drainages despite partial overlap of the Dry Creek 1 and Polychrome Pass outcrops with Fairbanks outcrops in geochemical comparisons. Only two outcrops within the NRV, Dry Creek 1 and Carlo Creek, are represented in alluvial sample locations. Polychrome Pass and Dry Creek 2 did not contribute to any of the drainages sampled in this study. Although the Dry Creek 1, Polychrome Pass, and Fairbanks outcrops share enough geochemical affinity that they cannot be entirely discriminated from each other, significant mean differences in two elements (Zr and Nb) between Dry

Table 4.9. Statistical summaries (ppm) of minimum, maximum, mean, standard deviation (St Dev), and percent standard deviation (%SD) of element concentrations measured from alluvial basalt sample locations. Summaries for two collection localities (the confluence of the Savage and Teklanika Rivers and Suntrana) were excluded because respective sample numbers were n = 2.

Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Bear Creek (N = 20)	Mn	128.72	2021.99	737.89	555.75	75.32
	Fe	3314.20	72311.06	35318.33	21290.21	60.28
	Zn	31.39	429.43	115.18	84.99	73.79
	Ga	3.19	29.30	16.56	6.98	42.14
	Rb	24.71	115.47	68.31	25.95	37.99
	Sr	37.06	340.73	128.08	88.73	69.28
	Y	12.74	42.85	22.92	8.66	37.79
	Zr	41.32	269.06	138.66	53.31	38.45
	Nb	2.89	25.40	11.07	5.58	50.38
	Th	0.40	9.86	5.54	2.63	47.50
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Birch Creek (N = 20)	Mn	100.68	1972.44	641.66	405.70	63.23
	Fe	14144.43	57849.62	36670.12	11381.93	31.04
	Zn	47.46	162.25	104.00	32.95	31.68
	Ga	14.48	24.55	20.23	2.76	13.62
	Rb	32.12	119.64	74.49	20.13	27.02
	Sr	53.12	475.33	151.87	115.92	76.33
	Y	13.80	34.73	21.68	5.18	23.88
	Zr	107.88	196.63	142.62	23.47	16.45
	Nb	5.31	12.91	9.95	1.98	19.94
	Th	1.24	10.04	6.29	2.45	38.93
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
California Creek (N = 25)	Mn	183.54	1995.38	962.91	419.36	43.55
	Fe	5176.74	82312.93	43259.55	17815.22	41.18
	Zn	30.67	161.66	101.95	34.04	33.39
	Ga	11.24	26.41	19.74	4.32	21.88
	Rb	6.32	192.00	73.39	42.78	58.29
	Sr	15.45	704.51	176.33	142.24	80.67
	Y	12.24	42.07	23.58	5.97	25.32
	Zr	46.46	249.97	130.21	48.48	37.23
	Nb	2.48	21.41	10.21	4.63	45.41
	Th	0.05	17.97	6.69	4.42	66.11

Table 4.9 Continued.

Location	Element	Min	Max	Mean	St Dev	%SD
Carlo Creek (N = 20)	Fe	25025.59	67562.15	40177.91	11319.62	28.17
	Zn	62.72	164.44	102.92	30.08	29.22
	Ga	13.85	25.72	19.03	3.49	18.36
	Rb	29.44	107.02	69.56	23.08	33.17
	Sr	74.18	293.08	155.72	64.76	41.59
	Y	16.02	32.75	21.13	3.91	18.50
	Zr	95.51	186.87	142.42	23.35	16.39
	Nb	6.90	13.27	10.06	1.83	18.19
	Th	3.29	12.39	6.96	2.34	33.68
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Chicken Creek (N = 12)	Mn	144.78	2554.63	700.92	684.44	97.65
	Fe	2775.27	59700.56	25667.09	18222.95	71.00
	Zn	25.20	347.85	97.30	89.40	91.87
	Ga	4.50	29.37	14.22	6.98	49.09
	Rb	9.75	93.13	38.93	30.63	78.69
	Sr	5.94	688.25	120.01	192.89	160.72
	Y	3.57	38.44	15.61	10.58	67.77
	Zr	25.20	153.94	82.05	50.32	61.32
	Nb	0.58	15.59	5.59	4.83	86.34
	Th	0.10	9.01	4.05	2.91	71.94
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Lower Cindy and James Creek (N = 20)	Mn	143.11	3308.77	770.25	747.85	97.09
	Fe	15665.92	50198.69	33901.09	8687.08	25.62
	Zn	42.70	128.43	99.60	25.84	25.94
	Ga	11.70	23.92	17.64	4.08	23.12
	Rb	16.11	116.71	79.23	22.77	28.74
	Sr	67.01	216.66	136.17	46.25	33.97
	Y	19.24	30.98	23.68	3.09	13.06
	Zr	109.07	179.16	144.13	18.94	13.14
	Nb	5.59	14.15	10.73	1.95	18.14
	Th	0.00	0.00	0.00	0.00	0.00
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Cottonwood Creek (N = 20)	Mn	172.08	1287.60	688.54	353.13	51.29
	Fe	7231.89	54035.95	36798.32	11482.08	31.20
	Zn	67.87	192.44	114.93	30.50	26.54
	Ga	9.94	26.10	18.64	3.92	21.03
	Rb	37.95	106.12	77.30	17.58	22.74
	Sr	55.08	911.44	188.97	187.92	99.45
	Y	19.66	65.67	26.03	9.75	37.48

Table 4.9 Continued.

Location	Element	Min	Max	Mean	St Dev	%SD
	Zr	109.94	324.14	153.14	45.50	29.71
	Nb	6.73	13.50	10.23	1.85	18.07
	Th	2.89	12.40	6.96	2.26	32.47
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Dry Creek Alluvium 1 (N = 40)	Mn	51.40	2582.06	656.38	528.96	80.59
	Fe	6562.43	70690.67	36295.28	16910.52	46.59
	Zn	8.88	169.67	96.71	40.27	41.64
	Ga	8.93	23.14	17.22	3.90	22.63
	Rb	8.19	129.50	75.13	30.72	40.89
	Sr	22.90	375.02	127.64	73.79	57.81
	Y	4.23	40.91	21.47	6.77	31.55
	Zr	38.55	282.79	142.14	48.80	34.34
	Nb	1.72	20.97	10.34	3.52	34.07
	Th	0.55	11.90	6.19	2.84	45.79
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Dry Creek Alluvium 2 (N = 55)	Mn	240.64	1542.82	1037.72	427.24	41.17
	Fe	19162.32	76188.11	49076.69	14181.20	28.90
	Zn	46.32	242.89	109.59	34.76	31.72
	Ga	13.17	32.84	18.67	3.53	18.91
	Rb	38.26	171.87	80.45	29.90	37.16
	Sr	46.07	379.81	201.61	99.50	49.35
	Y	16.13	38.09	28.01	6.35	22.68
	Zr	83.23	312.41	179.75	55.40	30.82
	Nb	5.40	30.20	13.73	4.31	31.42
	Th	2.62	17.88	6.84	2.73	39.94
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Dry Creek Alluvium 3 (N = 15)	Mn	155.59	2200.20	1321.58	498.29	37.70
	Fe	10810.87	79765.23	62097.46	18300.78	29.47
	Zn	21.70	121.59	94.46	25.84	27.35
	Ga	7.68	25.72	19.12	4.27	22.34
	Rb	4.50	70.28	44.67	17.20	38.50
	Sr	12.75	384.20	303.82	88.48	29.12
	Y	12.08	53.29	32.27	8.57	26.55
	Zr	165.39	242.63	215.80	24.24	11.23
	Nb	5.33	22.37	15.67	4.54	28.95
	Th	0.37	8.12	4.54	2.44	53.84
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
	Mn	1236.24	80.49	6.51	1151.05	1354.31

Table 4.9 Continued.

Location	Element	Min	Max	Mean	St Dev	%SD
Dry Creek Alluvium 4 (N = 5)	Fe	1151.05	1354.31	1236.24	80.49	6.51
	Zn	56153.21	69847.62	63890.64	5183.71	8.11
	Ga	85.61	120.02	99.12	14.91	15.04
	Rb	17.51	22.26	20.90	2.04	9.78
	Sr	40.17	63.05	50.21	10.36	20.63
	Y	323.68	396.53	349.16	30.82	8.83
	Zr	26.27	38.95	32.71	4.65	14.21
	Nb	199.95	248.69	223.94	18.01	8.04
	Th	15.39	18.34	17.42	1.20	6.91
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Dry Creek Alluvium 5 (N = 15)	Mn	155.59	2200.20	1321.58	498.29	37.70
	Fe	10810.87	79765.23	62097.46	18300.78	29.47
	Zn	21.70	121.59	94.46	25.84	27.35
	Ga	7.68	25.72	19.12	4.27	22.34
	Rb	4.50	70.28	44.67	17.20	38.50
	Sr	12.75	384.20	303.82	88.48	29.12
	Y	12.08	53.29	32.27	8.57	26.55
	Zr	165.39	242.63	215.80	24.24	11.23
	Nb	5.33	22.37	15.67	4.54	28.95
	Th	0.37	8.12	4.54	2.44	53.84
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Dry Creek Alluvium 6 (N = 30)	Mn	411.34	2904.89	1296.83	596.41	45.99
	Fe	29894.69	84870.61	52662.65	13993.57	26.57
	Zn	63.10	277.48	125.79	49.40	39.27
	Ga	10.35	27.96	19.72	5.24	26.58
	Rb	8.30	142.81	56.76	30.21	53.22
	Sr	42.65	654.34	227.06	130.36	57.41
	Y	11.21	43.32	23.27	8.01	34.44
	Zr	42.15	233.77	144.31	53.46	37.04
	Nb	2.56	19.52	10.99	4.94	44.96
	Th	0.61	11.36	5.61	2.72	48.44
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
First Creek (N = 20)	Mn	32.45	1153.63	541.11	332.81	61.50
	Fe	6540.85	73485.01	35767.55	17839.41	49.88
	Zn	18.56	168.34	108.31	31.96	29.50
	Ga	6.95	39.56	18.80	7.18	38.16
	Rb	13.17	128.98	68.23	37.87	55.51
	Sr	14.34	217.55	113.46	52.58	46.34

Table 4.9 Continued.

Location	Element	Min	Max	Mean	St Dev	%SD
	Y	9.39	91.08	24.95	17.31	69.41
	Zr	50.54	174.28	119.36	38.87	32.57
	Nb	2.86	14.40	9.53	3.25	34.13
	Th	0.67	12.70	6.39	3.20	50.01
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Fish Creek (N = 30)	Mn	362.49	3360.00	1113.21	59.12	793.97
	Fe	9627.61	89523.48	33320.09	49.21	18307.37
	Zn	22.14	373.29	115.51	47.60	61.34
	Ga	3.70	27.17	15.31	36.06	6.08
	Rb	12.78	120.71	56.70	48.13	31.95
	Sr	15.26	217.94	91.83	51.20	56.49
	Y	10.35	59.36	21.71	36.71	8.37
	Zr	35.36	210.06	128.72	27.80	37.60
	Nb	2.06	17.45	9.17	32.76	3.24
	Th	0.86	10.91	4.99	45.47	2.63
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Jenny Creek (N = 20)	Mn	184.42	3477.32	1001.64	1128.59	112.67
	Fe	2864.05	66501.23	21179.10	20726.16	97.86
	Zn	13.07	109.08	47.89	30.25	63.16
	Ga	1.76	25.25	14.16	7.25	51.24
	Rb	7.41	56.30	22.10	15.83	71.65
	Sr	20.94	803.61	330.73	269.07	81.36
	Y	8.37	32.79	16.93	7.93	46.82
	Zr	27.00	439.89	142.58	103.85	72.84
	Nb	0.88	15.76	5.47	4.64	84.72
	Th	0.53	9.93	3.58	2.17	60.61
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Little Panguingue Creek (N = 20)	Mn	264.88	2345.39	785.07	563.32	71.75
	Fe	15525.05	67021.01	30839.23	13812.55	44.79
	Zn	43.37	138.22	77.44	24.24	31.30
	Ga	10.51	25.65	16.40	4.15	25.33
	Rb	31.71	102.21	66.62	24.06	36.11
	Sr	42.87	398.43	153.13	96.32	62.90
	Y	16.66	33.59	21.47	4.32	20.14
	Zr	82.08	338.97	155.56	54.76	35.20
	Nb	7.27	16.74	10.92	2.55	23.37
	Th	2.60	11.68	5.85	2.24	38.35
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**

Table 4.9 Continued.

Location	Element	Min	Max	Mean	St Dev	%SD
Lower Moose Creek (N = 24)	Mn	98.74	2875.41	738.20	654.07	88.60
	Fe	1184.83	65407.86	23376.06	19596.86	83.83
	Zn	14.99	298.45	73.61	58.96	80.11
	Ga	2.40	28.23	12.40	6.90	55.64
	Rb	5.06	127.78	44.12	35.82	81.18
	Sr	1.60	337.78	102.91	112.59	109.41
	Y	2.55	54.65	16.23	11.96	73.69
	Zr	22.03	189.20	84.36	53.13	62.98
	Nb	0.04	14.63	5.82	4.38	75.27
	Th	0.10	12.45	4.99	3.95	79.18
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Nenana River 1 (N = 25)	Mn	267.47	3179.43	844.19	622.05	73.69
	Fe	7584.01	83819.50	39847.41	21053.48	52.84
	Zn	25.48	239.53	99.00	45.78	46.25
	Ga	5.11	26.35	17.25	5.91	34.24
	Rb	6.65	163.60	70.52	42.95	60.91
	Sr	14.54	394.53	157.66	92.07	58.40
	Y	3.87	35.15	21.41	6.73	31.43
	Zr	40.21	294.67	146.59	63.34	43.21
	Nb	1.32	36.04	10.39	6.34	61.04
	Th	0.11	14.71	6.87	3.49	50.83
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Nenana River 2 (N = 25)	Mn	172.88	2039.02	736.67	507.43	68.88
	Fe	2936.40	101409.32	37754.48	21181.53	56.10
	Zn	22.55	207.31	94.36	49.53	52.49
	Ga	1.36	25.65	14.23	6.62	46.50
	Rb	8.72	108.28	58.60	30.21	51.54
	Sr	2.92	511.65	129.84	114.31	88.04
	Y	6.62	34.09	19.08	7.42	38.86
	Zr	19.56	344.50	131.89	74.73	56.66
	Nb	0.96	26.89	8.88	5.55	62.54
	Th	1.46	17.49	5.92	3.68	62.17
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Nenana River 3 (N = 25)	Mn	392.12	1966.46	1028.53	465.13	45.22
	Fe	10936.49	100627.52	42557.33	21698.03	50.99
	Zn	16.06	366.35	117.87	64.55	54.76
	Ga	0.14	31.60	16.75	6.85	40.88
	Rb	9.52	125.79	63.77	30.05	47.12

Table 4.9 Continued.

Location	Element	Min	Max	Mean	St Dev	%SD
	Sr	20.28	592.36	147.91	121.81	82.36
	Y	5.83	41.00	21.93	8.43	38.47
	Zr	35.70	227.07	127.94	42.75	33.41
	Nb	3.77	17.63	9.42	2.98	31.68
	Th	2.62	9.40	5.94	1.82	30.70
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Nenana River 4 (N = 25)	Mn	183.28	2312.25	985.21	643.50	65.32
	Fe	8708.83	115593.17	46742.70	30115.00	64.43
	Zn	29.56	370.94	128.02	69.76	54.49
	Ga	3.57	37.70	21.07	8.67	41.14
	Rb	7.01	162.21	60.44	43.62	72.18
	Sr	16.21	389.20	151.55	103.81	68.50
	Y	3.32	230.90	33.49	42.53	127.01
	Zr	19.46	269.40	131.37	53.35	40.61
	Nb	0.93	22.39	10.11	5.12	50.61
	Th	0.12	10.92	5.54	3.40	61.41
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Nenana River 5 (N = 25)	Mn	298.48	3304.35	942.30	768.54	81.56
	Fe	10576.55	89902.02	42146.50	20627.19	48.94
	Zn	30.20	152.53	104.09	34.97	33.59
	Ga	2.44	25.97	16.61	5.63	33.92
	Rb	8.57	328.90	72.02	63.53	88.22
	Sr	15.59	318.86	136.05	79.62	58.52
	Y	8.53	43.39	20.67	6.90	33.38
	Zr	28.03	773.59	145.08	135.71	93.54
	Nb	1.74	14.51	8.70	3.39	38.99
	Th	0.33	30.84	6.88	6.16	89.56
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Panguingue Creek (N = 24)	Mn	239.10	2953.68	1187.99	684.65	57.63
	Fe	7279.88	88003.21	41781.00	20662.62	49.45
	Zn	48.43	196.93	109.04	38.22	35.05
	Ga	7.74	37.50	18.59	6.18	33.25
	Rb	11.81	160.65	64.20	36.79	57.30
	Sr	39.99	317.77	142.90	77.63	54.33
	Y	9.75	34.15	21.62	5.48	25.36
	Zr	54.32	230.61	138.11	47.53	34.42
	Nb	2.81	14.30	8.89	3.43	38.56
	Th	0.74	12.83	5.89	2.90	49.14

Table 4.9 Continued.

Location	Element	Min	Max	Mean	St Dev	%SD
Riley Creek (N = 20)	Mn	234.11	2064.34	974.87	562.09	57.66
	Fe	21537.30	101396.33	58840.59	23327.49	39.65
	Zn	42.04	198.33	111.44	37.10	33.29
	Ga	6.45	36.85	19.95	6.48	32.49
	Rb	12.22	157.50	61.64	34.18	55.45
	Sr	20.22	381.16	160.68	117.17	72.92
	Y	7.28	41.33	25.18	8.97	35.64
	Zr	56.63	229.82	143.07	50.76	35.48
	Nb	3.65	18.93	11.72	4.55	38.85
	Th	2.23	13.87	6.61	2.63	39.72
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Rock Creek (N = 20)	Mn	858.45	2269.51	1376.33	332.88	24.19
	Fe	54450.50	87457.38	73593.44	8006.46	10.88
	Zn	92.32	133.56	114.82	12.38	10.78
	Ga	17.37	33.43	26.89	4.32	16.07
	Rb	45.98	73.78	62.84	7.97	12.67
	Sr	254.81	414.08	347.35	38.77	11.16
	Y	27.65	43.16	36.18	3.48	9.61
	Zr	153.77	244.99	218.89	20.58	9.40
	Nb	12.69	21.39	17.83	2.16	12.13
	Th	4.85	10.16	7.71	1.68	21.82
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Savage River (N = 20)	Mn	76.20	2435.83	841.47	656.29	77.99
	Fe	6170.64	69119.21	45331.48	15092.91	33.29
	Zn	16.98	191.26	110.08	45.02	40.90
	Ga	9.14	24.62	16.07	3.60	22.41
	Rb	21.45	96.92	38.49	17.33	45.03
	Sr	37.48	408.22	79.27	83.92	105.87
	Y	9.91	30.26	16.89	4.50	26.66
	Zr	62.42	185.83	115.37	33.90	29.39
	Nb	3.75	10.44	7.12	1.87	26.31
	Th	1.78	8.23	4.16	1.79	42.98
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Slate Creek (N = 27)	Mn	98.51	3097.60	1134.58	792.33	69.83
	Fe	1976.42	92375.11	44179.37	23724.95	53.70
	Zn	19.81	289.08	112.78	53.87	47.77
	Ga	3.48	28.18	18.01	6.55	36.39
	Rb	7.75	137.00	65.90	32.47	49.26

Table 4.9 Continued.

Location	Element	Min	Max	Mean	St Dev	%SD
	Sr	10.73	360.87	113.88	81.09	71.21
	Y	9.89	43.58	23.73	8.38	35.30
	Zr	37.46	206.96	130.20	40.40	31.03
	Nb	0.98	17.46	9.07	3.78	41.71
	Th	0.68	14.64	6.71	3.09	46.09
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Tatlanika Creek (N = 13)	Mn	25.45	1205.52	269.58	323.91	120.15
	Fe	1914.08	62072.06	18427.56	20875.45	113.28
	Zn	11.33	197.25	46.96	53.31	113.51
	Ga	3.25	25.13	11.68	7.31	62.58
	Rb	9.59	221.80	61.69	58.19	94.32
	Sr	3.50	395.97	89.80	113.49	126.39
	Y	4.74	34.27	15.27	10.76	70.46
	Zr	31.20	292.57	101.21	91.97	90.87
	Nb	1.39	17.28	6.71	5.45	81.23
	Th	0.10	13.94	5.26	5.09	96.72
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Teklanika River (N = 20)	Mn	91.78	1518.52	786.91	493.32	62.69
	Fe	3588.41	78563.31	41972.45	25576.52	60.94
	Zn	13.63	145.84	87.80	35.72	40.68
	Ga	6.97	28.73	19.35	6.19	31.97
	Rb	16.69	128.25	55.51	33.93	61.13
	Sr	35.43	1050.73	308.26	245.60	79.67
	Y	6.31	47.80	27.86	11.21	40.22
	Zr	30.14	379.13	184.83	90.58	49.01
	Nb	0.82	26.76	13.38	7.50	56.04
	Th	2.86	13.12	5.88	2.37	40.25
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Toklat River (N = 20)	Mn	12.50	1390.93	378.07	297.44	78.67
	Fe	2143.13	72058.86	28816.78	16688.87	57.91
	Zn	6.17	148.99	59.25	34.82	58.77
	Ga	7.88	26.31	18.01	4.68	25.99
	Rb	10.54	186.38	85.33	48.35	56.67
	Sr	11.71	778.26	241.18	221.64	91.90
	Y	7.58	44.35	21.44	7.52	35.06
	Zr	34.75	320.59	123.38	56.64	45.91
	Nb	1.09	28.36	8.83	5.79	65.61
	Th	2.44	9.95	6.69	2.21	33.07

Table 4.9 Continued.

Location	Element	Min	Max	Mean	St Dev	%SD
Upper Moose Creek (N = 20)	Mn	210.17	3031.58	759.53	773.53	101.84
	Fe	5167.33	51045.53	27443.46	13008.45	47.40
	Zn	17.67	184.38	88.64	44.68	50.40
	Ga	4.18	23.34	15.27	4.48	29.35
	Rb	7.45	116.16	57.62	34.13	59.24
	Sr	25.66	350.74	119.36	78.13	65.46
	Y	9.18	56.28	21.29	10.13	47.60
	Zr	65.36	238.80	125.48	42.84	34.14
	Nb	2.98	22.21	9.24	4.56	49.38
	Th	0.00	0.00	0.00	0.00	0.00
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Walker Creek (N = 20)	Mn	83.64	1507.56	652.41	372.18	57.05
	Fe	16634.25	73683.47	36220.34	12233.87	33.78
	Zn	45.58	200.19	97.88	33.75	34.48
	Ga	4.36	25.94	16.53	6.12	37.03
	Rb	14.69	103.35	69.91	24.29	34.74
	Sr	12.56	296.76	118.12	74.60	63.15
	Y	13.45	42.90	23.79	6.61	27.79
	Zr	72.29	170.64	136.32	24.94	18.29
	Nb	6.02	17.27	10.36	2.58	24.89
	Th	1.15	9.36	6.54	2.67	40.89
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Upper Cindy and James Creek (N = 20)	Mn	101.84	1507.56	544.99	372.18	57.05
	Fe	47.40	73683.47	34329.76	12233.87	33.78
	Zn	50.40	200.19	93.20	33.75	34.48
	Ga	29.35	25.94	15.02	6.12	37.03
	Rb	59.24	103.35	64.03	24.29	34.74
	Sr	65.46	296.76	94.57	74.60	63.15
	Y	47.60	42.90	22.97	6.61	27.79
	Zr	34.14	170.64	133.75	24.94	18.29
	Nb	49.38	17.27	10.06	2.58	24.89
	Th	0.00	0.00	0.00	0.00	0.00
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Windy Creek (N = 25)	Mn	113.63	2875.59	937.77	661.69	70.56
	Fe	10911.31	109557.20	44611.84	20916.36	46.89
	Zn	41.91	451.76	139.08	91.78	65.99
	Ga	1.52	34.32	16.96	6.09	35.93
	Rb	10.31	102.63	66.97	25.81	38.54

Table 4.9 Continued.

Location	Element	Min	Max	Mean	St Dev	%SD
	Sr	19.65	965.73	147.34	219.85	149.21
	Y	6.19	39.87	20.74	6.60	31.83
	Zr	42.32	169.94	123.58	30.73	24.87
	Nb	0.32	16.81	8.83	3.50	39.59
	Th	2.15	8.64	5.66	1.86	32.83

Table 4.10. Eigenvalues and percentage of variance explained by principal components calculated from the variance-covariance matrix of concentration data (log-10 ppm) for outcrop and alluvial geological basalt data, as well as principal-component scores for each element.

Principal Component		Eigenvalue	% Variance	Cumulative % Variance	
1		0.2302	58.42	58.42	
2		0.1040	26.41	84.83	
3		0.0442	11.21	96.04	
4		0.0090	2.27	98.31	
5		0.0067	1.69	100	
Element	**PC 1**	**PC 2**	**PC3**	**PC4**	**PC5**
Rb	0.25	0.75	-0.60	-0.04	0.08
Sr	0.70	-0.56	-0.43	0.05	-0.07
Y	0.33	0.06	0.30	-0.80	0.38
Zr	0.35	0.14	0.36	0.59	0.63
Nb	0.47	0.30	0.48	0.08	-0.67

Creek 1 and Polychrome Pass, Brown's Hill Quarry, and Sage Hill 2 and three elements (Rb, Zr, and Nb) between Dry Creek 1 and Sage Hill 1 are enough to assign alluvial samples to Dry Creek 1, but not to any other outcrop that Dry Creek 1 overlaps with (Figure 4.3c, 4.3d, 4.5; Table 4.7). In other words, the Dry Creek 1 outcrop geochemistry is not identical to that of the Polychrome pass and Fairbanks outcrops, and alluvium samples that match the Dry Creek 1 outcrop's geochemistry have values of two or more elements that definitively exclude them from any other outcrop, despite Dry

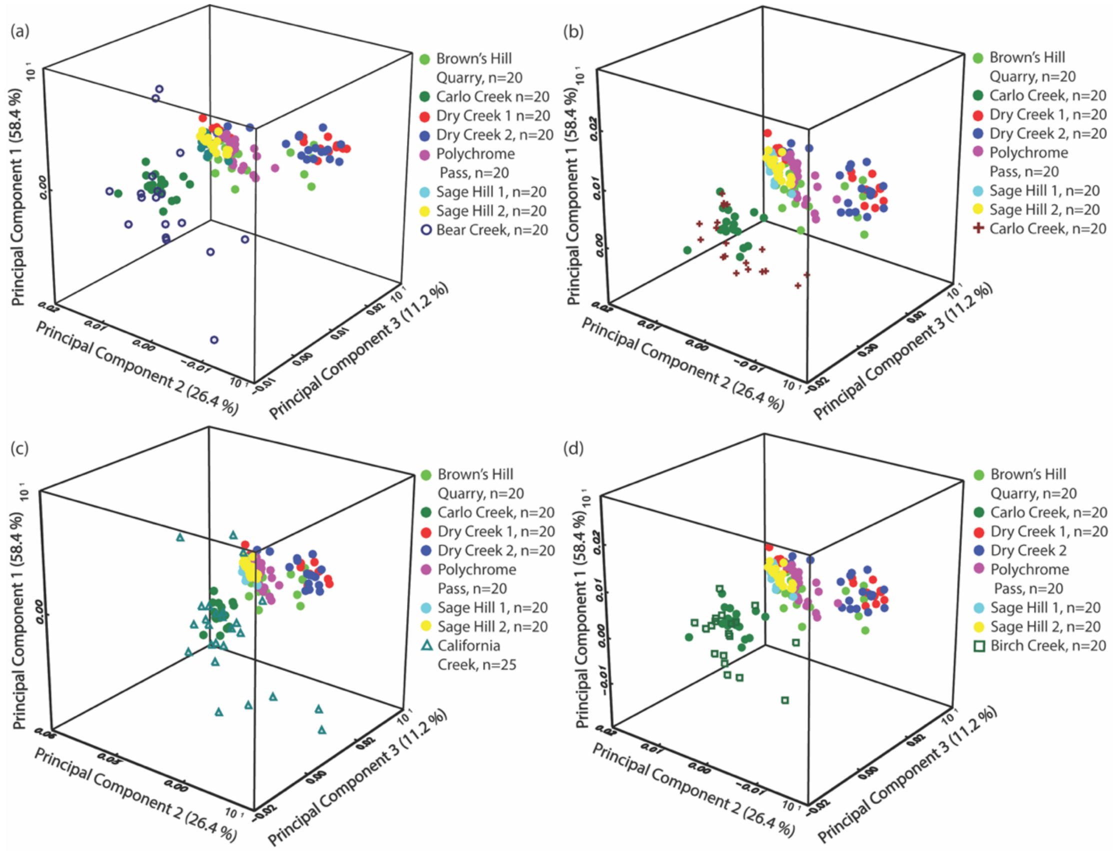

Figure 4.6. Logged (base 10) 3D plots of principal component 1, 2, and 3 scores of basalt outcrop samples compared with four basalt alluvial samples: (a) Bear Creek; (b) Carlo Creek; (c) California Creek; and (d) Birch Creek.

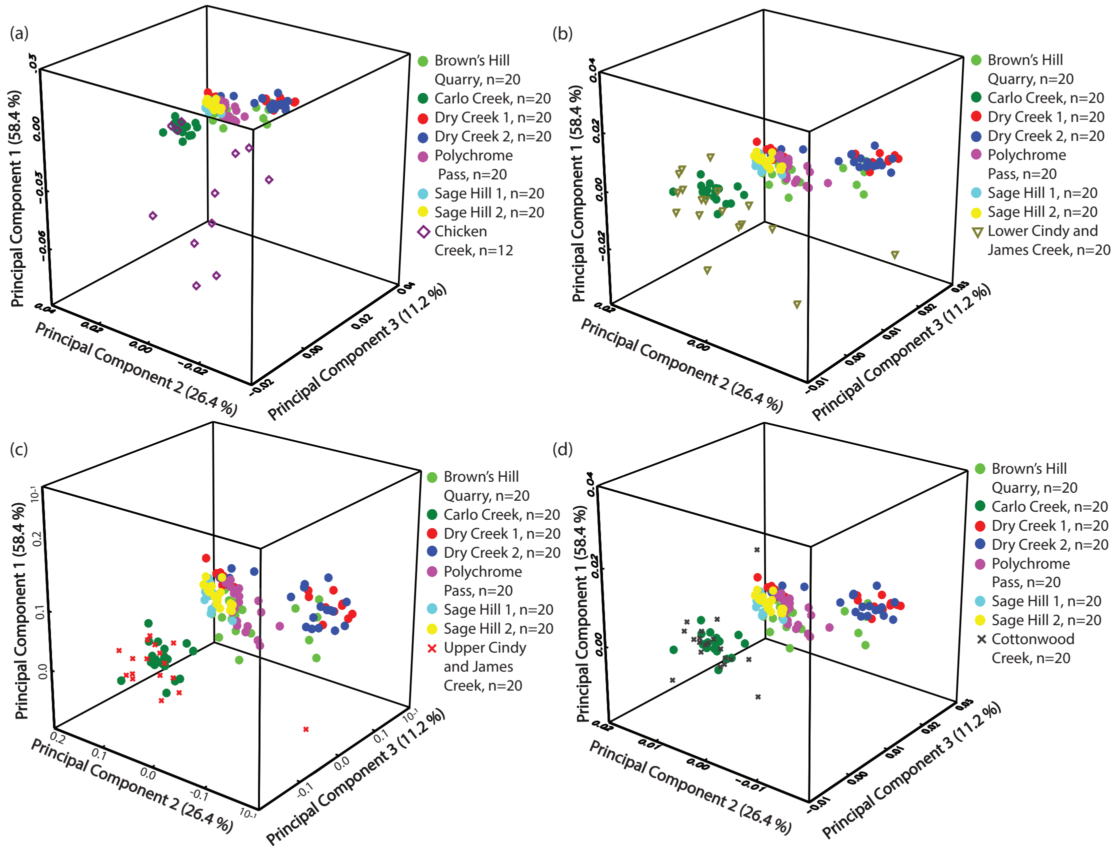

Figure 4.7. Logged (base 10) 3D plots of principal component 1, 2, and 3 scores of basalt outcrop samples compared with four basalt alluvial samples: (a) Chicken Creek; (b) Lower Cindy and James Creek; (c) Upper Cindy and James Creek; and (d) Cottonwood Creek.

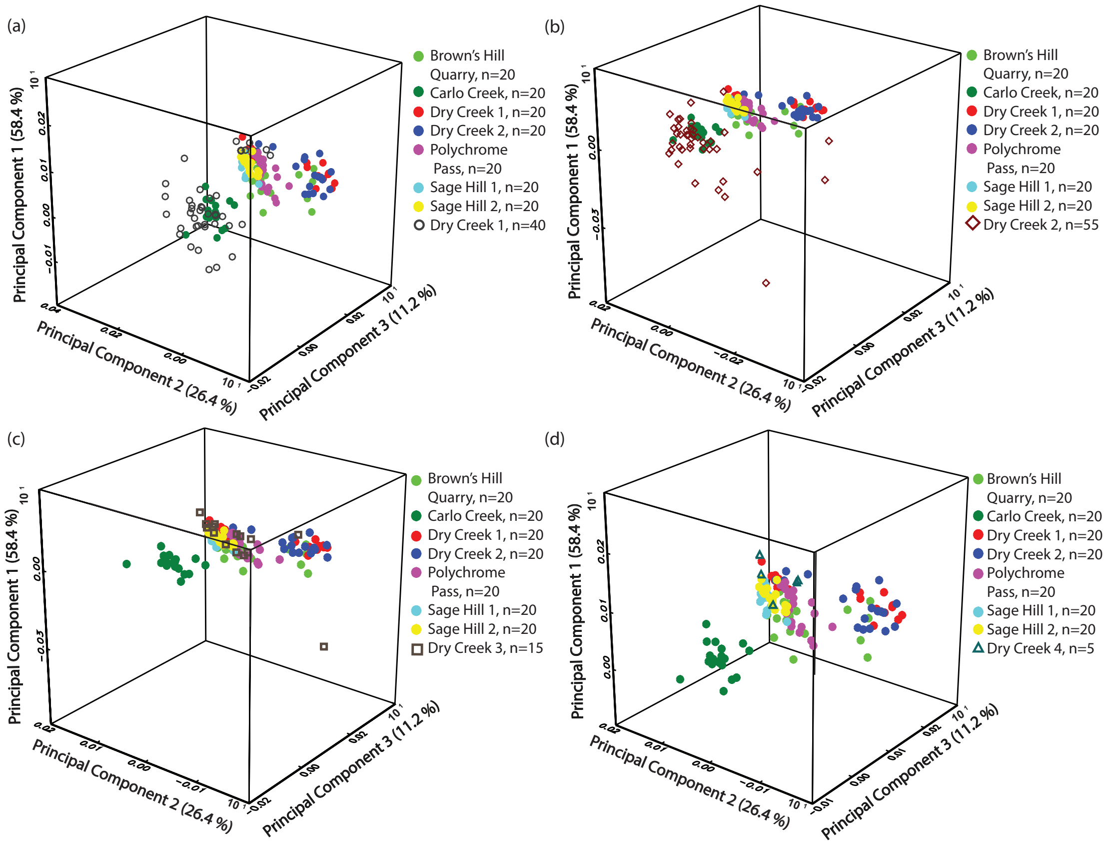

Figure 4.8. Logged (base 10) 3D plots of principal component 1, 2, and 3 scores of basalt outcrop samples compared with four basalt alluvial samples: (a) Dry Creek Alluvium 1; (b) Dry Creek Alluvium 2; (c) Dry Creek Alluvium 3; and (d) Dry Creek Alluvium 4.

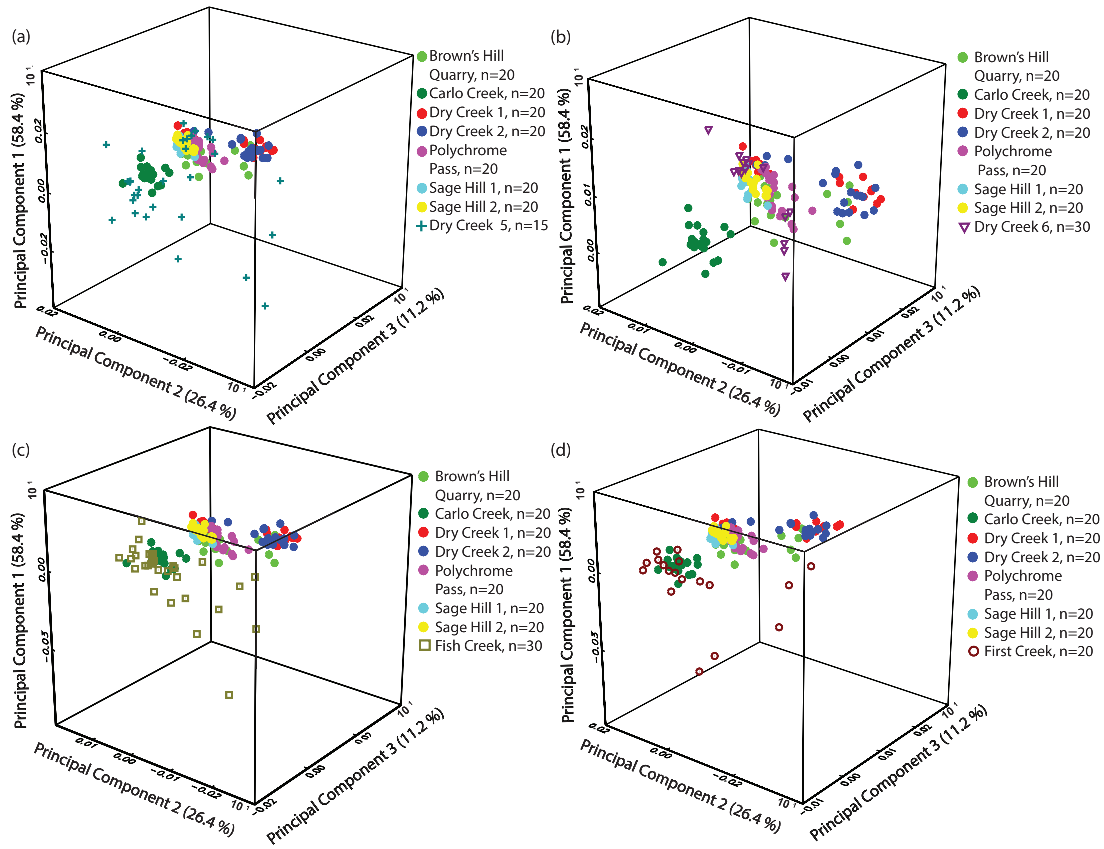

Figure 4.9. Logged (base 10) 3D plots of principal component 1, 2, and 3 scores of basalt outcrop samples compared with four basalt alluvial samples: (a) Dry Creek Alluvium 5; (b) Dry Creek Alluvium 6; (c) Fish Creek; and (d) First Creek. *

*First Creek is an unofficial name for the stream flowing into the Teklanika River (from the east) at the Owl Ridge site

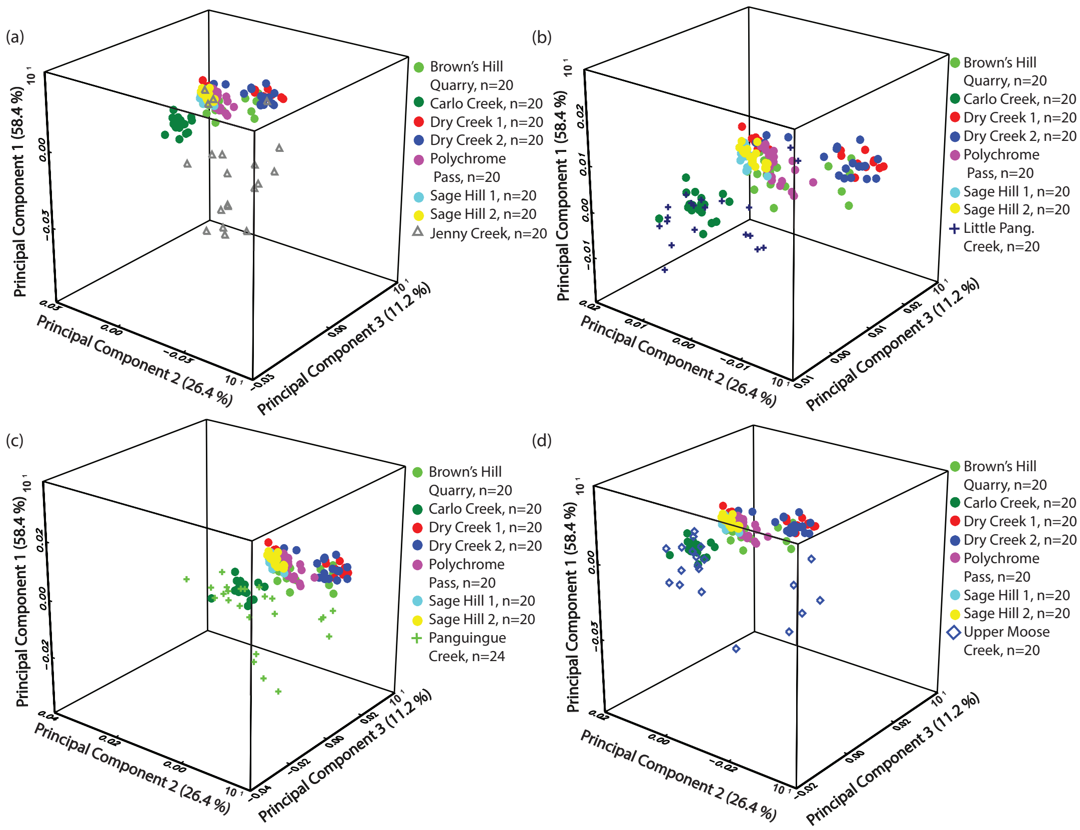

Figure 4.10. Logged (base 10) 3D plots of principal component 1, 2, and 3 scores of basalt outcrop samples compared with four basalt alluvial samples: (a) Jenny Creek; (b) Little Panguingue Creek; (c) Panguingue Creek; and (d) Upper Moose Creek.

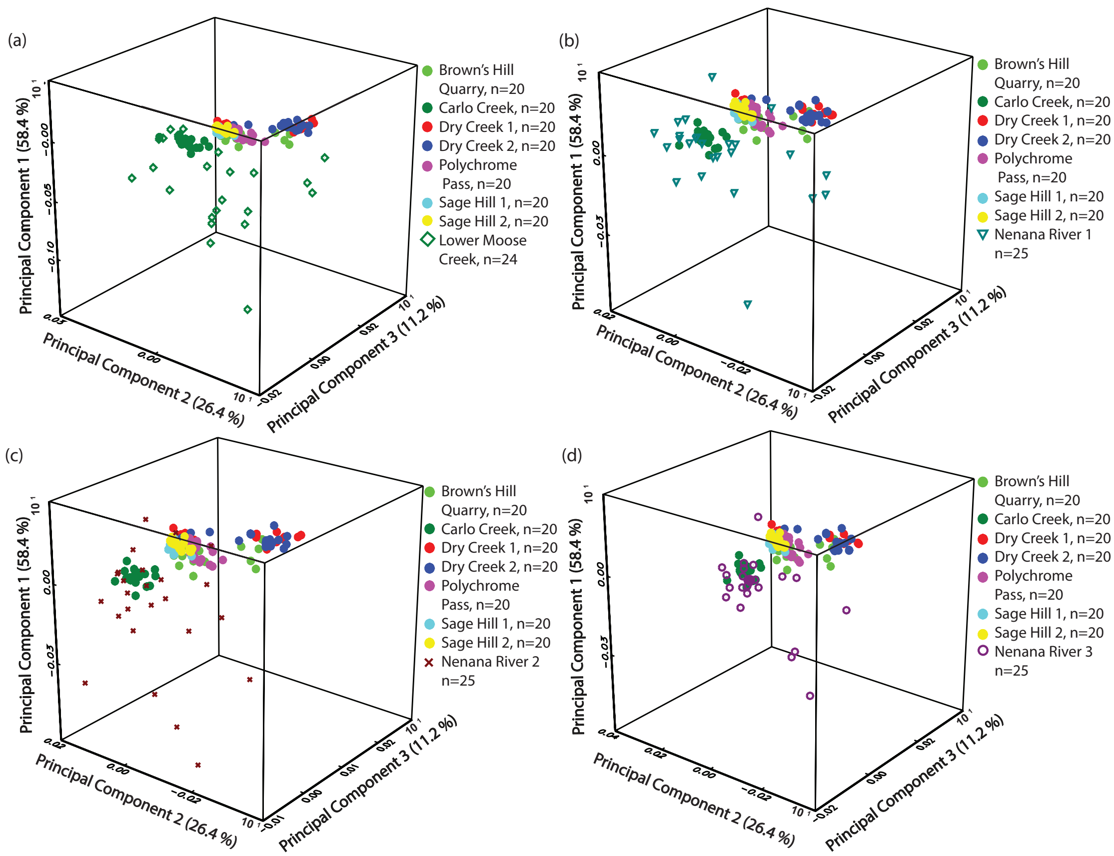

Figure 4.11. Logged (base 10) 3D plots of principal component 1, 2, and 3 scores of basalt outcrop samples compared with four basalt alluvial samples: (a) Lower Moose Creek; (b) Nenana River 1; (c) Nenana River 2; and (d) Nenana River 3.

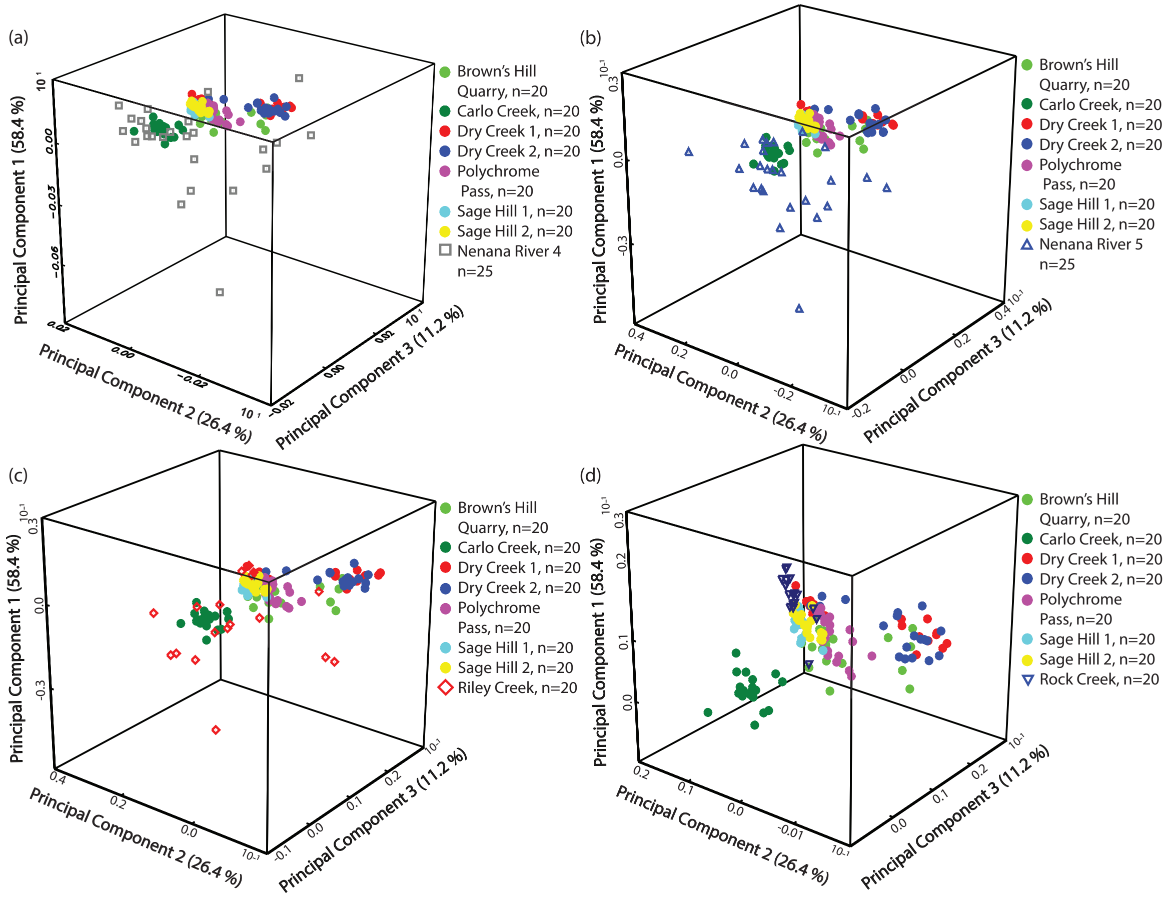

Figure 4.12. Logged (base 10) 3D plots of principal component 1, 2, and 3 scores of basalt outcrop samples compared with four basalt alluvial samples: (a) Nenana River 4; (b) Nenana River 5; (c) Riley Creek; and (d) Rock Creek.

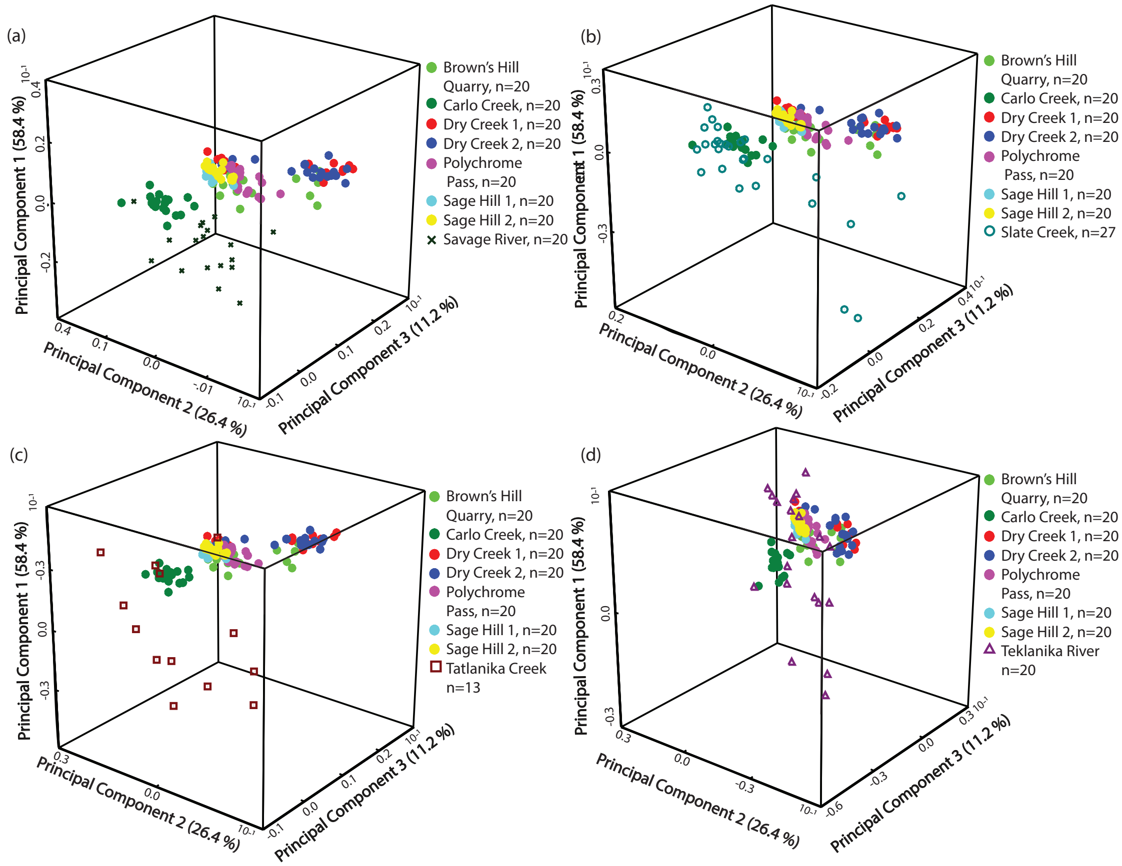

Figure 4.13. Logged (base 10) 3D plots of principal component 1, 2, and 3 scores of basalt outcrop samples compared with four basalt alluvial samples: (a) Savage River; (b) Slate Creek; (c) Tatlanika Creek; and (d) Teklanika River.

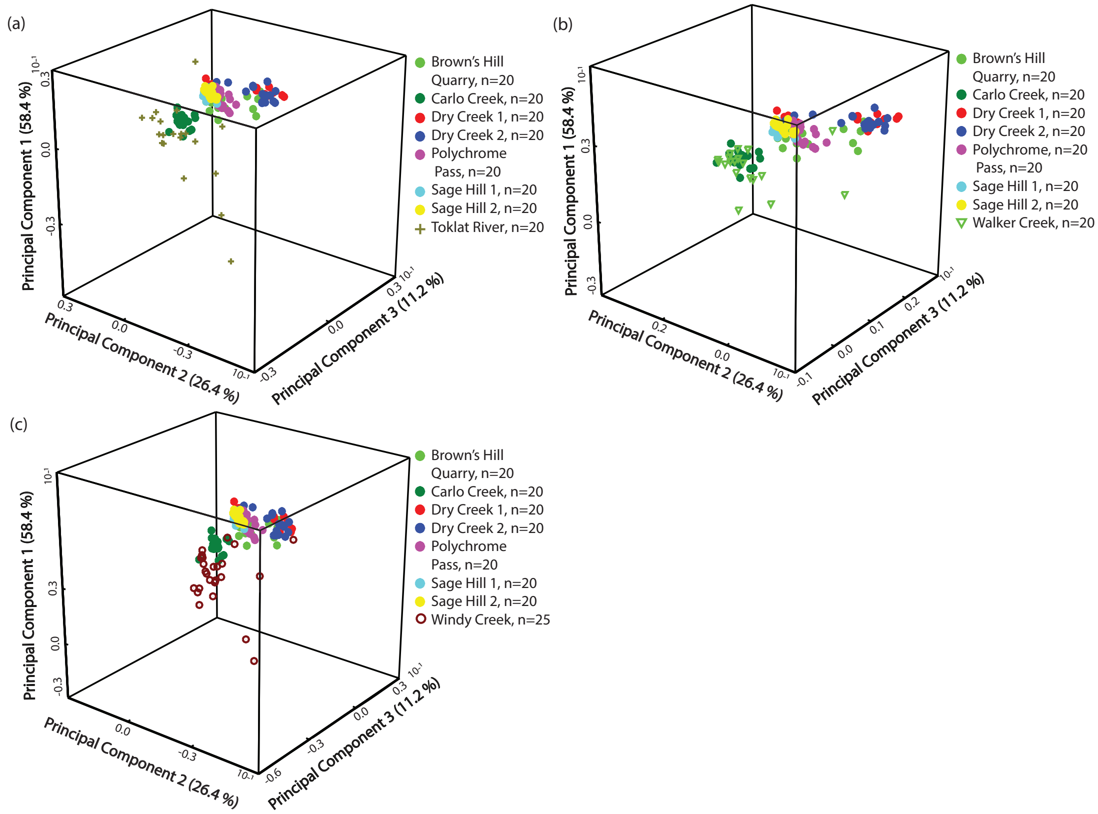

Figure 4.14. Logged (base 10) 3D plots of principal component 1, 2, and 3 scores of basalt outcrop samples compared with four basalt alluvial samples: Toklat River (a); Walker Creek (b); and Windy Creek (d).

Creek 1's slight overlap with Polychrome Pass, Brown's Hill Quarry, and Sage Hill outcrops.

4.5.2.3. Dry Creek Outcrop 1 Distribution in Alluvium

Twenty-six alluvial samples were found to match the Dry Creek 1 outcrop geochemical signature, falling outside the range of overlap between Dry Creek 1 and Fairbanks outcrops (Table 4.11). Several alluvial samples from Dry Creek match with the Dry Creek 1 outcrop, including Dry Creek Alluvium 2, Dry Creek Alluvium 4, Dry

Table 4.11. Number of geological alluvium samples from each collection location that fall within the geochemical signature of each basalt outcrop.

Alluvial Samples	Basalt Outcrop Samples								
	Dry Creek Outcrop 1	***Dry Creek Outcrop 2***	***Carlo Creek***	***Polychrome Pass***	***Brown's Hill Quarry***	***Sage Hill Outcrop 1***	***Sage Hill Outcrop 2***	***Unknown***	***Total***
Bear Creek	--	--	3	--	--	--	--	17	20
Birch Creek	--	--	5	--	--	--	--	15	20
California Creek	--	--	4	--	--	--	--	21	25
Carlo Creek	--	--	4	--	--	--	--	16	20
Chicken Creek	--	--	--	--	--	--	--	12	12
Upper Cindy and James Creek	--	--	4	--	--	--	--	16	20
Lower Cindy and James Creek	--	--	2	--	--	--	--	18	20
Cottonwood Creek	--	--	4	--	--	--	--	16	20
Dry Creek Alluvium 1	--	--	2	--	--	--	--	38	40
Dry Creek Alluvium 2	9	--	7	--	--	--	--	39	55
Dry Creek Alluvium 3	--	--	--	--	--	--	--	15	15
Dry Creek Alluvium 4	3	--	--	--	--	--	--	2	5
Dry Creek Alluvium 5	4	--	--	--	1	--	--	10	15
Dry Creek Alluvium 6	5	--	1	--	--	--	--	24	30

Table 4.11 Continued.

Alluvial Samples	**Basalt Outcrop Samples**								
	Dry Creek Outcrop 1	***Dry Creek Outcrop 2***	***Carlo Creek***	***Polychrome Pass***	***Brown's Hill Quarry***	***Sage Hill Outcrop 1***	***Sage Hill Outcrop 2***	***Unknown***	***Total***
First Creek	--	--	2	--	--	--	--	18	20
Fish Creek	--	--	4	--	--	--	--	26	30
Jenny Creek	1	--	--	--	--	--	--	19	20
Little Panguingue Creek	--	--	1	--	--	--	--	19	20
Lower Moose Creek	--	--	--	--	--	--	--	24	24
Nenana River 1	1	--	--	--	--	--	--	24	25
Nenana River 2	--	--	1	--	--	--	--	24	25
Nenana River 3	--	--	3	--	--	--	--	22	25
Nenana River 4	--	--	--	--	--	--	--	25	25
Nenana River 5	--	--	--	--	--	--	--	25	25
Panguingue Creek	--	--	1	--	--	--	--	23	24
Riley Creek	--	--	--	--	--	--	--	20	20
Rock Creek	3	--	--	--	--	--	--	17	20
Savage River	--	--	--	--	--	--	--	20	20
Slate Creek	--	--	3	--	--	--	--	24	27
Tatlanika Creek	--	--	1	--	--	--	--	12	13
Teklanika River	--	--	--	--	--	--	--	20	20
Toklat River	--	--	--	--	--	--	--	20	20
Upper Moose	--	--	1	--	--	--	--	19	20
Walker Creek	--	--	4	--	--	--	--	16	20
Windy Creek	--	--	--	--	--	--	--	25	25
Total	26	--	57	--	1	--	--	701	785

Creek Alluvium 5, Dry Creek Alluvium 6, and Nenana River 1 sample locations (Figures 4.1, 4.15), all of which are in close proximity to the outcrop. Material matching this signature outside of drainages local to this outcrop include Rock Creek, located down the valley close to the village of Ferry, and Jenny Creek located within Denali Park. This material is limited to the west side of the valley and located mostly in the Dry Creek drainage on the north slope of Mt. Healy (Figure 4.15). Its presence in Jenny Creek south of the mountain, and its absence from the streams flowing off its south side suggest this basalt may outcrop in another place in the Jenny Creek drainage. Away from Mt. Healy and Dry Creek, however, the Dry Creek outcrops contribute almost nothing to the overall alluvial basalt landscape of the Nenana valley.

4.5.2.4. Carlo Creek Outcrop Distribution in Alluvium

Fifty-six alluvial samples were found to match the Carlo Creek outcrop geochemical signature (Table 4.11). The geochemical signature of the Carlo Creek outcrop is widely represented in the valley. Materials from this outcrop are found in the Carlo Creek drainage nearby, but also in several additional drainages in the valley (Figure 4.16), including, on the east side of the Nenana River, Upper and Lower Cindy and James, Cottonwood, Upper Moose, and Walker creeks; and on the west side of the river, Bear, Birch, Fish, Little Panguingue, Panguingue, Rock, and Slate creeks, as well as three sample locations along Dry Creek (Dry Creek Alluvium 1, 2 and 6); and two locations from the Nenana River itself (Nenana River 2 and Nenana River 3) (Figure 4.16). Surprisingly, the Carlo Creek outcrop's geochemical signature also occurs in alluvium of Tatlanika Creek, California Creek, and First Creek, both located outside the

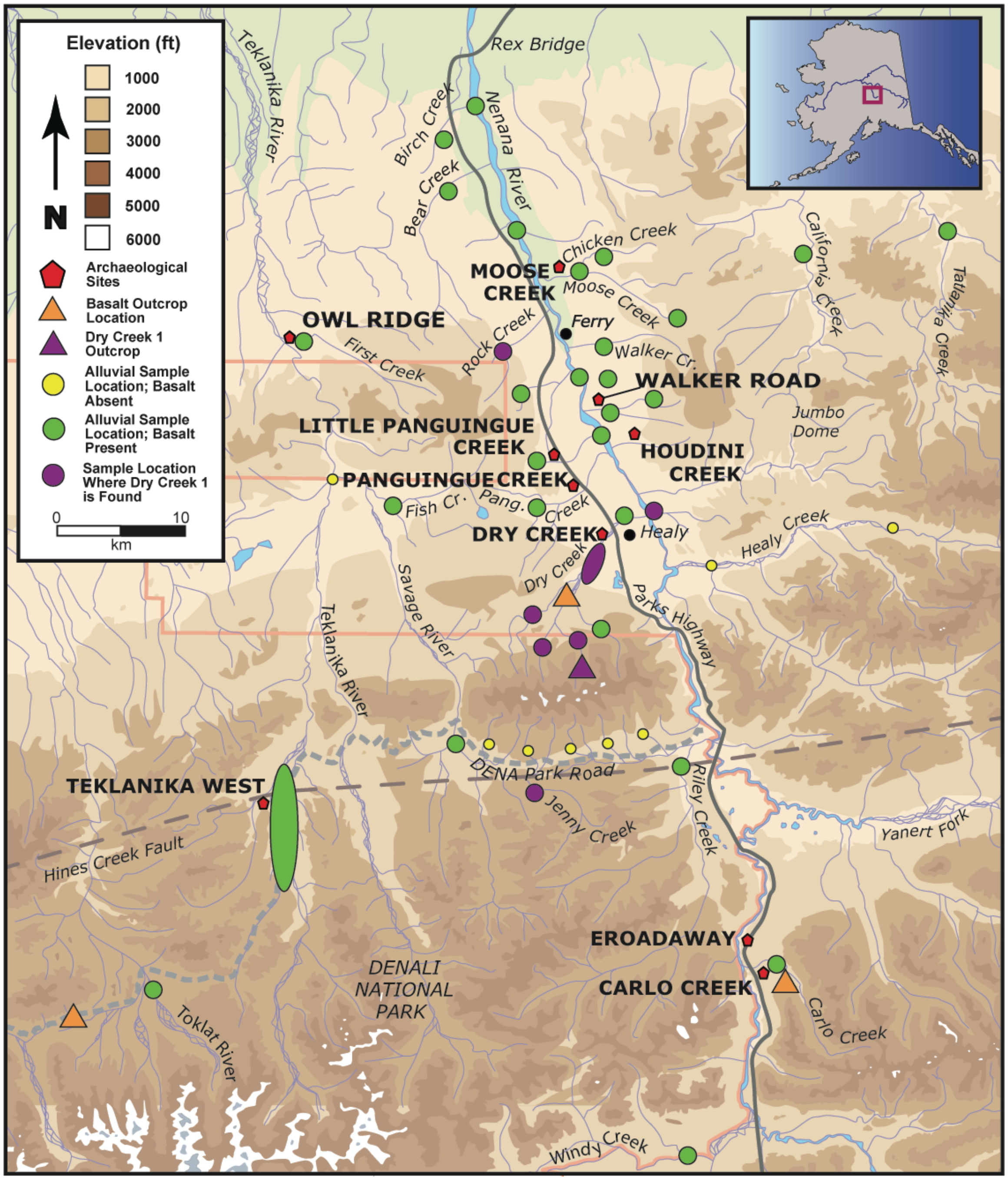

Figure 4.15. Distribution map of alluvial sample locations with samples matching the Dry Creek 1 outcrop. Adapted from Gore and Graf 2018.

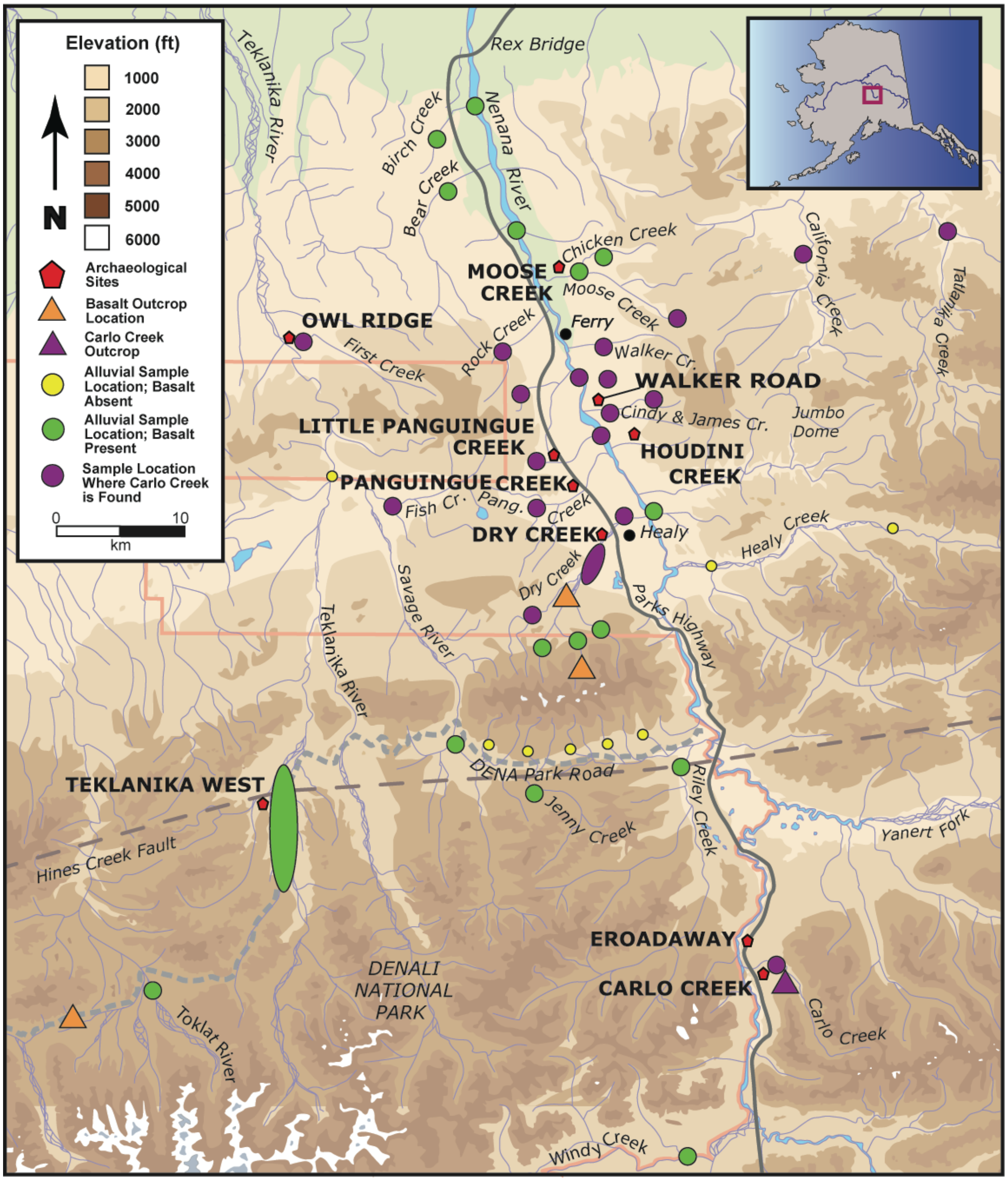

Figure 4.16. Distribution map of alluvial sample locations with samples matching the Carlo Creek outcrop. Adapted from Gore and Graf 2018.

Nenana valley in neighboring basins. Its wide distribution is significant, suggesting its parent flow was originally much larger than the single outcrop sampled here, and it is a major basalt contributor to the region's alluvium, unlike the Dry Creek outcrops.

4.5.2.5. Mismatches in Alluvium

Ten alluvial sample locations provided basalt cobbles that did not match any sampled outcrops: Windy and Riley creeks and Teklanika, Toklat, and Savage rivers in Denali Park; and Chicken and Lower Moose creeks, Dry Creek Alluvium 3, and Nenana River locations 4 and 5 in the foothills. These geochemical mismatches could have resulted for several reasons, but perhaps some of the alluvial sample locations contained basalt nodules that came from other unknown basalt outcrops.

To test this last hypothesis, alluvial samples that could not be assigned to sampled outcrops were further investigated to isolate additional geochemical groups (Figure 4.17). Only one small group, Alluvial Group A, can be distinguished from the rest of the alluvial samples and thus appears to represent material from an unknown outcrop. Alluvial Group A is characterized by moderately low Rb, moderate Sr, low Y, and moderate Zr (Table 4.12). Only 12 alluvial collection locations contain Alluvial Group A, with just 37 samples in total (5.3%). Most of these samples (n = 24, 65% of the sample) come from the Dry Creek drainage (Table 4.13). The remainder of alluvial geological samples (n = 664) provide no additional clustering and were found dispersed away from Alluvial Group A.

Geographically, Alluvial Group A is primarily concentrated in the foothills portion of the Nenana valley and especially concentrated at the headwaters and middle of the Dry Creek drainage (Figure 4.18). A handful of Alluvial Group A samples were also found in the Riley Creek and Teklanika River drainages south and southwest of Mt. Healy, but they are otherwise absent from the southerly portions of the valley. One sample also came from the Tatlanika Creek valley in the northeastern part of the study area (Figure 4.18). This group's distribution is mainly concentrated west of the Nenana River, but beyond this broad pattern, there are no remarkable spatial trends in its distribution.

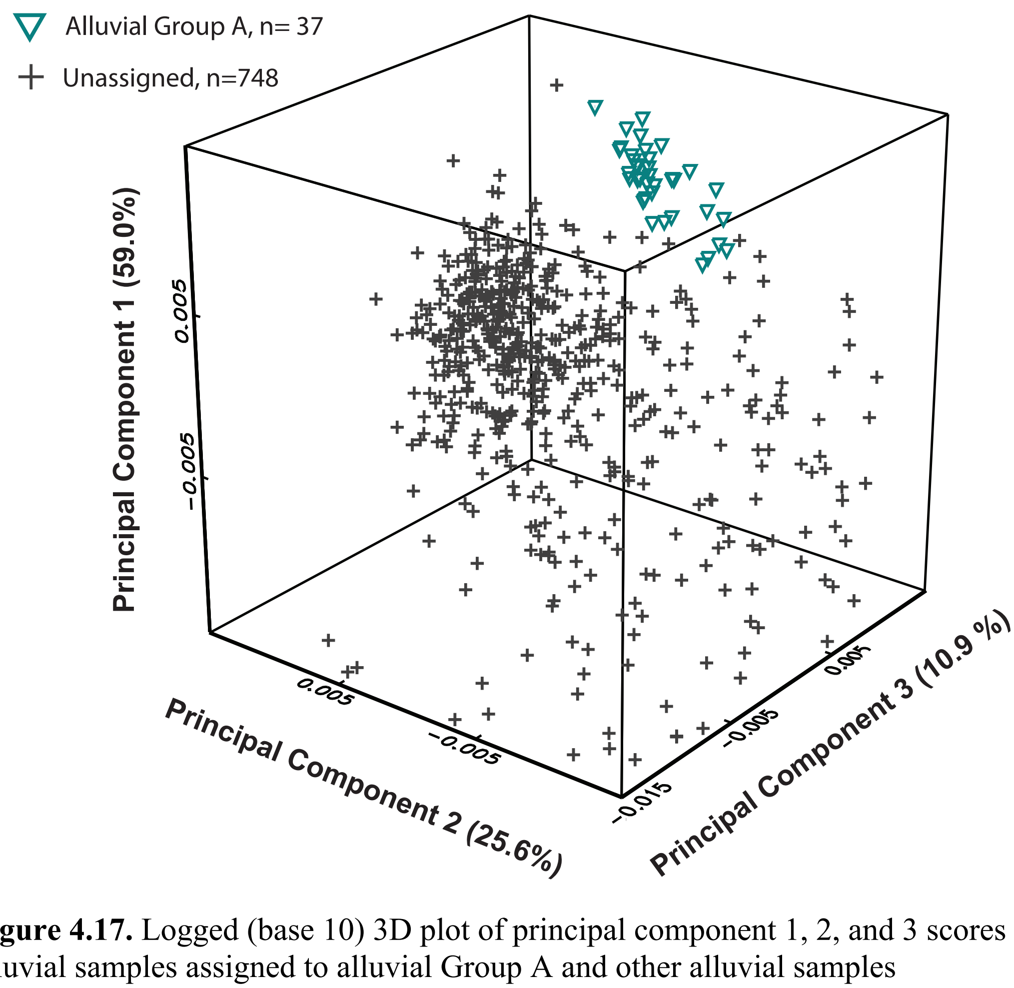

Figure 4.17. Logged (base 10) 3D plot of principal component 1, 2, and 3 scores of alluvial samples assigned to alluvial Group A and other alluvial samples (unassigned in this analysis).

Table 4.12. Statistical summaries (ppm) of minimum, maximum, mean, standard deviation (St Dev), and percent standard deviation (%SD) of element concentrations measured from alluvial sample Group A.

Group	Element	Min	Max	Mean	St Dev	%SD
A (N = 37)	Mn	906.53	3238.16	1408.69	501.79	35.62
	Fe	38994.66	78563.31	65370.89	7204.40	11.02
	Zn	55.56	156.56	105.11	15.95	15.17
	Ga	12.78	32.80	22.54	4.30	19.08
	Rb	30.89	86.44	52.03	12.37	23.78
	Sr	272.21	414.08	340.71	44.26	12.99
	Y	26.18	43.32	33.66	4.05	12.03
	Zr	187.86	292.57	221.08	24.83	11.23
	Nb	11.06	21.17	16.29	2.38	14.59
	Th	1.51	9.55	5.97	2.10	35.23

Table 4.13. Number of geological samples from alluvial collection sites that fall within the geochemical signature of alluvial sample Group 1 or are unknown.

Collection Location	Alluvial Samples		
	Alluvial Group A Total	Unknown	Total
Bear Creek	--	17	17
Birch Creek	--	15	15
California Creek	--	21	21
Carlo Creek	--	16	16
Chicken Creek	--	12	12
Upper Cindy and James Creek	--	16	16
Lower Cindy and James Creek	--	18	18
Cottonwood Creek	--	16	16
Dry Creek Alluvium 1	--	38	38
Dry Creek Alluvium 2	9	30	39
Dry Creek Alluvium 3	4	11	15
Dry Creek Alluvium 4	--	2	2
Dry Creek Alluvium 5	7	3	10
Dry Creek Dry Creek Alluvium 6	4	20	24

Table 4.13 Continued.

Collection Location	**Alluvial Samples**		
	Alluvial Group A Total	**Unknown**	**Total**
First Creek	--	18	18
Fish Creek	--	26	26
Jenny Creek	1	18	19
Little Panguingue Creek	2	17	19
Lower Moose Creek	--	24	24
Nenana River 1	--	24	24
Nenana River 2	1	23	24
Nenana River 3	1	21	22
Nenana River 4	--	25	25
Nenana River 5	--	25	25
Panguingue Creek	--	23	23
Riley Creek	2	18	20
Rock Creek	2	15	17
Savage River	--	20	20
Slate Creek	--	24	24
Tatlanika Creek	1	11	12
Teklanika River	3	17	20
Toklat River	--	20	20
Upper Moose	--	19	19
Walker Creek	--	16	16
Windy Creek	--	25	25
Total	37	664	701

4.5.2.6. Distribution of Unassigned Alluvium

Alluvial collection sites that produced nodules that could not be assigned to an outcrop or Alluvial Group A were analyzed for meaningful geographic patterns. First, alluvial collection sites were divided into two sets based on their geographical location relative to the Hines Creek Fault (Csejtey et al. 1992). One set is the sample locations north of the fault, including Bear, Birch, California, Chicken, Cindy and James,

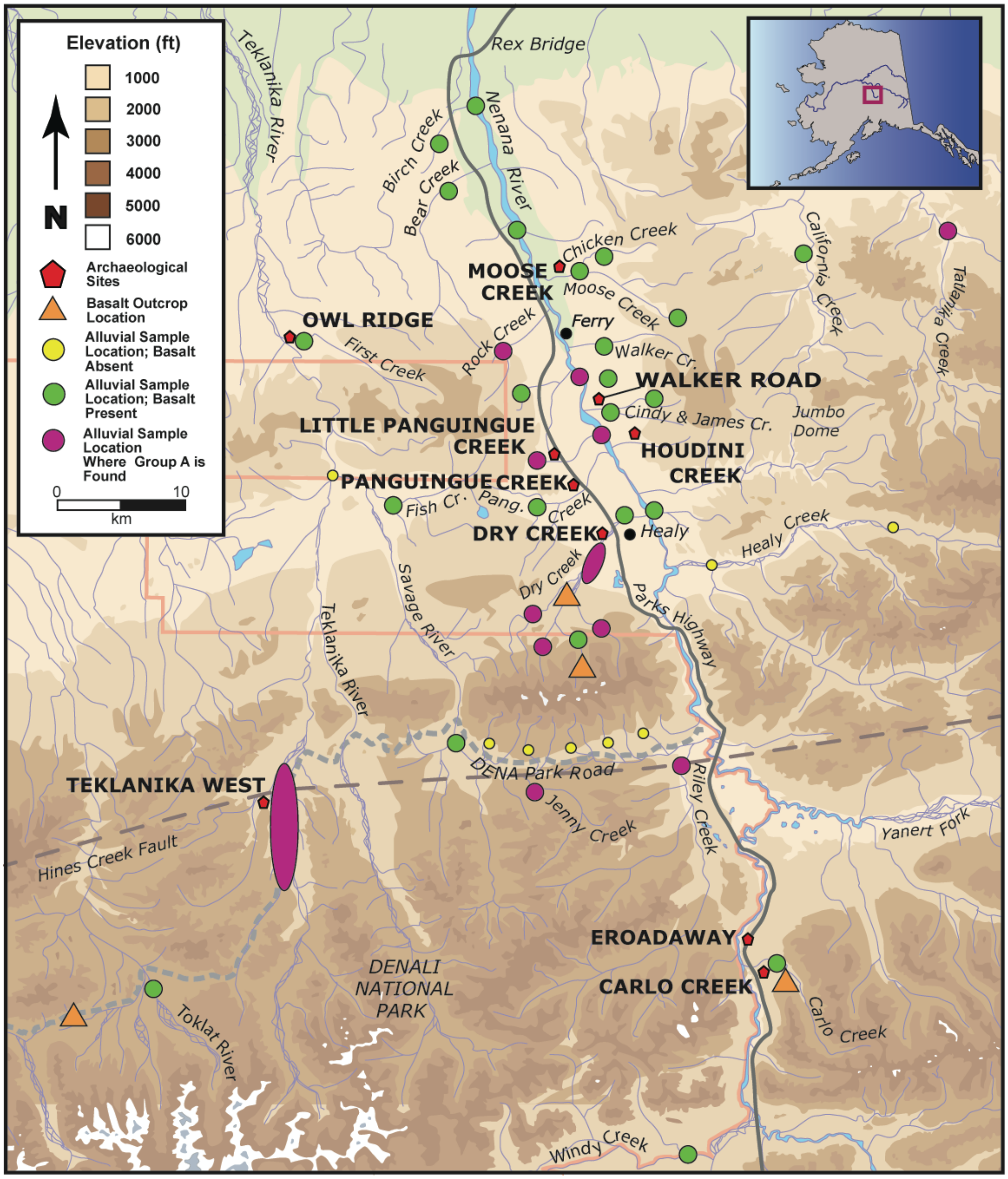

Figure 4.18. Distribution map of alluvial sample locations with samples assigned to alluvial Group A. Adapted from Gore and Graf 2018.

Cottonwood, First, Fish, Little Panguingue, Moose, Rock, Slate, Tatlanika, and Walker creeks, and all Dry Creek locations. The other set, located south of the fault line, includes Carlo, Jenny, Riley, and Windy creeks as well as the Savage and Teklanika rivers (Figure 4.1). Nenana River samples were excluded because basalts from the southern area could travel downstream to the northern area, potentially obscuring spatial patterns. There is no discernable distribution of northern versus southern samples (Figure 4.19). This same procedure was repeated for samples located on the east and west sides of the Nenana River, with Nenana River samples excluded to prevent the inclusion of potentially mixed samples. Again, no clear patterning exists between western and eastern samples (Figure 4.20). Therefore, the basalt alluvium that could not be assigned to an outcrop or Alluvial Group A is representative of a wide geochemical range of basalts with no detectable geographical patterning, apart from become more geochemically variable in downstream locations (e.g., the Nenana River) vs. locations from higher elevations. This situation may be the result of a diverse valley alluvium that resulted from many basalt flows that since their formation have been significantly (even completely) eroded from their original flows, being extensively reworked and widely redistributed across the valley by ancient glacial processes.

4.5.3. Geochemical Analysis of Basalt Artifacts

I analyzed a total of 742 basalt artifacts from the Nenana valley's archaeological sites to assess variation in their geochemical signatures. Resulting signatures are widely variable, limiting the identification of discrete groups. Nevertheless, several clusters could be observed. Eight groups were identified, but 293 artifacts could not be assigned to a specific geochemical group (Tables 4.14-4.16).

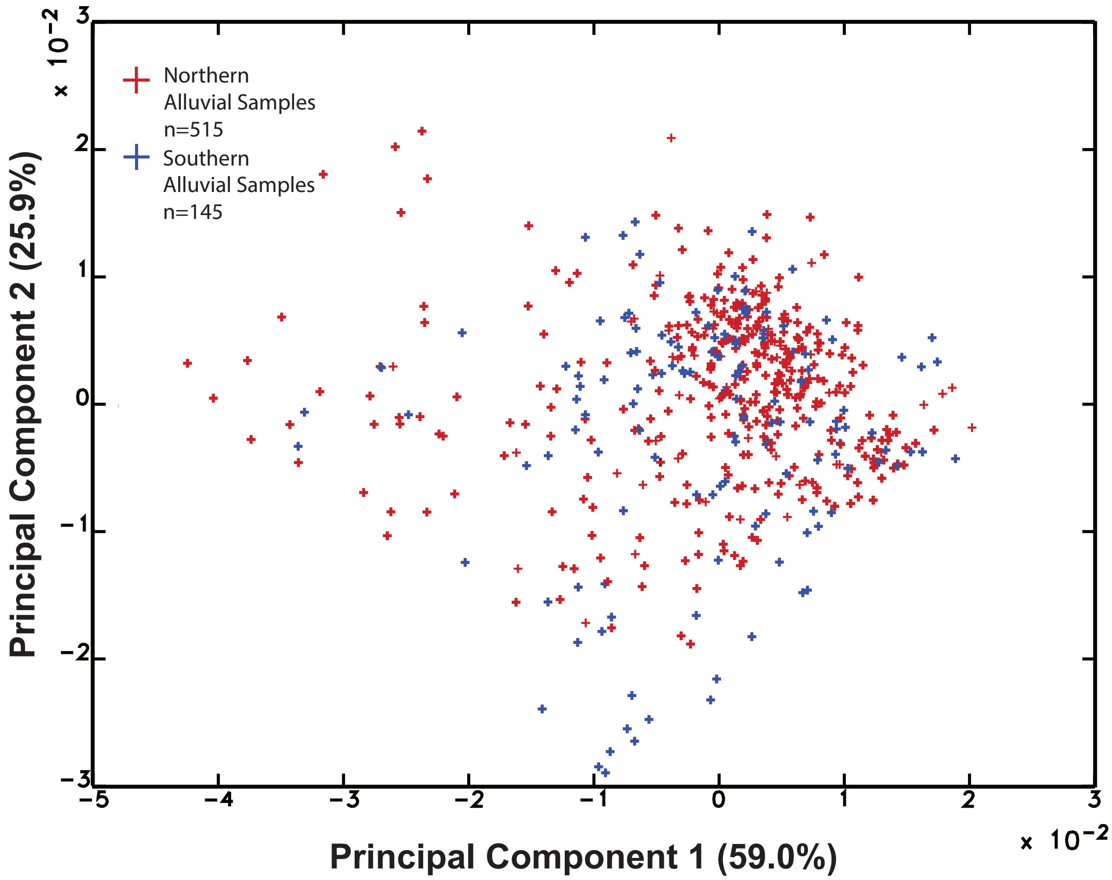

Figure 4.19. Logged (base 10) biplot of principal-component 1 and 2 scores for unassigned alluvial samples. Red-colored samples were collected from locations north of Hines Creek Fault and blue-colored samples were collected from locations south of Hines Creek Fault.

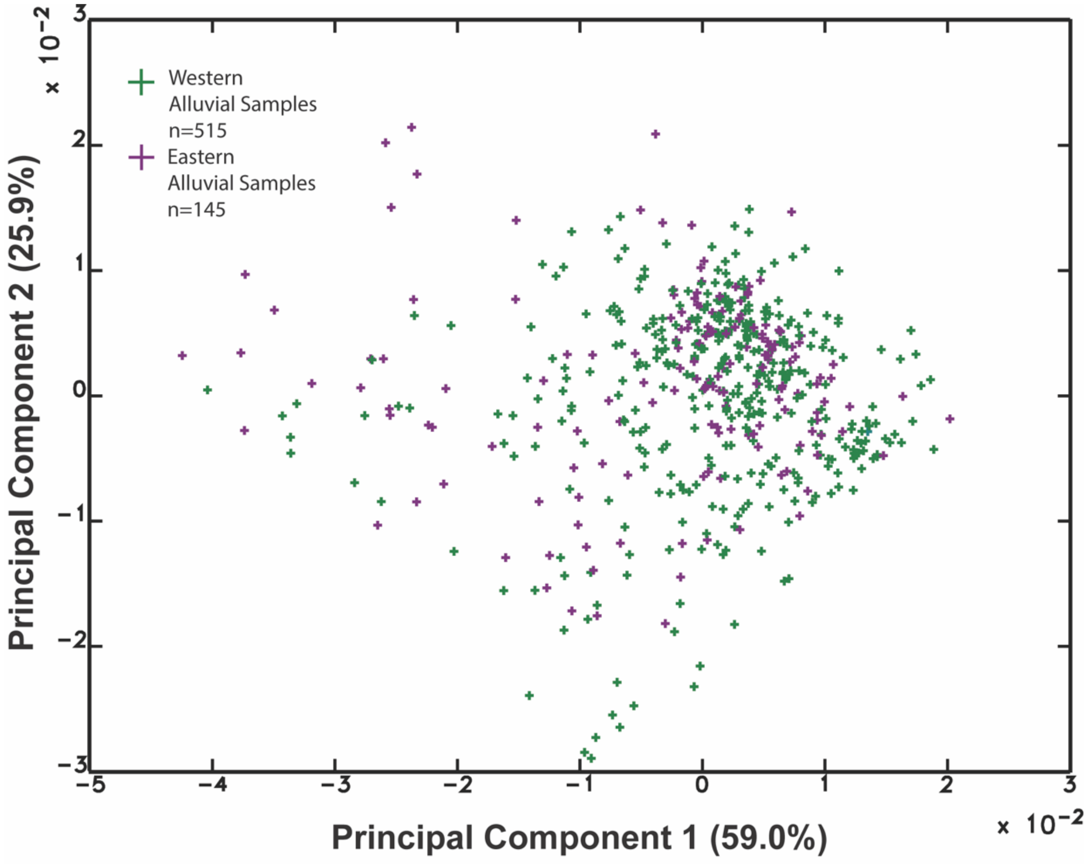

Figure 4.20. Logged (base 10) biplot of principal-component 1 and 2 scores for unassigned alluvial samples. Green-colored samples were collected from locations west of the Nenana River and purple-colored samples were collected from locations east of the Nenana River.

Table 4.14. Number of artifacts from archaeological assemblages that fall within the geochemical signature of each basalt artifact group organized by time period.

	Basalt Artifact Group									
Assemblages by Time	**Total (%)**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Una[1]**
13.5 - 12.8 ka										
Dry Creek 1	92 (11.6)	6 (0.8)	14 (1.8)				52 (6.6)			20 (2.5)
Walker Road	98 (12.4)						57 (7.2)	2 (0.3)		39 (4.9)
Moose Creek 1	27 (3.4)		7 (0.9)	2 (0.3)	2 (0.3)		4 (0.5)	1 (0.1)		11 (1.4)
Owl Ridge 1	34 (4.3)		1 (0.1)	1 (0.1)			6 (0.8)			26 (3.3)
Eroadaway	59 (7.4)		3 (0.4)				17 (2.1)			39 (4.9)
Subtotal	310 (41.8)									
12.5 - 11.7 ka										
Moose Creek 2	1 (0.1)						1 (0.1)			
Owl Ridge 2	16 (2.0)						4 (0.5)			12 (1.5)
Panguingue 1	10 (1.3)						7 (0.9)			3 (0.4)
Subtotal	27 (3.6)									
11.7-9 ka										
Carlo Creek 1	55 (6.9)						24 (3.0)			31 (3.9)
Dry Creek 2	136 (17.2)	18 (2.3)		2 (0.3)	1 (0.1)		83 (10.5)	1 (0.1)		31 (3.9)
Owl Ridge. 3	32 (4.0)						19 (2.4)			13 (1.6)
Panguingue 2	41 (5.2)						22 (2.8)			19 (2.4)
Little Panguingue Creek	13 (1.6)								4 (0.5)	9 (1.1)
Subtotal	277 (37.3)									
8 – 3.5 ka										
Houdini Creek	34 (4.3)						22 (2.8)			12 (1.5)
Tek West	34 (4.3)		9 (1.1)	3 (0.4)			4 (0.5)			18 (2.3)
Moose Creek 3	2 (0.3)					1 (0.1)				1 (0.1)

Table 4.14 Continued.

Assemblages by Time	Total (%)	A	B	C	D	E	F	G	H	Una[1]
Panguingue 3	3 (0.4)						1 (0.1)			2 (0.3)
Dry Creek 4	55 (6.9)	1 (0.1)		7 (0.9)	11 (1.4)	26 (3.3)	3 (0.4)			7 (0.9)
Subtotal	128 (17.3)									
Total	**742 (100)**	**25 (3.4)**	**34 (4.6)**	**15 (2.0)**	**14 (1.9)**	**27 (3.6)**	**326 (43.9)**	**4 (0.5)**	**4 (0.5)**	**293 (39.5)**

[1] Number of unassigned artifacts.

Table 4.15. Statistical summaries (ppm) of minimum, maximum, mean, standard deviation (St Dev), and percent standard deviation (%SD) of element concentrations measured from artifact group data.

Artifact Group	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Artifact Group A (N = 25)	Mn	829.20	1507.95	1199.43	179.24	14.94
	Fe	42333.29	88441.58	66340.01	11393.25	17.17
	Zn	75.43	143.39	110.10	18.13	16.47
	Ga	21.44	52.31	36.12	10.08	27.91
	Rb	124.97	173.27	147.10	15.15	10.30
	Sr	159.93	259.08	214.03	30.44	14.22
	Y	47.82	67.78	59.07	5.29	8.95
	Zr	554.02	866.25	727.17	90.30	12.42
	Nb	28.80	38.33	33.90	3.48	10.27
	Th	11.23	18.54	15.04	2.43	16.16
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Artifact Group B (N = 34)	Mn	600.98	2370.17	1028.05	359.40	34.96
	Fe	37896.69	71342.89	52020.09	8750.06	16.82
	Zn	89.43	284.70	141.54	44.11	31.17
	Ga	27.44	54.91	39.79	8.00	20.10
	Rb	55.18	84.11	69.58	8.94	12.86
	Sr	243.56	417.49	330.24	41.36	12.53
	Y	37.07	58.82	48.84	6.39	13.08
	Zr	260.89	447.73	368.07	39.50	10.73
	Nb	14.22	25.94	19.04	2.63	13.81
	Th	2.99	10.52	6.53	2.00	30.57
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
	Mn	827.45	3044.62	1472.93	604.70	41.05

Table 4.15 Continued.

Location	Element	Min	Max	Mean	St Dev	%SD
Artifact Group C (N = 15)	Fe	34968.94	64162.66	47818.94	8636.29	18.06
	Zn	80.02	260.06	110.05	43.79	39.79
	Ga	24.01	44.91	32.93	6.75	20.51
	Rb	49.96	73.05	59.45	6.11	10.28
	Sr	319.51	457.11	372.65	37.36	10.03
	Y	29.06	44.63	34.63	4.47	12.90
	Zr	209.38	312.85	245.73	28.17	11.47
	Nb	13.62	26.21	18.00	4.07	22.61
	Th	2.91	9.40	5.56	1.76	31.72
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Artifact Group D (N = 14)	Mn	1491.88	2311.83	1790.14	241.99	13.52
	Fe	41851.12	70659.11	53413.81	8049.75	15.07
	Zn	123.55	242.26	158.53	33.54	21.16
	Ga	21.11	56.39	41.40	9.24	22.32
	Rb	39.15	57.54	46.96	5.33	11.35
	Sr	303.49	465.18	378.98	43.81	11.56
	Y	46.22	68.30	56.99	6.06	10.64
	Zr	226.31	308.67	272.65	24.65	9.04
	Nb	12.29	19.90	15.58	2.22	14.28
	Th	1.18	6.86	3.87	1.38	35.66
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Artifact Group E (N = 27)	Mn	634.10	1415.74	1132.18	152.93	13.51
	Fe	24424.63	43787.62	36369.32	4064.24	11.17
	Zn	73.61	117.04	96.48	10.79	11.18
	Ga	18.58	46.67	36.08	6.06	16.80
	Rb	58.79	77.82	66.15	5.18	7.83
	Sr	353.38	512.47	448.98	35.42	7.89
	Y	19.32	30.68	25.80	1.99	7.70
	Zr	256.87	316.80	287.12	14.91	5.19
	Nb	7.33	10.83	8.88	0.77	8.71
	Th	4.08	8.21	6.24	1.01	16.25
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Artifact Group F (N = 326)	Mn	34.30	2965.49	768.07	434.43	56.56
	Fe	9229.30	85523.55	41001.92	12274.58	29.94
	Zn	45.75	471.31	132.89	39.84	29.98
	Ga	10.60	58.57	25.60	7.88	30.80
	Rb	53.83	168.63	96.80	21.77	22.49
	Sr	84.98	305.88	172.49	47.09	27.30

Table 4.15 Continued.

Location	Element	Min	Max	Mean	St Dev	%SD
	Y	18.69	36.95	25.84	3.88	15.00
	Zr	123.34	210.53	158.23	17.63	11.14
	Nb	8.55	18.78	12.87	1.96	15.22
	Th	3.32	20.58	8.94	2.57	28.78
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Artifact Group G (N = 4)	Mn	312.44	562.75	393.51	115.96	29.47
	Fe	23099.94	32739.86	27295.80	4537.76	16.62
	Zn	43.06	268.40	170.82	98.07	57.41
	Ga	35.30	52.28	44.90	7.52	16.75
	Rb	171.41	268.24	227.39	40.79	17.94
	Sr	15.16	21.66	18.40	2.87	15.58
	Y	33.88	57.38	44.92	9.78	21.78
	Zr	165.51	203.61	182.86	15.99	8.74
	Nb	15.65	23.91	19.16	3.45	18.01
	Th	9.13	42.59	29.44	15.23	51.73
Location	**Element**	**Min**	**Max**	**Mean**	**St Dev**	**%SD**
Artifact Group H (N = 4)	Mn	130.03	234.82	176.80	48.25	27.29
	Fe	7410.65	11320.46	9261.71	1708.61	18.45
	Zn	34.07	50.80	43.10	6.92	16.06
	Ga	4.05	4.05	4.05	0.00	0.00
	Rb	8.88	11.06	10.08	0.90	8.91
	Sr	5.01	6.07	5.69	0.47	8.19
	Y	8.95	12.36	10.66	1.42	13.35
	Zr	44.10	56.14	50.08	5.02	10.01
	Nb	3.15	5.56	4.57	1.02	22.20
	Th	12.15	15.69	13.31	1.64	12.32

Figure 4.21 visualizes these groups, comprising 81.2% and 37.3% of the total variance, respectively. Artifact groups A, F, G, and H are separated from artifact groups B, C, D, and E by the first, second and third PCs (Figure 4.21a, b), and artifact groups B, C, D, and E are separated from each other by PC 2 and 3 (Figure 4.21b). Artifact Group A (3.4% of total) is characterized by high levels of Rb, Y, Zr, and Nb, and moderate levels of Sr compared to remaining artifact groups. Group B (4.6% of total) is

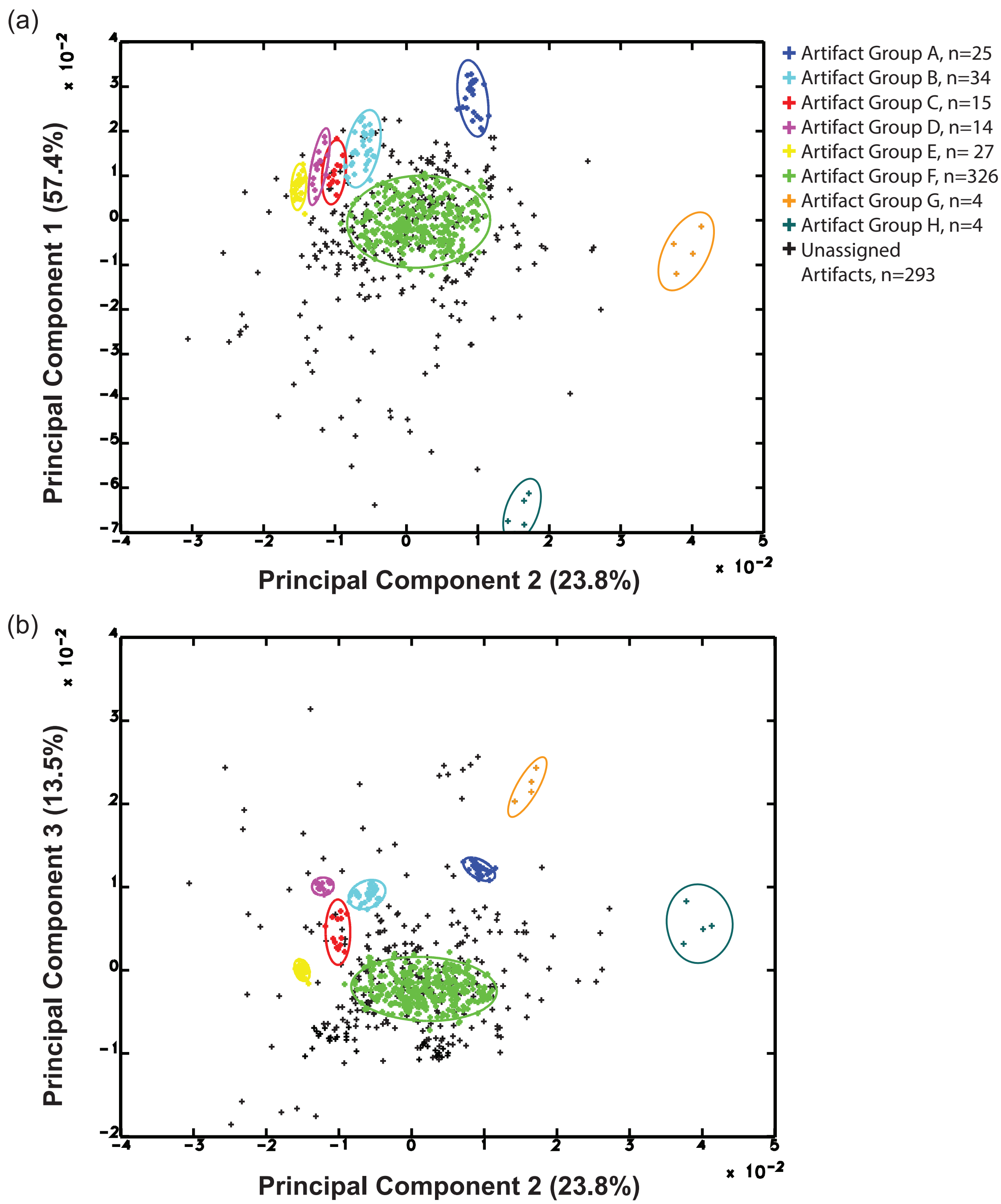

Figure 4.21. Logged (base 10) biplots of principal component 1 and 2 scores (a) and principal component 2 and 3 scores (b) of basalt artifact groups and unassigned artifacts. Ellipse confidence intervals drawn at 90%.

Table 4.16. Eigenvalues and percentages of variance explained by principal components calculated from the variance-covariance matrix of concentration data (log-10 ppm) for basalt artifact data, as well as resulting principal-component scores for elements.

Principal Component		Eigenvalue	% Variance		Cumulative % Variance
1		0.1323	57.43		57.43
2		0.0549	23.82		81.24
3		0.0312	13.54		94.78
4		0.0074	3.22		98.00
5		0.0046	2.00		100.00
Element	**PC 1**	**PC 2**	**PC3**	**PC4**	**PC5**
Rb	0.41	0.56	-0.68	-0.19	-0.14
Sr	0.54	-0.77	-0.33	0.04	0.08
Y	0.38	0.10	0.30	0.55	-0.67
Zr	0.46	0.04	0.53	-0.71	-0.08
Nb	0.43	0.29	0.24	0.39	0.72

characterized by high Sr, moderately high Rb and Zr, and moderate Y and Nb compared to remaining groups. Basalts belonging to Group C (2.0% of total) are differentiated by high Sr and moderate levels of Rb, Y, Zr, and Nb. Group D basalts (1.9% of total) are characterized by high Sr and Y, and moderate Rb, Zr, and Nb. Basalts belonging to artifact Group E (3.6% of total) are differentiated by very high Sr, moderate Rb, Y, and Zr, and low Nb. Group F is the largest cluster of basalt artifacts (43.9% of total) and geochemically variable, characterized by moderate Rb, Sr, Y, Zr, and Nb. Group G (0.5% of total) is characterized by very high Rb, moderate Y, Zr, and Nb , and low Sr. Group H (0.5% of total) is characterized by low concentrations of Rb Sr, Y, Zr, and Nb (Figure 4.21; Tables 4.14, 4.15).

4.5.4. Combining Geochemical Analyses of Geological and Archaeological Samples

Below, I present a comparison of geological samples collected from outcrop locations and alluvium with archaeological samples (Figures 4.22-4.26; Tables 4.17-

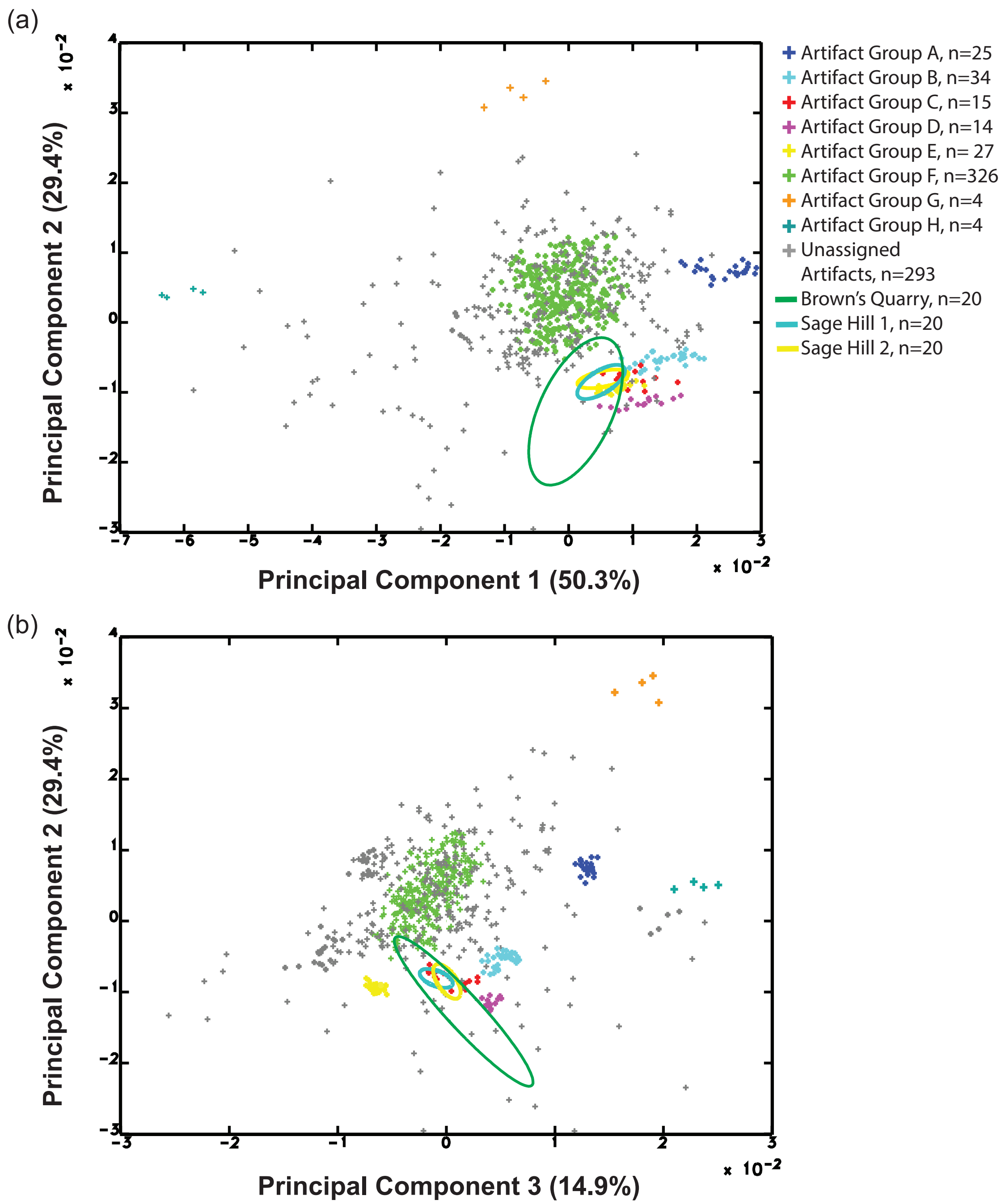

Figure 4.22. Logged (base 10) biplots of (a) principal-component 1 and 2 scores and (b) principal-component 2 and 3 scores of basalt artifact groups and unassigned artifacts compared with Fairbanks outcrop samples (Brown's Hill Quarry, Sage Hill 1 and 2). Ellipse confidence intervals drawn at 90%.

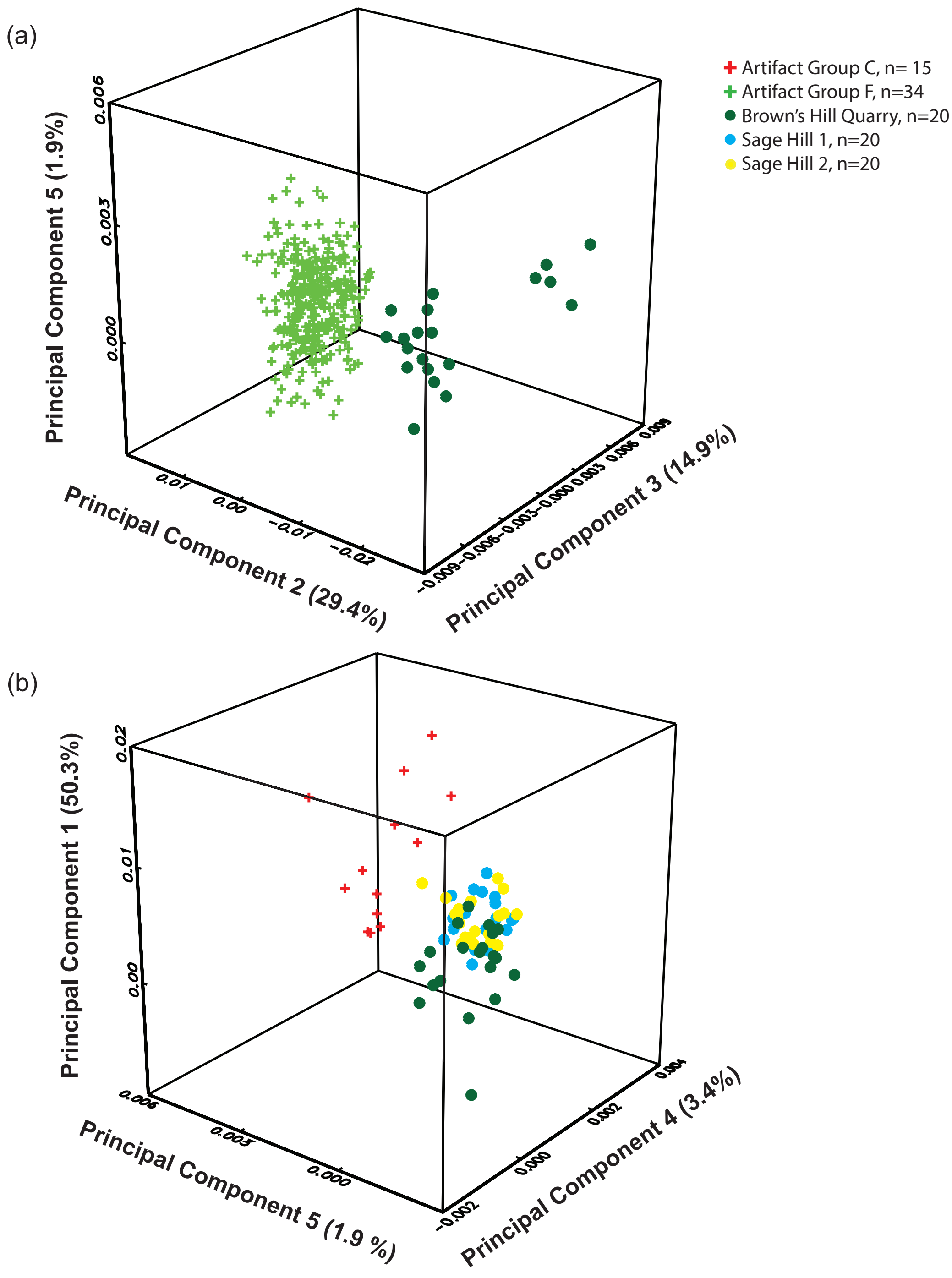

Figure 4.23. Logged (base 10) biplots of (a) principal-component 2, 3, and 5 scores comparing basalt artifact Group F samples with Brown's Hill Quarry outcrop samples, and (b) principal-component 1, 4, and 5 scores comparing basalt artifact Group C samples with Fairbanks outcrops samples (Brown's Hill Quarry, Sage Hill 1 and 2). Ellipse confidence intervals drawn at 90%.

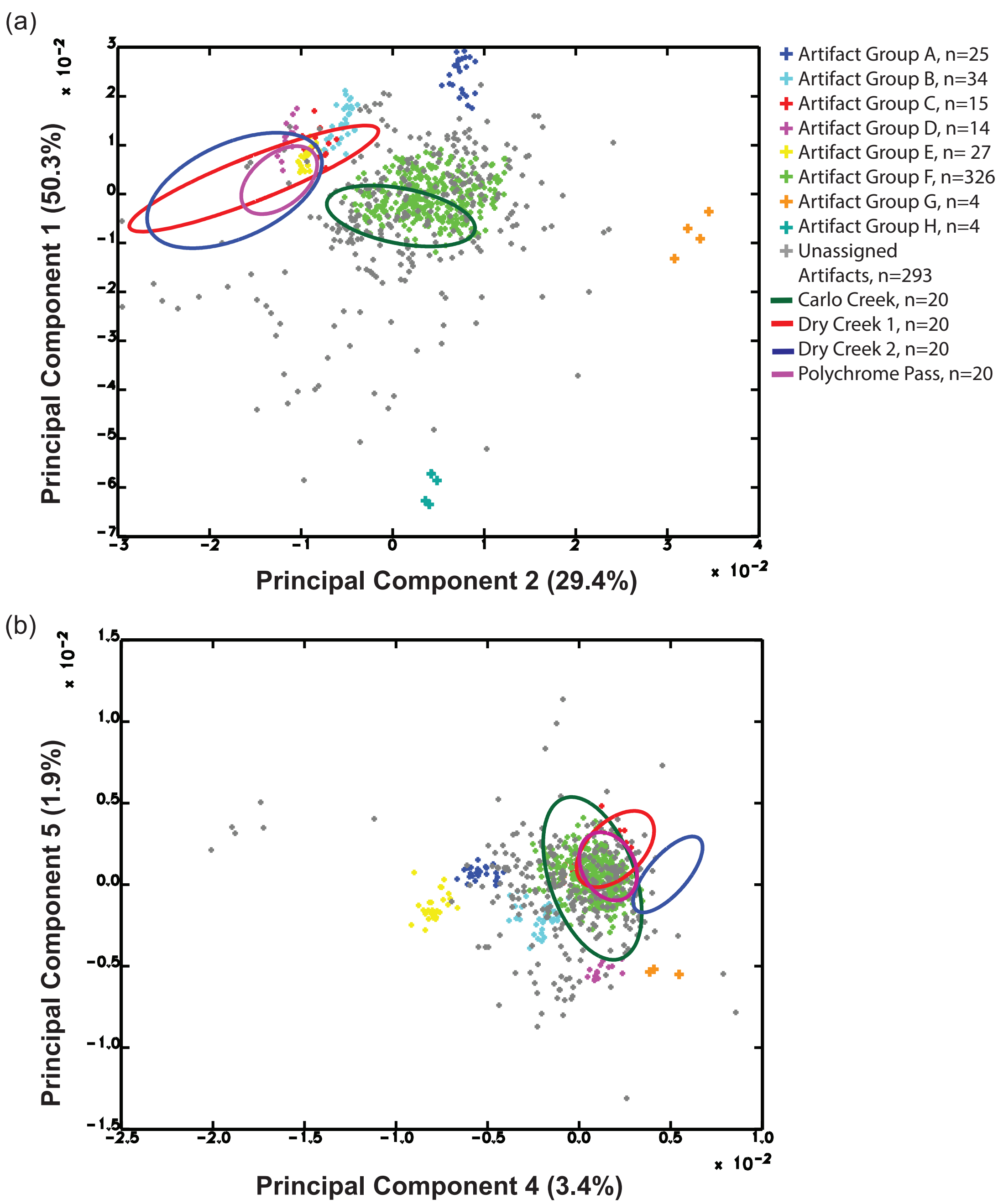

Figure 4.24. Logged (base 10) biplots of (a) principal-component 1 and 2 scores and (b) principal-component 4 and 5 scores comparing basalt artifact samples with Nenana valley outcrop samples (Carlo Creek, Dry Creek 1 and 2, Polychrome Pass). Ellipse confidence intervals drawn at 90%.

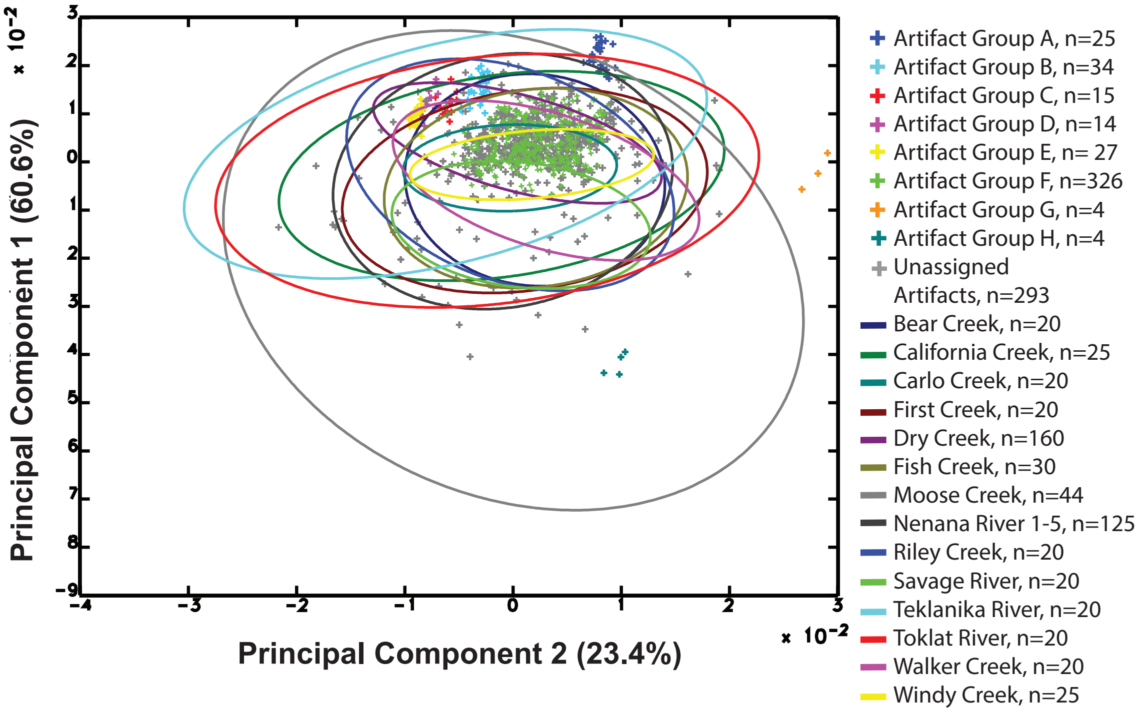

Figure 4.25. Logged (base 10) biplot of principal-component 1 and 2 scores comparing basalt artifact samples and select alluvial geological samples. Ellipse confidence intervals drawn at 90%.

Table 4.17. Eigenvalues and percentage of variance explained by principal components calculated from the variance-covariance matrix of concentration data (log-10 ppm) for basalt artifact and outcrop data, as well as resulting principal-component scores for elements.

Principal Component	**Eigenvalue**	**% Variance**	**Cumulative % Variance**
1	0.1148	50.28	50.28
2	0.0672	29.44	79.72
3	0.0341	14.94	94.66
4	0.0078	3.41	98.07
5	0.0044	1.93	100.00

Element	**PC 1**	**PC 2**	**PC3**	**PC4**	**PC5**
Rb	0.41	0.61	-0.67	-0.07	-0.13
Sr	0.59	-0.74	-0.32	0.00	0.07
Y	0.34	0.05	0.33	0.56	-0.68
Zr	0.39	0.10	0.45	-0.77	-0.21
Nb	0.47	0.27	0.38	0.30	0.69

4.18). Because there were no geographical patterns apparent among the distribution of Alluvial Group A, these alluvial samples were not treated as a separate group in geochemical comparisons between alluvial samples and artifact samples. When comparing alluvial samples with artifacts, it became necessary to combine all individual alluvial samples from Dry Creek (Dry Creek Alluvium 1-6), the Nenana River (Nenana River 1-5), and Moose Creek (Upper and Lower Moose Creek) into single stream "groups," represented by single confidence intervals for each stream (Figure 4.25).

Table 4.18. Eigenvalues and percentage of variance explained by principal components calculated from the variance-covariance matrix of concentration data (log-10 ppm) for basalt artifact and alluvium data, as well as resulting principal-component scores for elements.

Principal Component	**Eigenvalue**	**% Variance**	**Cumulative % Variance**
1	0.1936	60.65	60.65
2	0.0753	23.59	84.24
3	0.0350	10.96	95.20
4	0.0088	2.76	97.96
5	0.0065	2.04	100.00

Element	**PC 1**	**PC 2**	**PC3**	**PC4**	**PC5**
Rb	0.41	0.61	-0.67	-0.07	-0.13
Sr	0.59	-0.74	-0.32	0.00	0.07
Y	0.34	0.05	0.33	0.56	-0.68
Zr	0.39	0.10	0.45	-0.77	-0.21
Nb	0.47	0.27	0.38	0.30	0.69

4.5.4.1. Basalt Artifacts and Outcrops

Plots of PCs 1, 2, and 3 (representing 94.6% of variance) compare Fairbanks outcrop samples (Brown's Hill Quarry, Sage Hill 1/2 outcrops) with artifact data (Figures 4.22 and 4.23). Ultimately, no unassigned artifacts or artifact groups matched the Fairbanks outcrops. Artifact groups A, B, G, and H are separated from Fairbanks outcrop samples by PCs 1, 2, and 3 (Figure 4.22a), and artifact groups D and E are separated from Fairbanks outcrop samples by PC1 and PC 3 (Figure 4.22b). Artifacts from Group F, initially appearing to overlap with Brown's Hill Quarry, are separated by PCs 2, 3, and 5 (Figure 4.23a), while artifacts from Group C, initially appearing to fall within the range of Brown's Hill Quarry and Sage Hill outcrops, are separated by PCs 1, 4, and 5 (Figure 4.23b). No unassigned artifacts were able to be definitively assigned to any Fairbanks outcrops sample after analysis of biplots of all PC combinations and element values.

Plots of PCs 1 and 2 and PCs 4 and 5 (79.7% and 5.3% of the variance, respectively) show artifact samples compared with known Nenana valley outcrops (Figure 4.24). Artifact groups compared with outcrop samples from Dry Creek 1 and 2, Carlo Creek, and Polychrome Pass show some geochemical similarity. For example, artifacts from Group C fall within the range of the Dry Creek 1 outcrop, and artifacts from Group F fall within the range of the Carlo Creek outcrop (Figure 4.24a). Eight unassigned artifacts also fall within the range of the Carlo Creek outcrop after cross-checking comparisons of principal-component plots with plots of element values. Artifact groups A, G, and H are separated from all Nenana valley outcrops by PCs 1 and 2 (Figure 4.24a). Artifacts from Group B appearing to fall within the range of Dry Creek 1 in Figure 4.24a but plot outside of them when considering other PCs (Figure 4.24b). Similarly, when comparing PCs 1 and 2, many artifacts of groups D and E appear to share geochemical affinity with the Dry Creek 2 outcrop ellipse (Figure 4.24a), but when PCs 4 and 5 were considered, no artifacts fall within the geochemical signatures of the

Dry Creek 2 outcrop (Figure 4.24b). These results were cross validated with plots of element values to confirm their assignments. One pattern that was consistent is that numerous artifacts from Group F consistently overlap with the Carlo Creek outcrop ellipse.

4.5.4.2. Basalt Artifacts and Alluvium

A comparison of basalt artifacts with a representative sample (n = 14) of valley alluvium shows that 11 Nenana valley alluvial geochemical signatures encompass most artifacts sampled, including most artifact groups; however, there is some variability (Figure 4.25). First, Carlo Creek, Savage River, and Windy Creek alluvium only overlap with artifacts of Group F and several unassigned artifacts, not with the other groups. Second, groups A, G, and H generally fall outside the range of variation for the region's alluvium. Additional, more detailed comparisons of groups A and H with the alluvium of the Nenana, Teklanika, and Toklat rivers and Moose and California creeks and using PCs 2, 3, and 4 establish separation of these artifacts from most similar alluvial signatures as well (Figure 4.26). Out of the entire artifact sample, just 32 artifacts from artifact groups A, G, and H fell outside the geochemical range of local alluvium sources.

4.5.4.3. Summary

In sum, there are several important patterns to highlight. First, most basalt outcrops are not well represented in the Nenana valley's alluvium. Only the Carlo Creek and, to a lesser extent, Dry Creek 1 outcrops match basalt alluvium. Similarly, most basalt outcrops, apart from Carlo Creek, do not match any of the sampled basalt artifacts from the Nenana valley's archaeological sites, so these rocks do not appear to have been sources that humans used in prehistory. Group F is the only artifact group that partially overlaps with the alluvium sampled in Carlo Creek and the Carlo Creek outcrop. Importantly, this is the most common group recognized among the sampled artifacts, totaling 326, and it is represented in all but two of the archaeological assemblages analyzed. However, given that basalt cobbles matching the Carlo Creek outcrop are so widely distributed in the valley, and Group F is a large, geochemically variable, diffuse group that only partially overlaps with it, we cannot presently label Group F as a unique Carlo Creek geochemical group located only in the Nenana valley. Despite this, we can say that the Carlo Creek outcrop is the most isolatable basalt in the valley and that it does not overlap with other outcrops sampled in the study area, including around Fairbanks, so it is potentially discernible when comparing basalts from outside the Nenana valley. More work to geochemically characterize other basalt outcrops outside the valley will be important to fully characterize and map the complete distribution of basalts matching the Carlo Creek outcrop to finally determine whether this truly represents a distinct Nenana valley basalt group.

Four of the other basalt artifact groups identified, groups B, C, D, and E, fall within the geochemical range of most Nenana valley alluvial samples. In the principal-components analyses, these generally cluster close to each other but away from the others, groups A, F, G, and H. Given this, at present we can interpret them as local, but we do not know whether they represent basalt from distinguishable sources, and we cannot connect them to an individual outcrop or alluvial location. Though a significant number of artifacts (n = 293) remain geochemically unassigned to an artifact group, like most of the assigned groups, all of these fall within the geochemical signature of one or more alluvial sample locations. Future work may help to decrease the unassigned numbers reported. The Dry Creek 2 outcrop was discriminated from all other outcrops and did not match local alluvium, indicating it could be considered a geochemically unique basalt amenable to sourcing in future studies, but currently no artifact samples match this outcrop. Finally, groups A, G, and H do not clearly overlap with any geological samples obtained in this study. Therefore, they may represent nonlocal sources of basalt. This final pattern is further explored below.

4.5.5. Basalt Transport and Provisioning

4.5.5.1. Basalt Transport

Artifact group frequencies and cortex presence inform on transport patterns. Of the artifacts analyzed here, 310 date to the Allerød, 27 date to the YD, 277 date to the early Holocene, and 128 date to the middle Holocene (Table 4.14). The total number of identifiable artifact groups is small, but the frequency of their occurrence in the archaeological assemblages varies through time. During the Allerød, six total artifact groups were used, four matching local alluvium samples (groups B, C, D, and F) and two that did not match any geological source (groups A and G). The YD assemblages have just one group used (F). Five basalt groups were used during the early Holocene (three local C, D, and F; and two groups, A and G, from unknown locations). Six groups were used during the middle Holocene (five from local sources, groups B, C, D, E, and F; and one, Group A, from an unknown location) (Table 4.14). Artifact Group F dominates in total sample frequency (43.9%) through time, making up 17.2% of the

Allerød assemblages, 1.5% of the YD assemblages, 18.7% of the early Holocene assemblages, and 3.8% of the middle Holocene assemblage. This group is continuously used within each time period (Table 4.14) and the only identified group used in the YD assemblages. Artifact Group H is found in just one assemblage in the early Holocene. Artifact groups A, B, C, D, E, and G are also found in low frequencies, 3.4%, 4.6%, 2.0%, 1.9%, 3.6%, 0.5%, and 0.5% of total artifacts, respectively, each found in fewer than five assemblages. Artifacts unassigned to any group represent nearly 40% of the entire artifact sample and are present in high frequencies in nearly every assemblage save for Moose Creek C2, perhaps representing locally procured basalts (Table 4.14).

4.5.5.2. Cortex Frequencies

Cortex is present on only 113 of the 742 basalt artifacts analyzed here, making up 15.2% of the total (Table 19). In each time period, artifact Group F dominates (46.9%) cortical pieces, and likely represents a basalt local to the Nenana valley, another sign of its connection to Carlo Creek. By contrast, artifact groups A, B, and C exhibit just a handful of cortical pieces, numbering two (1.8%), three (2.7%), and one (0.9%), respectively. These mostly date to the Allerød with one cortical piece of artifact Group A dating to the early Holocene. Finally, artifact groups D, E, G, and H exhibit no cortex (Table 19). Because groups D and E overlap with most drainages, they are likely local to the Nenana valley, but due to the lack of cortex they may have been procured from some distance within the valley, whereas groups G and H do not match geological samples and likely represent nonlocal basalts. Unassigned basalt artifacts represent the highest amount within cortex frequencies, 48.7% of the sample, and are present in every time period (Table 4.14). Though unknown, several of these unassigned basalt artifacts probably represent local toolstones.

Table 4.19. Count and percentage of cortical artifacts in each archaeological assemblage and their assigned artifact group.

	Basalt Artifact Group									
Assemblages by Time	**Total (%)**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Una[1]**
13.5 - 12.8 ka										
Dry Creek 1	16 (14.2)	1 (0.9)	2 (1.8)				7 (6.2)			6 (5.3)
Walker Road	28 (24.8)						16			12
Moose Creek 1	1 (0.9)									1 (0.9)
Owl Ridge 1	5 (4.4)			1 (0.9)			1 (0.9)			3 (2.7)
Eroadaway	5 (4.4)						2 (1.8)			3 (2.7)
Subtotal	55 (48.7)									
12.5 - 11.7 ka										
Moose Creek 2	0 (0.0)									
Owl Ridge 2	5 (4.4)									5 (4.4)
Panguingue 1	0 (0.0)									
Subtotal	5 (4.4)									
11.7-9 ka										
Carlo Creek 1	12 (10.6)						3 (2.7)			9 (8.0)
Dry Creek 2	14 (12.4)	1 (0.9)					9 (8.0)			4 (3.5)
Owl Ridge. 3	12 (10.6)						9 (8.0)			3 (2.7)
Panguingue 2	4 (3.5)						2 (1.8)			2 (1.8)
Little Panguingue Creek	0 (0.0)									
Subtotal	42 (37.2)									
8 – 3.5 ka										
Houdini Creek	4 (3.5)						2 (1.8)			2 (1.8)
Tek West 3	5 (4.4)						1 (0.9)			4 (3.5)
Moose Creek 3	0 (0.0)									
Panguingue 3	1 (0.9)						1 (0.9)			
Dry Creek 4	1 (0.9)									1 (0.9)
Subtotal	11 (9.7)									

Table 4.19 Continued.

Assemblages by Time	Total (%)	A	B	C	D	E	F	G	H	Una[1]
Total	**113 (100)**	**2 (1.8)**	**3 (2.7)**	**1 (0.9)**	**0 (0.0)**	**0 (0.0)**	**53 (46.9)**	**0 (0.0)**	**0 (0.0)**	**55 (48.7)**
[1] Number of unassigned artifacts.										

In sum, most observed artifact groups are likely local to the Nenana valley region. As mentioned above, Group F, which partially matches with Carlo Creek basalt, is present in high frequencies in nearly every assemblage within the valley through time, 16% of its assemblage is cortical, and it has the highest frequencies of cortex in the total cortical sample, compared to other groups. Without question, Group F represents the local basalt. Artifacts from groups A, B, and C are low in sample number and frequency, yet possess cortex (8%, 9%, and 7%% of the total, respectively) indicating they may be local, like artifact Group F. Artifact groups D and E are low in sample frequency and lack cortical pieces, but because they match locally sampled basalt alluvium, they appear to reflect use of local basalts. Artifact groups G and H lack cortex and do not match sampled local alluvium, leaving this handful of artifacts as the most likely candidates for nonlocal basalts. One caveat worthy of note, however, is that artifact group A does not match any of the local geological samples so it, too, could represent a nonlocal basalt despite cortex remaining on a fraction of its pieces.

4.6. Discussion

4.6.1.1. Geological Basalt Samples

The first goal of this paper was to geochemically characterize Nenana valley basalts from sampled outcrops and valley alluvium as well as artifacts from archaeological assemblages, and to compare these to potentially identifiable basalt sources. To begin, differentiating basalt outcrops based on their geochemistry was met with mixed success. Outcrop locations outside of the valley in the Fairbanks area, which could not be differentiated from each other, partially overlapped several Nenana valley outcrops, while the Nenana valley outcrop samples were distinguished from each other except for the partial overlap of Polychrome Pass and Dry Creek 1. These geochemical data refute the notion that increased distance between localities of mafic materials result in higher rates of geochemical uniqueness. For example, the Polychrome Pass outcrop, located in Denali Park, could be differentiated from only one Fairbanks outcrop (Sage Hill 1), while the Nenana valley outcrop of Dry Creek 1 could not be differentiated from any Fairbanks outcrop despite separation by over 140 km. In addition, some outcrop locations located within a few kilometers of each other could be differentiated (e.g., Dry Creek outcrops 1 and 2). At least one outcrop, Carlo Creek, was distinguished from all others within and outside the Nenana valley. Therefore, Carlo Creek and possibly Dry Creek 2 are discernible as potential basalt sources.

Geological samples from Nenana valley alluvial locations largely grouped away from most sampled basalt outcrops. This pattern could have resulted for several reasons. First, the absence could be that some of these locations are hydrographically distinct from most of the sampled outcrops. Second, the absence could be related to the small size of a basalt outcrop, so that it was never extensive enough to contribute significantly to valley alluvium (e.g., Dry Creek 1 outcrop), or was only recently exposed and had not yet had the opportunity to contribute to the alluvium (e.g., the Dry Creek 2 outcrop). Third, the absence may be related to the quality of the basalt, in that the basalt may be so brittle that it eroded quickly and did not persist long drainage alluvium (e.g., the Polychrome Pass outcrop).

However, a handful of samples from several alluvial localities fell within close range of outcrop samples from within and outside the Nenana valley, preventing the complete separation of alluvial localities from outcrops. This pattern may be expected in waterways located near or flowing through respective outcrops, such as overlap between Carlo Creek alluvium and outcrop material or overlap of Dry Creek alluvium with samples from outcrops at the creek headwaters, given that erosional processes likely have transported these materials downstream. However, geochemical similarity also occurs between outcrops and alluvial materials from separate drainages, indicating the need for additional documentation and chemical characterization of geological basalts to determine the cause of this pattern. Moving forward, all mapped basalt outcrops in the valley not yet sampled should be investigated and compared with the data presented here.

Geochemical analyses revealed substantial overlap between several within-valley outcrops and alluvial geological locations. The factors influencing this pattern are both chemical and environmental in nature. Geochemical heterogeneity in basalt formations has been observed in previous studies (Lundblad et al. 2011) and may be the result of the chemical makeup of magma chambers, material solidification at differential rates, expansive mafic flows and eruptions, and/or weathering processes (Fertelmes and Glascock 2018, Lundblad et al. 2011). These factors, coupled with millennia of glacio-fluvial events recorded in the Nenana valley, have resulted in a landscape of continuously reworked and transported alluvial materials representative of many basalts that may or may not have distinct geochemical signatures (Ritter and Ten Brink 1986; Thorson 1986; Wahrhaftig 1968).

4.6.1.2. Artifact Samples

Geochemical analysis of artifacts revealed that a few clusters or groups of artifacts could be identified, but in general, one broad, diffuse group (Group F) dominates the total artifact sample. A large portion (nearly 40%) of the artifact sample could not be assigned to any cluster, supporting previous studies documenting the potentiality to record artifact groups (Mills et al. 2018; Rains 2014) and the presence of wide geochemical variability in mafic materials (Lundblad 2011; Mills 2010; Mills et al. 2018).

Comparison of basalt artifacts with geological samples revealed that no artifacts matched the Fairbanks outcrops or the Dry Creek 2 and Polychrome Pass outcrops. Artifact samples from Group D fell within the range of the Dry Creek 1 outcrop, and Group F fell within the range of the Carlo Creek outcrop, along with many unassigned artifacts. The wide range of geochemical variability of the valley’s basalt alluvium encompasses most artifacts, including those matching local outcrop samples.

Because the geochemical signature of several alluvial geological samples overlap with each other, it is difficult to assign artifact groups or unassigned artifacts to any one geological location within the valley. Most artifact clusters match multiple alluvial locations and may either represent one discrete basalt type that came to be reworked and redeposited throughout the Nenana valley or several geochemically similar materials distributed across the valley in the same manner. Given the environmental and geological history of the valley, these likely do not represent basalts from one single discrete "source" location, such as materials located at one outcrop or within just one drainage. Ultimately, specific within-valley source locations could not be determined for the artifact sample based on geochemical results alone. However, geochemical work may be coupled with additional variables informing on basalt transport and use to broadly describe transport patterns operating within, or outside of, the Nenana valley.

4.6.2. Basalt Transport

4.6.2.1. Transport

As discussed in the previous chapter, the local lithic landscape of the Nenana valley is comprised mostly of non-knappable materials such as quartz, quartzite, and schist. Considering basalts specifically, results of the geological survey carried out for this study provided multiple locations to procure mafic materials throughout the Nenana valley, though this material is truly abundant only in a handful of cases (e.g., some areas of Dry Creek and Windy Creek). Although mafic materials were few or absent in some alluvial sample locations within the valley, all archaeological sites are located within a 5-km range of a creek, drainage or river where basalts were recorded during the survey. Therefore, basalt is considered a toolstone that was locally available to humans inhabiting the Nenana valley throughout prehistory. If these local basalts were procured, they should retain higher frequencies of cobble cortex, allowing a coarse measure of transport distance. Here I discuss the significance of cortex presence and observed geochemical patterns informing on local and nonlocal transport behaviors.

4.6.2.2. Local Basalts

Artifact groups A, B, C, and F contain pieces with cortex (Table 4.19). Because we expect a high incidence of cortex in materials local to the valley, we may assume these artifacts were procured from local stream beds or exposed glacial outwash. These patterns confirm geochemical results showing artifact groups B, C, and F match local streambed alluvium. Though artifact Group A did not match any geological sources, it is presumed to be locally procured because its sample includes artifacts with cortex. This basalt occurs only at the Dry Creek site and may therefore represent a rare type procured from the local Dry Creek alluvium. Likewise, artifact groups D and E contain no artifacts preserving cortex, but they should be considered locally procured materials because their geochemical signature falls within the range of Nenana valley alluvium. Numerous artifacts were unable to be given a designated artifact group, but like artifact Group F, many of these pieces retain cortex indicative of relatively local origin.

4.6.2.3. Nonlocal Basalts

Artifacts from groups G and H are few in number, match no geological source, and have no cortical pieces present. These artifacts are the only candidates for nonlocal basalts, but the small sample size of each group is problematic because these groups are not well defined geochemically. If these pieces truly represent nonlocal material transported from outside the Nenana valley, they are greatly outnumbered by local materials. Overall, geochemical results coupled with the high incidence of cortex within the artifact sample support local sources for basalt artifacts found at all sites through time in the Nenana valley.

4.6.3. Provisioning Strategies

We expect mobile hunter-gatherers engaging in provisioning-place behaviors to rely on local materials, while people who choose to provision individuals are apt to rely on nonlocal materials brought with them to prepare for fewer encounters with quality materials. Geochemical results and the high incidence of cortex prevalent in all time periods show that basalt transport patterns were largely local. This study indicates Nenana valley folks continuously relied on local basalts obtained opportunistically from nearby alluvial deposits where they were readily available, a signature of people choosing to provision place irrespective of time. Results of rhyolite geochemistry reported in the previous chapter, however, show a more complex pattern.

Rhyolite geochemistry shows that mostly local rhyolites were procured during the Allerød and YD, with more nonlocal rhyolites used, overall, during the early and middle Holocene. Allerød sites Walker Road and Dry Creek (C1) have lithic assemblages previously described as the result of provisioning place (Goebel 2011; Graf and Goebel 2009), but these sites have higher-than-expected proportions of nonlocal rhyolites compared to remaining Allerød assemblages (e.g., Moose Creek C1, Owl Ridge C1, and Eroadaway). The previous chapter concluded the overall strategy of the Allerød was provisioning-place, but rhyolite selection patterns at the earliest sites in the valley, Dry Creek and Walker Road, reflect more of a provisioning-individuals strategy. Results of analysis presented in this chapter show that basalt provisioning during the Allerød was overwhelmingly local, but it is interesting to note that nonlocal Group G occurs in the Walker Road and Moose Creek C1 assemblages. Increased sampling in future studies is necessary to determine whether these artifacts are truly nonlocal to the valley and if the nonlocal signature is significant enough to echo the undercurrent of provisioning of individuals interpreted from the early Allerød rhyolites.

Basalt provisioning in all time periods after the Allerød remained local. Both basalt and rhyolite procurement during the YD were almost exclusively local, an expectation of provisioning-place strategies. However, as noted in Chapter 3, technologies associated with rhyolite are patterned and planned, characteristic of provisioning individuals (Gore and Graf 2018; Graf and Bigelow 2011), indicating humans may have provisioned-place with select toolstones while maintaining an overall highly mobile strategy. During the Holocene, rhyolite procurement patterns shifted from mostly local in the early Holocene to more nonlocal during the middle Holocene. Local basalt procurement during the early Holocene, coupled with mostly-local rhyolite procurement, confirms expectations of people choosing to provision place. During the middle Holocene, however, several site assemblages (Houdini Creek, Moose Creek C3, and Dry Creek C4) have mostly nonlocal rhyolites (an expectation of provisioning individuals) alongside basalts procured locally. An interesting pattern to note is that during the middle Holocene, proportionally fewer basalts were procured compared to rhyolites (Figure 3.17 in Chapter 3). Given that rhyolites seem to show more complexity in provisioning patterns compared to basalts, future studies should investigate how variables such as toolstone selection and site-occupation duration influenced how basalts were procured and used in regional assemblages.

4.6.4. Landscape Learning

The geochemical identification of artifact groups in this study is limited, but basalt transport and provisioning strategies inform on landscape learning. We expect that transport patterns reflecting mostly nonlocal procurement are a signature of people who did not know where to obtain high-quality materials and chose to provision individuals with high-quality materials to mitigate risk, while those who were actively learning or had extensive knowledge of the lithic landscape would choose to provision place and exploit locally available materials. This study shows that basalt transport was mostly local from the initial Allerød occupation of the valley into the middle Holocene, and, with the exception of the earliest Allerød occupations, provisioning-place strategies were likely chosen from the Allerød until the middle Holocene when provisioning signatures became mixed (Chapter 3). These behaviors meet the behavioral expectations of mobile hunter-gatherers who had knowledge of the local lithic landscape, but as mentioned above, incorporating rhyolite geochemical results into these interpretations requires further explanation.

During the Allerød, local basalts and mostly local rhyolites were used, with the exception of higher-than-expected amounts of nonlocal rhyolites at Walker Road and Dry Creek C1. Previous studies have suggested that during early Allerød occupations, humans were place-oriented and already actively engaged in the process of learning the local lithic landscape (Gore and Graf 2018; Gore 2021; Graf and Goebel 2009), which is generally supported by geochemical results of rhyolites and basalts. Whether humans in the Allerød knew the lithic landscape completely, or as suggested in the previous chapter, were still learning locations of less visible sources of high-quality toolstone (e.g., rhyolite), local Nenana valley basalts were easy to procure and use. Survey work reported here has shown that basalt is common and relatively easy to find in most drainages. Local basalts and a mix of local and nonlocal rhyolites (previous chapter) were employed variably from the YD through the early Holocene, showing that by this time, humans had learned the local lithic landscape well enough to continue to locate and use presumably local rhyolites while continuing to rely on basalts obtained from the local alluvium. This pattern continued into the middle Holocene when local basalts are exploited sparingly in favor of rhyolites and cherts at several sites, hinting that toolstone selection may have been an additional factor affecting toolstone transport patterns.

It is unclear how much constraint of the local lithic landscape, lacking in high-quality materials, contributed to transport and provisioning patterns. Raw material survey and lithic assemblage analysis suggest that humans operating in the Nenana valley would have been constrained by the lack of high-quality, knappable materials available (e.g., cherts). The increased availability of lower-quality basalts in valley waterways may have made their use an attractive cost-mitigating option that could have reduced the need for transporting and/or procuring alternative toolstones. Because these materials were located so close to sites, procuring them on-site or while engaging in other activities off-site would have been low-cost endeavors, so we might expect some degree of local basalt use in most assemblages regardless of the degree of landscape knowledge. Additional efforts to continue mapping the lithic landscape by locating and characterizing all knappable sources of toolstone and assemblage-wide technological analyses focused on investigating human response to toolstone quality and availability is needed to clarify how toolstone constraint shaped archaeological assemblages of the valley.

In the case of basalts, application of geochemical methods to Nenana valley sites may have provided results that are too coarse-grained to properly investigate the nuanced relationships between toolstone constraint, provisioning, and landscape knowledge. Clearly, landscape learning was a complex process encompassing more variables than the simple model and data set presented here account for (Rockman 2009; Schmuck et al. 2022; Tolan-Smith 2003). While this study provides tentative support for the assertion that the earliest known occupants of the Nenana valley were not landscape naïve, this is a broad generalization that requires assemblage-wide investigation, additional raw materials survey, and further geochemical work to confirm and clarify.

4.7. Conclusions

This paper sought to contribute to the growing body of lithic sourcing and raw material studies in central Alaska by integrating geochemical and behavioral methods. Geochemical comparison of geological basalt samples from both basalt outcrops and several valley alluvial locations show that outcrops could be discriminated from each other in some cases, but not in others. Further, increasing distance of these outcrops from each other was not always a good predictor of discrimination. Geological samples from alluvial locations had highly variable, overlapping geochemistry reflective of the dynamic nature of glaciofluvial processes acting upon the valley. Geochemical analysis of artifacts indicated that they were likely procured locally, although geochemical variation within these samples was likewise high. Some artifacts could not be matched to any geological sample, indicating the need to expand the basalt-sourcing study beyond the Nenana valley to encompass much of Alaska.

As noted in previous studies, sourcing of mafic fine-grained volcanic materials may be more difficult than rhyolite or obsidians. The chemical genesis and physical distribution of local mafic materials within the Nenana valley are still largely unknown and understudied, factors that complicate sourcing attempts. Additional destructive methods of chemical sourcing such as neutron activation analysis may be necessary to confidently separate outcrop sources described here. Such methods can be more successful at differentiating mafic materials because they accurately measure a wider range of elements compared to non-destructive techniques such as pXRF (Grave et al. 2012).

The integration of lithic technological analysis with geochemical methods in this study confirms one pattern: when basalts were employed at sites in the Nenana valley, humans chose to exploit local sources. The geochemical and technological results presented here support the notion that most of these materials were procured as cobbles from streambed deposits near sites and supports the viability of using the presence of cobble-cortex as a proxy for determining degrees of "localness" in the absence of geochemical methods. No shifts in basalt use attributable to environmental change were determined; rather, humans chose to depend on these local materials regularly from the late glacial through the middle Holocene. Previous lithic landscape investigations have shown that, overall, the Nenana valley is limited in high-quality raw materials. While operating on this restricted landscape, humans often chose to procure and use basalt despite its average quality, probably because it was easily accessible in many waterways throughout the Nenana valley, and because it still presents a durable material for a variety of tasks.

Future studies are necessary to fully address the major questions posed here. The material samples in this study are not exhaustive; therefore, increased sampling of both known and unknown localities of geological mafics and increased archaeological sampling from additional regions within eastern Beringia must be conducted to verify these patterns. Likewise, hypotheses about landscape learning are tentative, and more definitive statements regarding these questions must be addressed in future studies incorporating whole-assemblage analyses. Accomplishing this will no doubt help to clarify and illuminate the complex provisioning behaviors and adaptive strategies of humans who once lived on the Alaskan landscape.

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5. CONCLUSIONS

5.1. Introduction

The chapters in this dissertation seek to provide a new perspective on diachronic Alaskan assemblage variability through the integration of lithic technological analysis and geochemical techniques. The data I used to accomplish this were collected from multi-year geological surveys of the Nenana valley (NRV), lithic analyses of nineteen archaeological assemblages from the region whose dates span the Allerød through the middle Holocene and performing portable X-Ray fluorescence (pXRF) analyses on a subset of geological and archaeological materials sampled from these same assemblages. In Chapter 2, lithic technological analysis of three lithic assemblages from temporally distinct occupations at the Owl Ridge site provided a means of describing and comparing human site activities in the context of the known paleoenvironmental record of the region. Results of this study showed that the three occupations at Owl Ridge engaged in differing ways to procure and use toolstone through time. This analysis provides an in-depth look at the influence of environmental conditions on human behavior at the site level and helps to characterize procurement and selection patterns of terminal Pleistocene foragers in the region as well as presents a hypothetical scenario of landscape-learning and use that may be tested in the future. Chapter 3 focuses on regional procurement of archaeological rhyolites within the NRV, expanding on a previous study conducted in interior Alaska (Coffman and Rasic 2015). Results demonstrate the significance of incorporating non-obsidian materials in geochemical analyses, identifies new rhyolite groups and one new rhyolite source, and generates new insights into rhyolite procurement patterns through time. Lastly, Chapter 4 presents analyses and comparison of geological basalts and archaeological basalts from lithic assemblages in the

NRV, identifying provisional procurement patterns in the region. These results highlight the importance of considering secondary alluvial deposits in procurement models, inform on the utility of basalt geochemistry in a glacio-fluvial environment, and provide new information pertaining to basalt procurement through time.

This dissertation has generated new geochemical data on non-obsidian volcanic materials as well as new hypotheses regarding regional toolstone procurement and landscape-use behaviors in interior Alaska. These hypotheses are discussed in the context of environmental change and resource distribution on the landscape to provide a more nuanced picture of ancient technological organization and adaptational response in eastern Beringia.

5.2. Technologies and Environmental Change at Owl Ridge

Owl Ridge is an important multicomponent site located along the Teklanika River, interior Alaska, because it is one of a handful of sites in the region preserving evidence of the earliest humans in eastern Beringia (Graf and Bigelow 2011, Graf et al. 2020). This site was discovered and tested decades ago, but renewed excavations have produced new data to consider (Gore and Graf 2018; Graf et al. 2020; Graf and Bigelow 2011; Hoffecker et al. 1996; Melton 2015; Phippen 1988). Chapter 2 characterized and compared toolstone procurement and provisioning variables between three stratigraphically and temporally separate cultural occupations at Owl Ridge to answer questions about late Pleistocene technological variability and human response to environmental change (Goebel et al. 1991; Graf et al. 2020; Graf and Bigelow 2011; Graf and Goebel 2009; Goebel and Buvit 2011a, 2011b; Gómez-Coutouly and Holmes 2018; Hoffecker and Elias 2007; Holmes 2001, 2006; West 1996; Wygal 2011).

The lithic analysis reported in this chapter is significant because it provides new information helping to inform interpretations of human activity at the site-level and the variable lithic record of Alaska. For example, although Owl Ridge was repeatedly used as a special task site, results show that human technological organization changed through time. Humans at Owl Ridge during the late Allerød (Component 1 [C1]) engaged in primary and secondary reduction activities to make mostly informal cores, bifaces, and unifaces from both local and nonlocal sources. During the Younger Dryas (YD), the C2 assemblage signaled a focus on manufacturing and maintaining lanceolate bifaces, scrapers and other processing tools, mostly from toolstones procured on-site. The artifacts from C3 indicate humans performed primary reduction activities focused on producing unifacial tools, also from mostly-local materials but with slightly more non-local materials compared to C2. The terminal Pleistocene and early Holocene C2 and C3 occupations are more similar to each other in raw material procurement patterns and site activities than they are to the earliest C1 occupation, providing additional behavioral evidence that their Nenana and Denali complex designations should be retained as heuristic devices to help describe the character of technological trends in the region. Further, this study suggests that the earliest inhabitants at Owl Ridge were not as familiar with the lithic landscape as later populations who had become more familiar with lithic resources as time passed. As environments changed in the Teklanika valley, humans continued to visit Owl Ridge during and immediately after the YD, abandoning the site only as boreal forest vegetation entered the region. Although the analysis of this chapter was limited in size and scope, it suggests that humans were already involved in the process of landscape-learning when they first arrived at Owl Ridge and continued accumulating this knowledge as time passed.

Exploring toolstone procurement and selection in comparisons between multiple site occupations is a valuable approach to understanding how humans adapted technological organization and land-use patterns in the wake of significant environmental change. Results of this paper contribute to a better understanding of the behavioral differences in site activities and raw material use of three stratigraphically and temporally distinct occupations. In addition, results support behavioral and technological distinctions between the earliest “Nenana” cultural component and later occupations at Owl Ridge and provide new hypotheses regarding toolstone procurement and landscape learning processes to be tested in the future.

5.3. Diachronic Rhyolite Use in the Nenana Valley

Currently, we know little about exactly how initial inhabitants of the NRV learned and established themselves on the eastern Beringian landscape. The archaeological record of the NRV is abundant in well-preserved, mostly-lithic assemblages spanning the late Pleistocene to middle Holocene (Goebel 1996, 2011; Goebel and Bigelow 1996; Gómez-Coutouly et al. 2019; Graf et al. 2015, 2020; Graf and Bigelow 2011; Pearson 1999; Holmes et al. 2018; Potter et al. 2007; Powers and Maxwell 1986; Powers et al. 2017). Because the record is mostly-lithic, toolstone procurement studies are well-suited to answer questions regarding behavior, land-use, and settlement in interior Alaska. Geochemical studies can be particularly informative to these questions but the majority of studies in Alaska have thus-far focused on obsidian, resulting in only broad generalizations regarding landscape-use and its variability through time (Coffman and Rasic 2015; Gore 2021; Graf and Goebel 2009; Goebel et al. 2008; Gómez-Coutouly 2019; Reuther et al. 2011; Slobodina et al. 2009). Chapter 3 focused on the geochemical characterization of geological rhyolites and archaeological rhyolites to explore the availability and use of rhyolites within the NRV, assess if rhyolite use changed as environmental regimes shifted, and better understand if landscape learning can be observed in the rhyolite record.

This chapter significantly expands our knowledge of the local lithic landscape of the region (Gore 2021; Graf and Goebel 2009). Raw material surveys conducted for this paper revealed several rhyolite outcrops located within the NRV but very limited availability of rhyolites in the local alluvium. Geological rhyolites from these alluvial and rock outcrop locations were sampled along with archaeological rhyolites from 19 NRV assemblages dating from 14 – 3.5 ka for comparative geochemical analysis, resulting in the characterization of seven rhyolite outcrops, confirmation of 10 rhyolite artifact groups (Coffman and Rasic 2015), and identification of four new artifact groups. One of these outcrops, Triple Lakes, is defined as a new source used in interior Alaska, but most NRV rhyolites sampled were not significantly valued by foragers during any time period. Rhyolite artifact group diversity and cortex values are used to inform on assemblage provisioning strategies to gauge relative degrees of rhyolite-landscape knowledge. Results show humans exploited a number of nonlocal and local rhyolite groups from the initial occupation of the NRV during the Allerød and later, but there is variability within and between specific time periods. In general, local rhyolites are under-represented in the earliest Allerød occupations of the valley, but by the end of the Allerød and through the end of the Younger Dryas, assemblages exhibit similarities in rhyolite procurement until the early Holocene when the first evidence of Triple Lakes rhyolite use occurs. Afterwards, middle Holocene foragers depended on fewer rhyolite types.

The quick accumulation of local and non-local rhyolites contributing to the diverse number represented in Allerød assemblages shows that humans settled-in and learned the landscape quickly upon arriving in the valley but may not yet have gained nuanced knowledge of rhyolite sources and their locations until later in time. Considering this study’s results in the context of environmental change, perhaps reduced dependence on several types of rhyolite during the middle Holocene was brought about by the establishment of the boreal-forest biome in this region, which limited source accessibility due to decreased visibility or shifting landscape strategies in response to perceived changes in resource distribution (Esdale 2008, 2009; Mason and Bigelow 2008; Mason et al. 2001; Potter 2007, 2008a, 2008b).

5.4. Diachronic Basalt Use in the Nenana Valley

Fine-grained volcanic materials are continuously relied upon in the NRV, but regional studies of these toolstones and their significance within archaeological assemblages are still lacking despite their potential for addressing long-standing questions of variability in the record (Gore 2021; Gore and Graf 2018; Goebel and Buvit 2011b; Graf and Goebel 2009; Graf and Bigelow 2011). Geochemical studies of mafic materials have been conducted in other regions with varying levels of success (Charleux et al. 2014; Fertelmes and Glascock 2018; Grave et al. 2012; Handley 2013; Lundblad et al. 2011; McAlister and Allen 2017; Mills et al. 2010; Palumbo et al. 2015), but the applicability of pXRF geochemical characterization of basalts in interior Alaska has not yet been tested. This chapter uses the same geological and geochemical approach described in the methodologies of Chapter 3, focusing on the distribution and use of basalts in NRV assemblages to illuminate patterns of procurement and use through time.

This study makes a significant contribution to our knowledge of the lithic landscape. Raw material surveys indicate basalt is a low-quality yet commonly-found material distributed variably across the NRV. Outcrops of basalt were mapped decades ago (Csejtey et al. 1992; Wahrhaftig 1958; Wahrhaftig 1970a, 1970b, 1970c, 1970d, 1970e; Wahrhaftig et al. 1969), but this study is the first to sample, geochemically characterize, and compare them with basalt artifacts from sites in the valley. Basalt outcrops were geochemically characterized and compared with artifacts from late Pleistocene and Holocene assemblages in the region to investigate patterns of use through time. Geochemical comparisons of regional outcrops found that some NRV outcrops could not be distinguished each other or from two outcrops found outside the valley. Basalts found within the alluvium represented a geochemically diverse mix of rocks that could not be separated from each other and did not display spatial trends. Geochemical analysis of basalt artifacts resulted in a few geochemically unique groupings, but comparison with geological basalts revealed that multiple valley-alluvium signatures encompassed most artifact groups. Only two artifact groups could not be assigned to a geological basalt source, perhaps indicative of a non-local basalt brought to the valley.

Because most basalt artifacts could not be distinguished from valley alluvium, their cortex values were high, and toolstone surveys indicate basalts are widely available. This material is assumed to be almost exclusively locally procured in all assemblages. No significant patterns in basalt procurement were established when comparing time periods with each other, however, reliance on basalts does vary between valley assemblages. Likely, the glacio-fluvial setting of the NRV contributed too much variability to the alluvial makeup of the region for pXRF to be informative, therefore, additional geochemical methods may be necessary to successfully source basalts in the future.

5.5. Future Studies

Although traditional interpretations of interior Alaskan technological variability have tended to focus on descriptive cultural typologies, more recent research explains this variability with regard to seasonality, specific site function, landscape use, and weapons systems (e.g., osseous vs. lithic projectiles) (Goebel and Buvit 2011b; Goebel et al. 1991; Gore and Graf 2018; Graf and Bigelow 2011; Holmes 2006, 2011; Lynch 2020; Potter 2008b; Potter et al. 2017). This dissertation sought to approach this variability through a perspective focusing on toolstone procurement, environmental adaptation, and landscape learning in a region-specific setting. More expansive studies and tests of the hypotheses suggested in these chapters are necessary to make broad and conclusive statements about what this variability represents.

Continued studies seeking to map the lithic landscape must be carried out to describe raw materials available within the Nenana valley and beyond. Raw material surveys conducted for the purposes of this dissertation are significant because they were the first to attempt a more comprehensive characterization of the lithic landscape available to humans in the past and the first to focus on documenting the range of materials available in both rock outcrops and alluvial settings. These surveys were not exhaustive, however, and many locations of high-quality rhyolites, obsidians, cherts, basalts, and other materials used by humans in Nenana valley have yet to be discovered (Coffman and Rasic 2015; Gore 2021; Graf and Goebel 2009; Malyk-Selivanova et al. 1998; Reuther et al. 2011). The ability to establish a greater number of geographical locations for unknown materials present in Alaskan assemblages would greatly add to reconstruction of technological organization and mobility systems of ancient Alaskans; therefore, these subjects warrant further exploration efforts. For example, at the Owl Ridge site, the early Holocene occupation focused almost exclusively on andesite. Future work should explore this volcanic toolstone.

Future work should focus on incorporating the entire range of toolstones within NRV assemblages. Undoubtedly this would contribute to better understanding of environmental influences on development and implementation of interior Alaskan toolkits through time and provide an integrative picture of toolstone selection patterns that will inform on behavioral differences and similarities within and between NRV site assemblages. Further, continued studies focusing on raw material and its movement within eastern Beringia on the whole will aid in clarifying interpretations of technological variability and landscape-learning scenarios (Graf and Goebel 2009).

Until this dissertation, geochemical data on non-obsidian, non-rhyolite materials in the NRV have been largely ignored despite their potential to inform on toolstone provisioning behaviors. Although rhyolite characterization has offered promising results and interesting pathways to pursue in future research, geochemical analysis of basalts in the NRV proved more complex and difficult in this specific regional setting. Given this, the incorporation of additional geochemical methodologies such as neutron activation analysis and inductively coupled plasma-mass spectrometry may reveal more informative and nuanced patterns of basalt procurement common in Alaskan assemblages. Further, expanded archaeological sampling within the NRV and in neighboring regions (e.g., the Tanana valley) is needed to characterize the full range of technological organization patterns evident in the record. Continued efforts to focus on the integration of technological, geochemical, and environmental studies are necessary to address lingering questions about the complexities of human-landscape interaction in interior Alaska.

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APPENDIX A

LITHIC TECHNOLOGICAL ANALYSIS

Artifact Class, Type and Size

The morphological and technological typology used to score artifact class and type incorporates definitions used by Andrefsky (1998, 2009), Graf (2010), Inizan et al. (1999) and Odell (2004). Artifact completeness was scored as complete or incomplete, and artifact size class was based on increments of 2 cm^2, increasing by this increment from size class 1-4.

Cores

Flake Core: A nodule of rock with detached pieces (flakes) removed and functions as a source for detached pieces. Types include unidirectional, bidirectional, multidirectional, or bifacial cores.

Bipolar Core: A nodule or core with flake removals that originate at opposite ends of the piece, showing evidence of compression: crushing on opposing ends of the piece, concentric ripple marks, concave or absent percussion bulbs.

Blade Core: A nodule of rock from which blades are removed as detached pieces. Types include unidirectional, bidirectional, and multidirectional.

Microblade Core: A core produced by selecting a core blank (such as a biface), removing a platform preparation spall from a lateral margin, and then removing another spall perpendicular to the platform to create the core front from which microblades are removed.

Assayed Cobble: Cobble that has been split or tested (exhibiting one or two flake removals), usually preserving at least 50% cortex on its surface.

Debitage

Technical Spall: Technical spalls are detached pieces produced during the preparation and/or rejuvenation of microblade cores and blade cores. Types include core tablets, ski spalls, crested blades, and rejuvenation spalls.

Cortical Spall: Cortical spalls are detached pieces possessing cortex on the dorsal surface. Primary cortical spalls are those with more than 50% cortex covering their dorsal surface; secondary cortical spalls are those preserving less than 50% cortex on their dorsal surface.

Flake: detached pieces preserving a bulb of percussion, platform (or partial platform), eraillure scar, and/or ripple marks; these are greater than $1cm^2$ in size and do not possess cortex.

Biface Thinning Flakes: detached pieces with low-angle, complex platforms (preserving 3 or more removal scars) or partial complex platforms indicative of removal from the edge of a biface.

Retouch Chip: detached pieces preserving all flake attributes but measuring less than $1cm^2$ in maximum dimension.

Blade: blades are defined as detached pieces with parallel margins and lengths twice their widths with triangular cross-sections produced by previous blade removals from the objective piece. Their widths are greater than 20 cm.

Microblade: Microblades are tiny, thin blades with parallel lateral margins and 1-4 dorsal ridges produced from previous microblade removals from the objective piece. Microblades typically measure 5-7 mm in width and 20-50 mm in length.

Angular Shatter: Blocky debris produced during tool or core production that does not possess dorsal or ventral surfaces or identifiable flake attributes.

Tools

Side Scraper: Unifacially worked blades or flakes with continuous and invasive retouch along one or more margins; retouched edges are usually steep.

End Scraper: Unifacially retouched pieces whose area of retouch is located along the distal margin; retouch is invasive and continuous.

Graver: A unifacial tool produced on a blade or flake with one or more intentionally manufactured spurs.

Burin: A unifacial tool produced on a flake with a chisel-edge produced by the removal of two spalls at right angles to one another.

Retouched Blade, Flake or Microblade: Blade, flake or microblade with one or more marginally retouched edge(s). Retouching is not invasive and is either continuous or discontinuous.

Notch: Unifacial tool with one margin retouched; the worked margin forms a discrete notch.

Denticulate: Unifacial tool with a series of small notches forming a serrated edge on the tool margin.

Wedge: Unifacial or bifacial tool with one or more narrow, acute-angled edge; rectangular shaped working edges.

Biface: Tool with two worked sides that meet to form a single edge. Types include ovate (oval shape), triangular (triangular shape), foliate (bipointed or leaf-shaped), teardrop (round base with pointed tip), amorphous (without defined shape), and lanceolate (expanding sides and lanceolate in shape with no shoulder or stem).

Cobble Tool: Tools produced on cobbles; types include hammerstones, anvils, choppers, and scraper-planes.

Combination Tool: Tools with a combination of tool margins. Types include scraper/plane; scraper/graver; graver/burin' scraper/biface; end scraper/ burin; retouched flake/graver; etc.

Raw Material Class and Type

Raw material class was determined by visual identification through comparison with hand specimens and macroscopic analysis (e.g., hand lens and 100x light microscope) and using definitions provided by Andrefsky (2009) and Odell (2004) Raw material types were determined based on visual inspection of color, cortex, inclusions, and texture. Color attributes (types) of each class were recorded using a Munsell Rock Color Book.

Chert/Cryptocrystalline Silicate: A sedimentary rock composed primarily of quartz silicate and very fine-grained texture typically not visually identifiable without microscopic techniques. Includes types colloquially known as chalcedony, agate, and jasper.

Macrocrystalline Silicate: Rock composed of quartz silicate with very-fine-grained but visually detectable texture.

Andesite: A fine-grained, intermediate igneous rock composed mostly of plagioclase and some pyroxene or hornblende. The extrusive form of plutonic diorite.

Basalt: A dark, fine-grained igneous rock low in silica and rich in magnesium and iron; the extrusive form of gabbro.

Dacite: A fine-grained igneous rock high in silica and intermediate in composition between andesite and rhyolite; composed mainly of plagioclase feldspar and quartz.

Rhyolite: A fine-grained, silica-rich volcanic rock composed predominantly of quartz, sanidine, and plagioclase; the extrusive form of plutonic granite.

Obsidian: An ultra-fine-grained, brittle, dark, glassy rock formed by the rapid solidification of felsic lava without crystallization; rhyolitic volcanic glass.

Quartzite: Generalized term for metamorphosed quartz sandstone.

Cortex Presence and Amount

Cortex is defined here as the chemical or mechanical weathered surface on rocks. Cortex presence was visually identified using a hand lens or light microscope (100x) Cortex amount was scored on a scale of 0 to 4, with 0 indicating no cortex, and 4 indicating 100% cortex presence.

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