AN ANALYSIS OF TACHYLYTE AND OTHER VOLCANIC GLASSES IN WASHINGTON ARCHAEOLOGY

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by

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Graduate Studies

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ABSTRACT

AN ANALYSIS OF TACHYLYTE AND OTHER VOLCANIC GLASSES
IN WASHINGTON ARCHAEOLOGY

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Within archaeological literature, a discussion of volcanic toolstones from Washington State is uncommon. Washington's volcanic glass landscape is relatively sparse, with low-quality sources scattered within and on the east side of the Cascades, including tachylyte, obsidian, and vitrophyric obsidian. Tachylyte is a volcanic glass that forms within low-silica, basalt flows while obsidian comes from high-silica, usually rhyolitic, eruptions. Vitrophyric is a textural term used to describe an igneous rock that has a glassy groundmass with conspicuously large crystals. The low-quality and dispersed nature of these toolstones are reflected in Washington's archaeological record by the more common occurrence of out-of-state volcanic glasses from Oregon and Idaho. The quality and abundance of these out-of-state sources has intrigued many researchers and studies but has ultimately left a gap in the literature that neglects to build a context for local, Washington State sources. After a reevaluation of x-ray fluorescence studies, 16 geochemically distinct sources were identified from Washington. This reevaluation included combination of three formerly distinct tachylyte sources (Cleman Mountain, Nasty Creek, Parke Creek) into a single source (Cleman Mountain) with five outcrop locations. An examination of the Northwest Research Obsidian Studies Laboratory

database as of 2020 showed 1,663 artifacts from 260 Washington sites with sourced volcanic glass, of which only 19.3% (323 artifacts) was materials from Washington sources. Out of the 12 Washington sources identified in these artifacts, vitrophyric obsidian was the most common glass type at 42%, followed by obsidian (37%), and tachylyte (21%) which likely represents a researcher bias when sending in samples. Four of the known sources have not yet been found in any geochemically analyzed artifacts. The source analysis showed little use of tachylyte outside of a local range of the source (<50 miles) while the appearance of Washington obsidian was more often found in sites considered non-local (>50 miles).

ACKNOWLEDGEMENTS

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Finally, I want to thank my daughter, Daphne Allen, who has literally been with me from my first day of class and has taught me that perfection is pointless and that being called “Mama” every day is better than finishing a thesis in two years.

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CHAPTER I

INTRODUCTION

Problem

The Pacific Northwest is home to some of the most spectacular sources of volcanic glasses in North America (Baxter et al. 2015; Connolly et al. 2015; Mack 2015; Reimer and Hamilton 2015; Stueber and Skinner 2015). However, current research does not give credit to the entirety of the volcanic glasses in the Pacific Northwest. Washington State has a variety of unique glasses (Figure 1) that has thus far received little attention in comparison to the abundance of research conducted on other Northwest sources. Home to obsidian, vitrophyric obsidian, and tachylyte, Washington's toolstone landscape has a vast amount of research potential that is currently starting to receive more attention from researchers (Kassa and McCutcheon 2016; Parfitt and McCutcheon 2017; McClure 2015; Mierendorf and Baldwin 2015). Many of these glasses have occurred in contexts outside what would be considered the local range of a toolstone source, (e.g., Connolly et al. 2015; McClure 2015; Reimer and Hamilton 2015) but because of their low representation in the archaeological record, have gone relatively unnoticed by Northwest archaeologists. This lack of research leaves a large data gap that, when addressed, could help continue to make connections about past population movement and trade networks.

Figure 1. Washington volcanic glass sources as of 2019 (Northwest Research Obsidian Studies Laboratory [NWROSL] 2019).

Purpose

The purpose of this research aims to add to the discussion concerning Washington volcanic glasses. Most recent work on Washington sources has focused on obsidian and vitrophyric obsidian (Galm 1994; Kassa and McCutcheon 2016; Parfitt and McCutcheon 2017; McClure 1989, 2015; Mierendorf and Baldwin 2015). Recently, two sources of Washington vitrophyric obsidian have been analyzed (Kassa and McCutcheon 2016; Mierendorf and Baldwin 2015) as has the Elk Pass obsidian source (McClure 1989, 2015). These studies are in contrast to tachylyte, which has received the least amount of analysis with only one study completed in the last 10 years (Parfitt and McCutcheon 2017). Therefore, part of my research will provide a more in-depth background on tachylyte via a macroscopic analysis and field recordation of sources similar to those conducted by other researchers for vitrophyric obsidian and obsidian (McClure 1989, 2015; Mierendorf and Baldwin 2015). Additionally, a spatial analysis of all volcanic glass occurrences in Washington archaeological assemblages will be conducted to better understand how these glasses fit into the larger lithic landscape of the Pacific Northwest. The following list details my five research objectives that lay the groundwork for achieving my purpose.

1) Research and establish the geologic and archaeological context of Washington's volcanic glasses.
2) Analyze and distinguish the raw material characteristics of the known tachylyte sources through a macroscopic analysis using a 40x microscope and established macroscopic analysis methods described by Parfitt and McCutcheon (2017).
3) Relocate, map, and collect samples at known tachylyte sources and send a selection of samples into the Northwest Research Obsidian Studies Laboratory (NWROSL) for XRF analysis.
4) Research the occurrence of Washington's volcanic glasses in archaeological assemblages to establish the extent of identified volcanic glass toolstone in Washington in relation to each other and to out-of-state volcanic glasses.

5) Analyze the distribution of Washington volcanic glass artifacts subject to XRF source analysis by NWROSL and their volcanic glass sources.

Significance

Much is known about the large, prolific obsidian sources of Oregon and Idaho (Carpenter and Fisher 2014; Connolly et al. 2015; MacDonald 2014; Reid 2014), but less is known about the smaller volcanic glass sources of Washington. Therefore, an analysis of these glasses is an integral part of our understanding of Washington's pre-contact landscape and the Pacific Northwest lithic landscape as a whole. There is a lack of literature concerning these glasses within the Pacific Northwest dialogue on toolstone movement and within the archaeological community at large. As a result, a large portion of this research will address this data gap and compile what is known about Washington tachylyte, vitrophyric obsidian, and obsidian, both in their geologic and archaeological context. Additionally, a spatial analysis concerned with the dispersal of Washington glasses throughout Washington's archaeological assemblages will contribute to the ongoing dialogue concerning trade patterns throughout the Northwest. Overall, this research is significant because it will bring under-represented toolstones to the forefront of archaeological research which will ultimately create a broader and more solid understanding of the lithic landscape in Washington State.

CHAPTER II

GEOLOGIC CONTEXT FOR WASHINGTON VOLCANICS

Geologic Context for Columbia Plateau and Cascades

Washington's unique topography is the result of several different geologic processes. However, the main geologic commonality between tachylyte, obsidian, and vitrophyric obsidian is their relation to the volcanic history present in the state. Within the state, these volcanic glasses are typically found on the Columbia Plateau of central Washington and within the heart of the northern and southern Cascades. All are from different types of eruptive processes that lead to a unique geochemical make-up and appearance and are discussed in more detail below.

Columbia Plateau

The Columbia Plateau is a geologic region heavily characterized by underlying flood basalts also known as the Columbia River Flood Basalt Province (CRFBP). These basaltic lava flows or floods came at varying times and intensities in the form of 350 flooding events over the course of 11.1 million years or from about 16.7 to 5.5 million years ago (Ma) (Reidel et al. 2013). The flood basalts cover approximately 210,000 km^3 of Washington and Oregon, in addition to areas of western Idaho and northwest Nevada (Reidel et al. 2013; see Figure 2). About 93% of the eruption took place over the course of 1.1 million years (16.7-15.6 Mya) and included five defined phases: Steens, Imnaha, Grande Ronde, Wanapum, and Saddle Mountains (Reidel et al. 2013). The Grande

Ronde Phase, which took place from about 16 to 15.6 Ma, lasted only 400,000 years but comprises 72 percent of all basalt on in the CRFBP with many floods reaching volumes of over 1,000 km^3 (Reidel et al. 2013). The thickest area of basalts is in the Columbia Basin and can reach up to 4 kilometers in depth (Reidel et al. 2013).

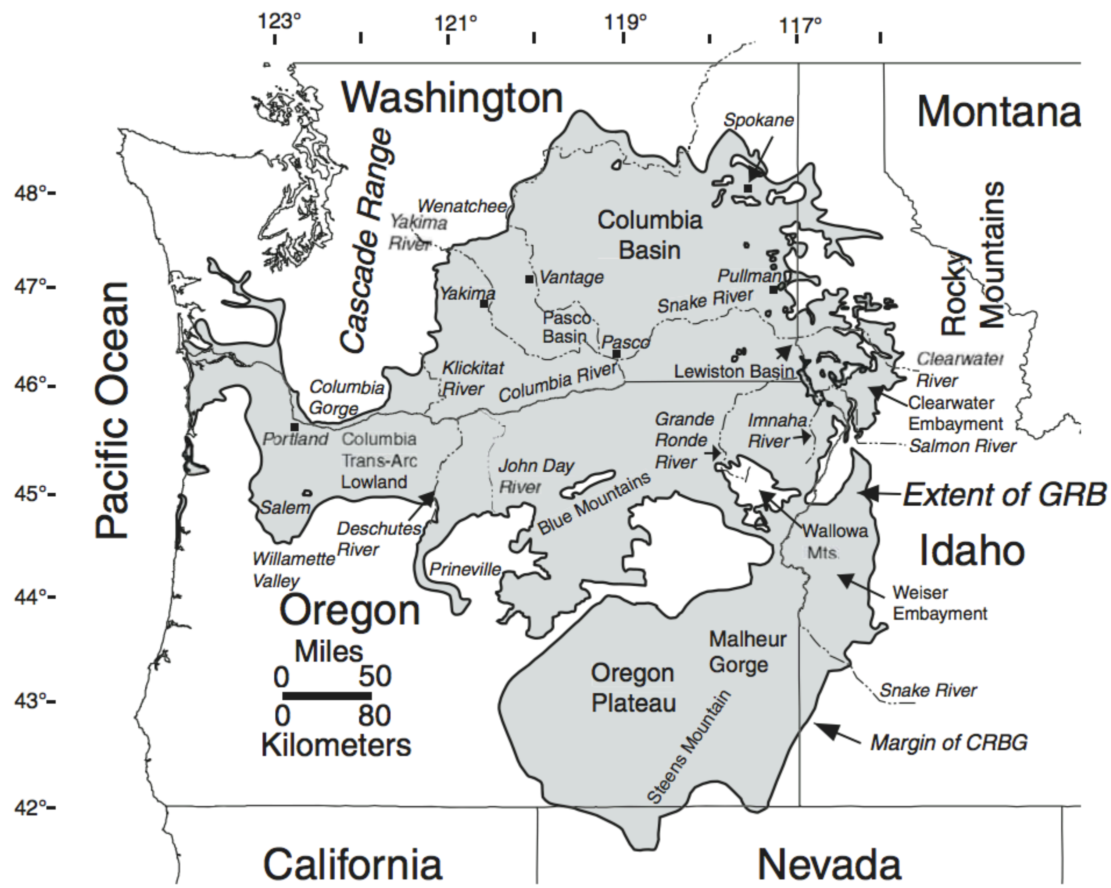


Figure 2. Columbia River Flood Basalt Province (USGS 2021a). This unit is also called CRBG (Columbia River Basalt Group). The Grande Ronde Basalt is denoted as "GRB".

Basalt, compared to other more silica-rich lavas, is less viscous and therefore can move at greater rates which can be upwards of 60 km/h towards the beginning of an eruptive event (Francis and Oppenheimer 2003:139). Once the lava has moved further away from the vent, the movement slows down as it cools, and it slowly becomes the consistency of molasses and reaches speeds of less than 1.5 km/h (Francis and Oppenheimer 2003). This leads to unique flow structures within the CRFBP that may look different at the beginning of the flow when it is moving rapidly than at the end after it slows down.

Understanding the flow structure of the CRFBP, and how the flow interacted with its environment while it was being erupted, is pertinent in understanding the occurrence of tachylyte within the CRFBP. Typical flows are made of five internal features; flow top, upper colonnade, entablature, lower colonnade, and flow bottom (Reidel et al. 2013; Figure 3). Within a flow structure, there are two likely locations that the eruptive event could make a glassy material (such as tachylyte): the flow top or the flow bottom, both of which have rapid cooling compared to the middle portions. The flow top is typically either vesicular in nature, meaning lots of bubbles present, or is angular, vesiculated basaltic rubble (Reidel et al. 2013:28). The flow bottom is dependent on the environment that the flow meets as it flows across the landscape. Basaltic glass or glass-like materials, in this context, are typically formed when the flow encounters water or sediments that lead to rapid cooling of the basalt (Reidel et al. 2013).

There are several theories for the mechanism of tachylyte formation. Researchers such as Ozbun (2015) and Skinner (2009) suggest tachylyte formed at the front of a basalt flow within the context of pillow basalts and formed during the quick reaction that water typically has with lava. However, Fisher and Schminkce (1984) argue that such glass typically weathers quickly into palagonite which would ultimately not be conducive for use as a toolstone. Additionally, if tachylyte were part of pillow basalt creation then

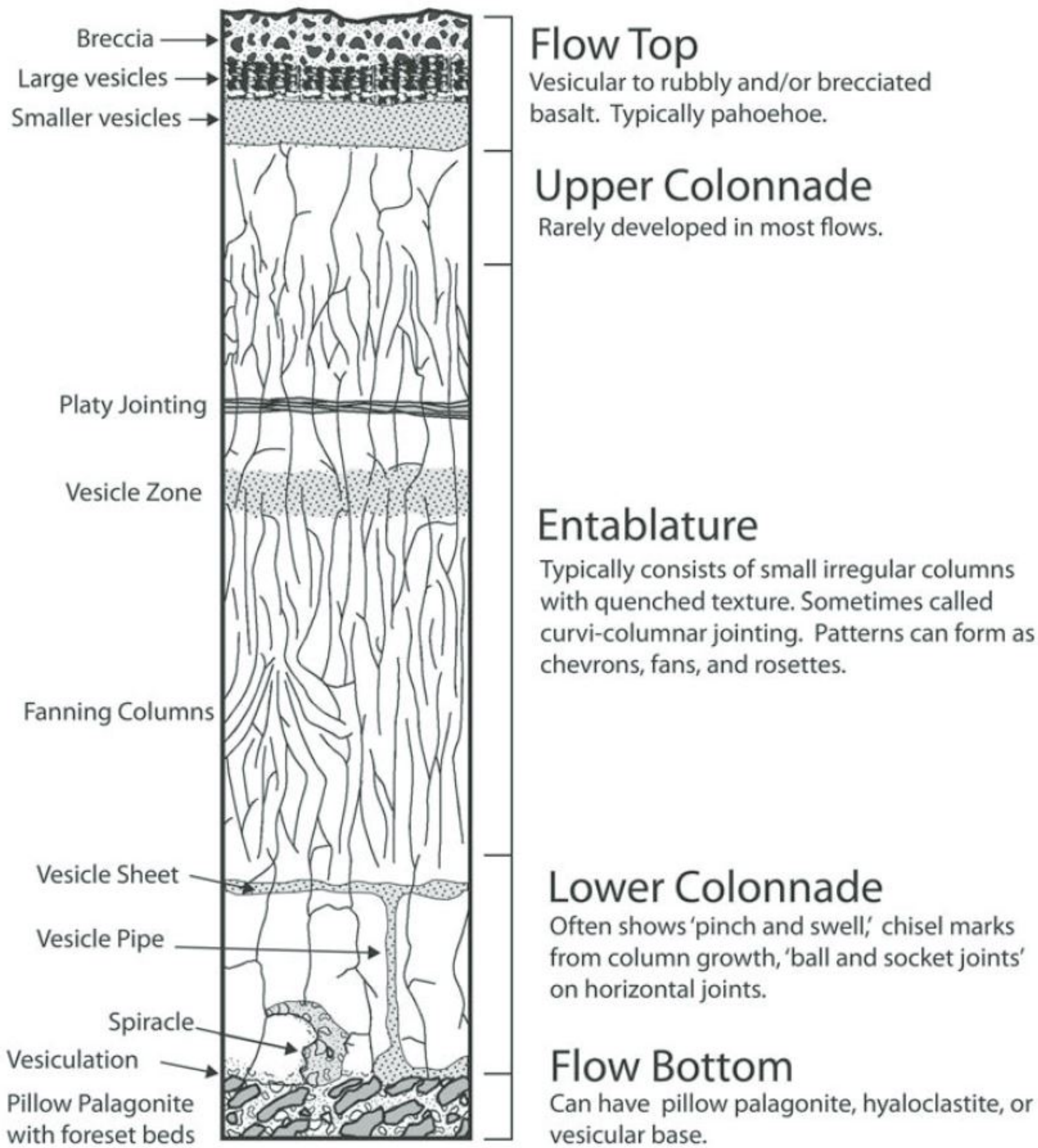


Figure 3. Internal Structure of a Columbia River Basalt Group flow (Reidel et al. 2013:Figure 14).

we would only be finding it at the front of flows, however, some researchers state that glassy materials are also found on top of basalt flows as rafted sediments (Reidel et al. 2013:32; Jack Powell, personal communication 2019). Due to the ongoing discussion amongst geologists and archaeologists alike, the exact mechanism for toolstone grade quality tachylyte is not yet fully understood.

In addition to attempts on pinning down the exact geologic context in which tachylyte forms, many researchers struggle within pinning down an appropriate definition of tachylyte. Early work by Peacock and Fuller (1928:373) on the CRFBP, specifically define tachylyte as "deep-brown, turgid, dohyaline, chilled selvages of basic intrusive bodies." However, the American Geological Institute's *Dictionary of Geological Terms* (Bates and Jackson 1984:352) simply states that it is a "volcanic glass of basaltic composition" and that it is synonymous with sideromelane. This statement directly contradicts Peacock and Fuller's (1928) work who state that tachylyte differs from sideromelane in that tachylyte is microcrystalline and not a pure glass like sideromelane. Fisher and Schminkce (1984) consider tachylyte a microcrystalline basalt, not a glass, and term the glass that forms on the outside of rapidly cooled lava as it makes contact with water "palagonite." These differences amongst geologist's definitions of tachylyte make it difficult for other professionals, such as archaeologists, to properly define this material type.

Within the archaeological community, the term "basaltic glass" is reasonably synonymous with tachylyte even if the geological community differs, to some extent, in this regard. Additionally, I have also heard of archaeologists calling tachylyte "black chert." Regardless of this difference of opinions, within this thesis I will be using "tachylyte" to describe the glass that comes from low-silica, basalt flows (Figure 4).

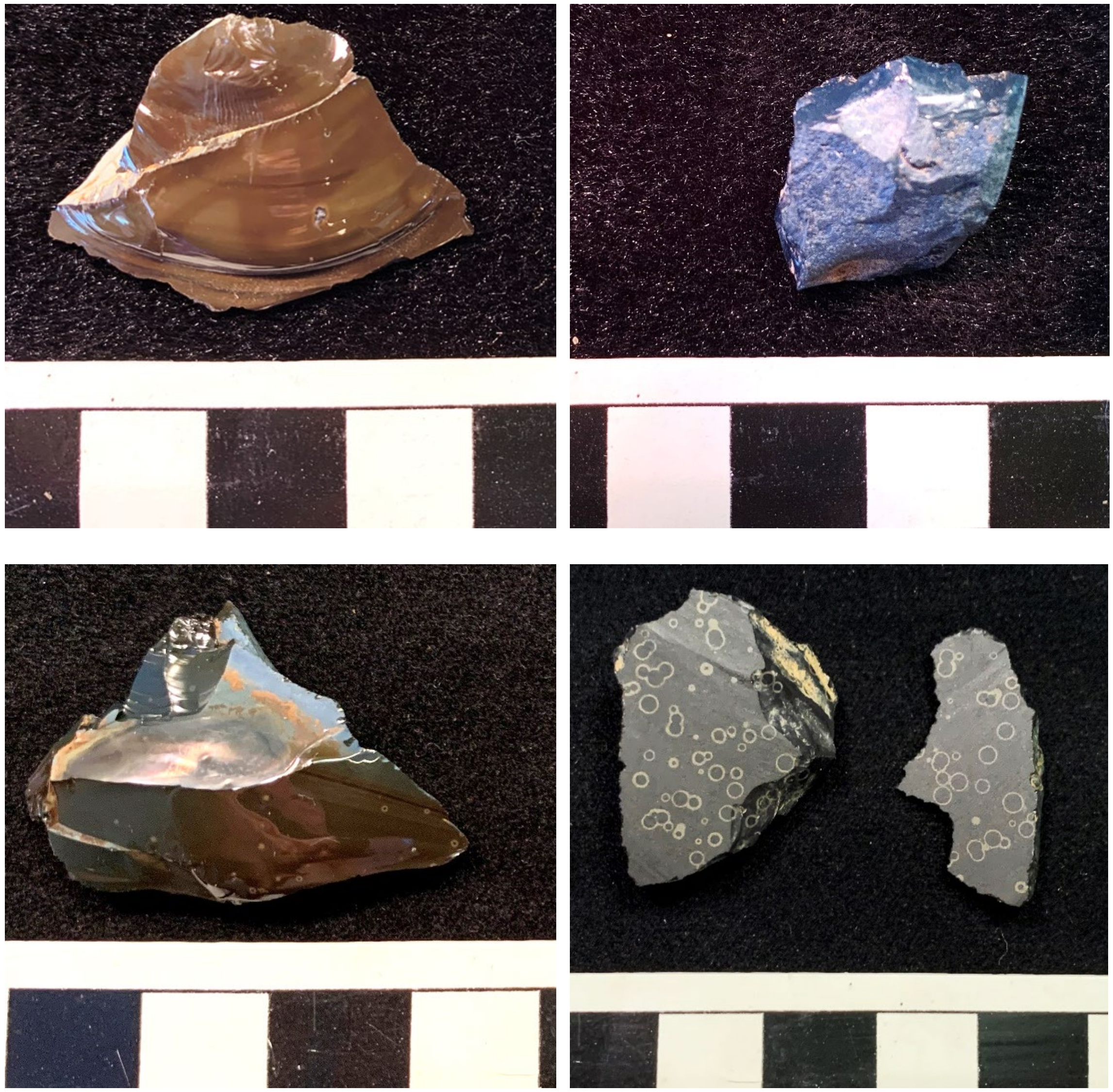


Figure 4. Examples of geologic samples of tachylyte. Note rock saw marks present on bottom right sample.

Cascades

Much of the Washington Cascades mountain range that we see today (the "High Cascades") was formed by volcanic activity that started approximately 4 Ma (du Bray and John 2011). This occurred after the CRFBP flows but was preceded by about 40 million years of ancestral Cascade magmatism (du Bray and John 2011). The ancestral

Cascade magmatism, as well as the High Cascade magmatism, commonly erupted magma that was rhyolitic, andesitic, and sometimes basaltic in nature (du Bray and John 2011). The rhyolitic flows, due to their high amount of silica, sometimes produced volcanic glasses, such as obsidian and vitrophyric obsidian, that was later used by Native Americans people to create tools. Although magmatism has been consistent throughout the last 4 million years, the volcanoes such as Mount Rainier, Mount Adams, and Mount Hood, have been erupting for the last 500,000 years with an average of two eruptions per century in the last four thousand years (Myers and Driedger 2008). The cause of the volcanism in the Cascades is due to the subduction of the oceanic crust (Juan de Fuca Plate) off the West Coast as it goes under the North American Plate (United States Geological Survey [USGS] 2021b, c; Figure 5). This subduction releases water that causes the overlying mantle to partially melt thus resulting in the volcanoes that we see today (USGS 2021c). Ultimately, some of these eruptions have resulted in the right type of conditions that produced the creation of obsidian and vitrophyric obsidian which will be discussed below.

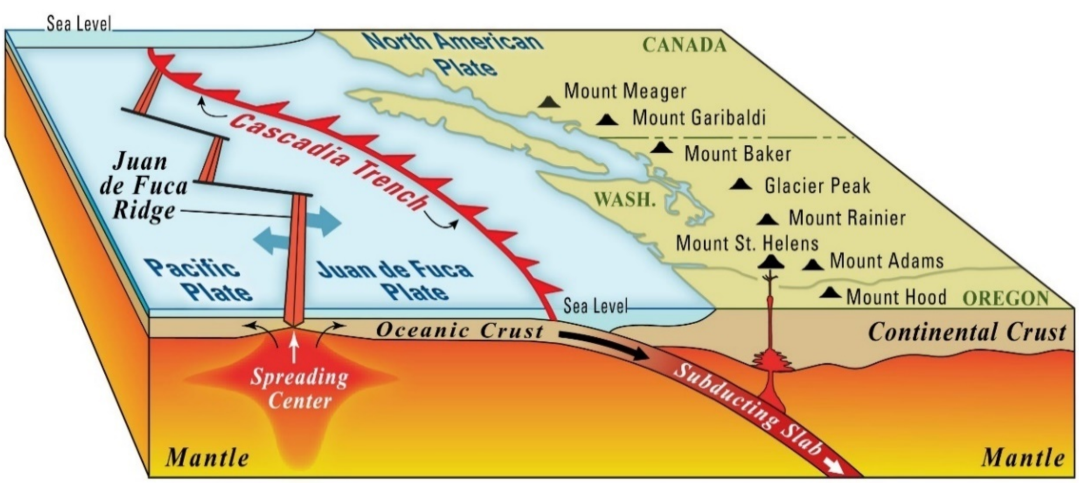


Figure 5. Subduction of the Juan de Fuca Plate beneath the North American Plate (USGS 2021c).

Obsidian, as defined in this thesis, is a glassy volcanic rock, usually of rhyolitic composition, and is characterized by a high silica content and low water content (Bates and Jackson 1984; Gill 2010). Obsidian flows are not all that geologically common given that highly silicic lavas will more likely turn into pyroclastic explosions than have the viscosity to flow like lava (Francis and Oppenheimer 2003). In fact, they are so infrequent, that an eruption that has resulted in an obsidian deposit has not been witnessed in historic times, other than a single underwater event, so the most that can be surmised about these eruptions is gleaned from geologic deposits and the subsequent spread of ash (Francis and Oppenheimer 2003). The single underwater event from 1953-1957 created the Tuluman Islands off the north coast of Papua New Guinea but considering that it was an underwater eruption and a small one at that, there was not much that could be observed (Francis and Oppenheimer 2003:162). Other eruptions in the more recent, but unrecorded, past include the Newberry Volcano eruptions in Oregon and the Medicine Lake eruptions in California (Francis and Oppenheimer 2003).

Not all rhyolitic eruptions lead to obsidian flows – the conditions for such a flow are unique and take place infrequently due to a variety of geologic factors. A rhyolitic eruption that leads to an obsidian flow typically separates into six layers with different viscosities and densities and has a high silica content. The bottom three layers are emplaced during the initial explosive eruption and are characterized by a tephra layer, a basal breccia layer, and a pumice layer (Francis and Oppenheimer 2003). The overlying layer is the main body of the obsidian and can vary in size, color, and folding patterns depending on the characteristics of the eruption itself (Francis and Oppenheimer 2003).

The top two layers of a typical obsidian flow are fine pumice and surface breccia. The layer that contains obsidian in the form of volcanic glass, is the middle layer which is formed due to the different densities and mixing of the magma in the chamber (Francis and Oppenheimer 2003).

The word "vitrophyre" or "vitrophyric" is used to describe any igneous rock with a porphyritic texture, i.e. conspicuous crystals or phenocrysts in a glassy groundmass (Bates and Jackson 1984). This loose definition essentially means that both tachylyte and obsidian could be called vitrophyric considering both are igneous and both could possibly contain phenocrysts within a glassy groundmass. Within the state of Washington, there are five obsidian sources that have been dubbed as "vitrophyric obsidian" and have been categorized as such throughout this thesis. These are distinguished from non-vitrophyric obsidians, which may simply be referred to as "obsidian" in this thesis.

Within the archaeological community there have been some other loose, albeit incorrect, uses of the term vitrophyre. Some researchers claim that the term vitrophyre is interchangeable with the word ignimbrite. However, ignimbrite is a rock type unto its own and is defined in the American Geological Institute's *Dictionary of Geological Terms* (Bates and Jackson 1984:254) as "the rock formed by widespread deposition and consolidation of ash flows…". Additionally, many archaeologists simply dub vitrophyre as a rock type and do not consider that it is a textural term only. In this thesis, I will use the phrase "vitrophyric obsidian" instead of the term of "vitrophyre" in order to start dispelling some of the confusion with the nomenclature surrounding this term.

Although not inherently part of the creation of volcanic glasses in Washington State, glaciation played a key role in the exposure of volcanic glasses located in high mountain ranges or passes. The North Cascades are known to currently contain over 350 glaciers (Pelto 2021) which is minimal compared to the glaciation present in the past several millennia which extended into the Columbia Plateau of north central Washington (USGS 2016; Figure 6). Glaciation began about 2.4 Ma and the northern and central part of Washington State has been through a series of ice ages since that time (Pelto 2021). As glaciers recede, they scrape the surrounding mountain landscapes and expose the underlying bedrock, which at times can contain types of toolstone that would have been used by Native American people.

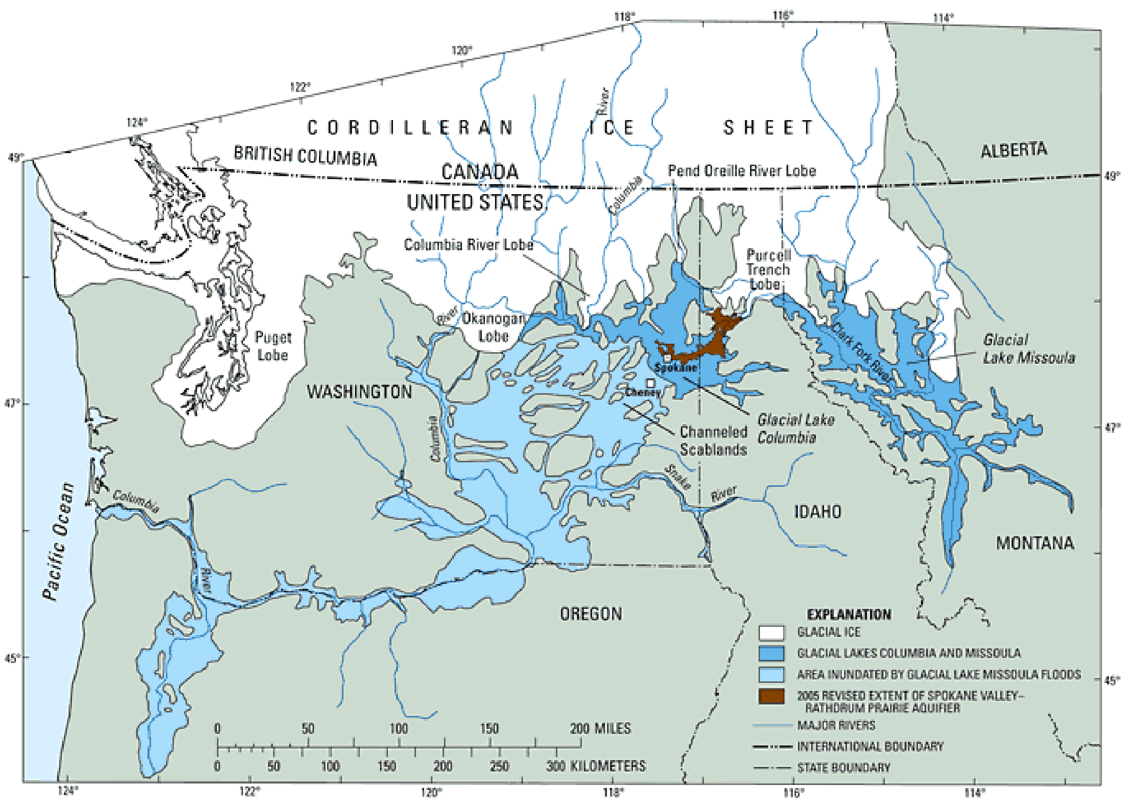


Figure 6. Extent of glacial ice in Washington State and surrounding area (USGS 2016; Figure 4). Also shown are glacial lakes and extent of glacial outburst floods.

CHAPTER III

CULTURAL CONTEXT OF WASHINGTON VOLCANICS

The majority of volcanic raw material sources covered in this thesis are located at the western margins of the Columbia Basin and within the Northern and Southern Cascade physiographic provinces (Figure 7). The Cascades lie between two major archaeological research traditions, the Northwest Coast to the west and the Plateau to the east. The primary locations of the raw material sources are on the east side of the Cascade Range so I will be mostly be focusing on the Columbia Basin-Cascade interface within the Plateau culture area of Washington State with a brief mention of the Central and South Coast Salish.

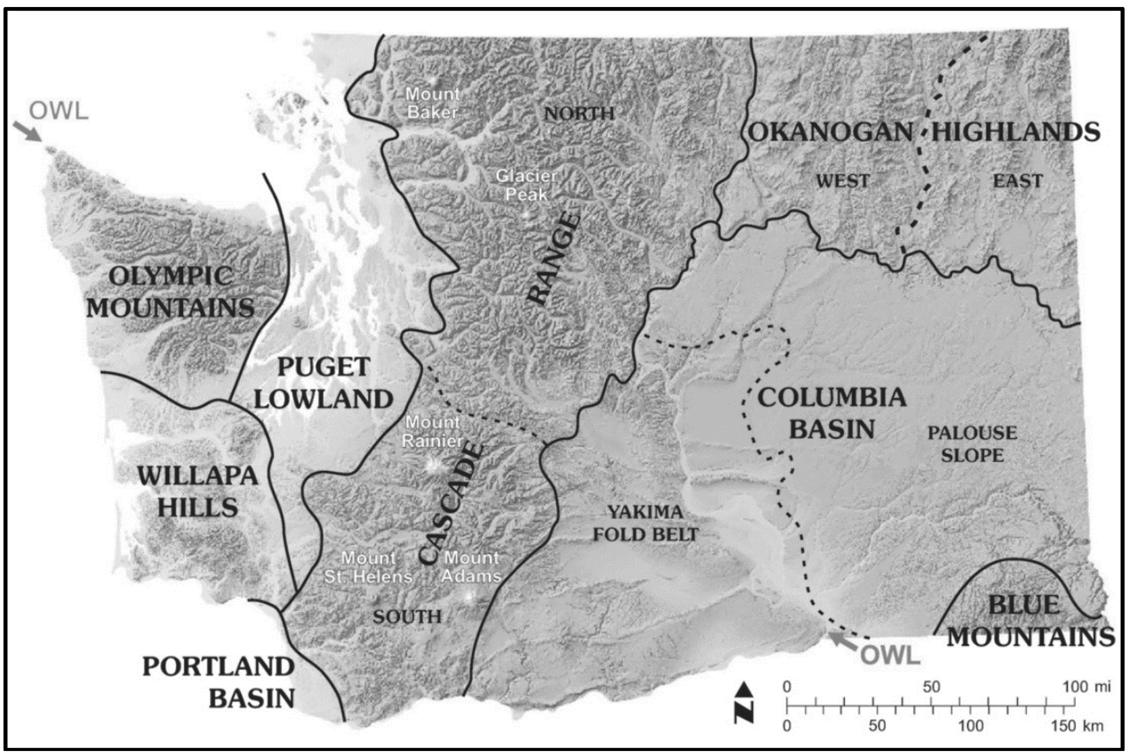


Figure 7. Physiographic provinces of Washington State (Washington State Department of Natural Resources 2021)

Ethnographic Background

Given that the entirety of Washington State will be discussed in the context of the dispersion of the volcanic glasses, I will be limiting the focus of the tribes discussed to those that had territories which overlapped the source locations (Table 1). The area covered in this study comprises almost the entirety of Washington, therefore it is necessary to describe the cultural regions broadly and within a physical context. There are three physiographic provinces most relevant to this study: North Cascades, South Cascades, and the Columbia Basin (see Figure 7). The physiographic areas are referenced to provide a physical context for the cultural traditions functioning within certain landscapes.

Table 1. Tribal Territories that Overlap Volcanic Glass Sources

Physiographic Province	Tribal Territory	Sources Potentially Encountered
Northern Cascades	Central Coast Salish	Copper Ridge Vitrophyric Obsidian
	South Coast Salish	Copper Ridge Vitrophyric Obsidian
Columbia Basin	Confederated Tribes of the Colville Reservation	Agnes Creek Obsidian Chelan Butte Vitrophyric Obsidian Douglas Creek Tachylyte Cleman Mountain Tachylyte (Parke Creek Outcrop) Stray Gulch Tachylyte
Columbia Basin and Southern Cascades	Yakama and Neighboring Groups	Stray Gulch Tachylyte Cleman Mountain Tachylyte Cleman Mountain Tachylyte (Manastash Ridge Outcrop) Cleman Mountain Tachylyte (Parke Creek Outcrop) Cleman Mountain Tachylyte (Nasty Creek Outcrop) Cleman Mountain Tachylyte (06-17-08-238/613 Outcrop) Elk Pass Obsidian Satus Creek Obsidian Indian Rock Obsidian (Unknown Variety A) Hosko A and B Obsidian Bickleton Ridge Obsidian Yakima Obsidian

Within the context of these physiographic provinces there are several cultural traditions present. The Central and South Coast Salish are within the Northern Cascades province. These groups are the most likely groups to access the Copper Ridge vitrophyric obsidian because their traditional lands (Suttles 1990:454; Suttles and Lane 1990:486) overlapped the areas where this source is located (Mierendorf and Baldwin 2015). The Confederated Tribes of the Colville Reservation (CTCR) are composed of 12 tribes that encompassed a large swath of central Washington, southern British Columbia, and northeastern Oregon (Johnson 2021). The sources of volcanic glass that they likely accessed included Agnes Creek obsidian, Chelan Butte vitrophyric obsidian, Cleman Mountain tachylyte (Parke Creek outcrop), Douglas Creek tachylyte, and Stray Gulch tachylyte (Figure 8). Yakama and neighboring group traditional lands contain all of the other sources (Bickleton Ridge obsidian, all four outcrops of the Cleman Mountain tachylyte, Elk Pass obsidian, Hosko A and B obsidian, Indian Rock [Unknown Variety A], and Satus Creek) in addition to two sources (Cleman Mountain tachylyte [Parke Creek outcrop], and Stray Gulch tachylyte) that overlap with the CTCR (Figure 9).

The cultures present in these areas are all unique, but a detailed discussion of lifeways, traditions, and customs will not be given here. Considering this research is focused heavily on the dispersal of the different volcanic glass across the Washington State landscape, the discussion will focus on trade, trade routes, and trade hubs. The ethnographic record makes little mention of chipped stone raw material sources, so the focus is on exchange more generally. Additionally, a discussion of different theories relating to the movement of trade goods and artifacts will also be provided.

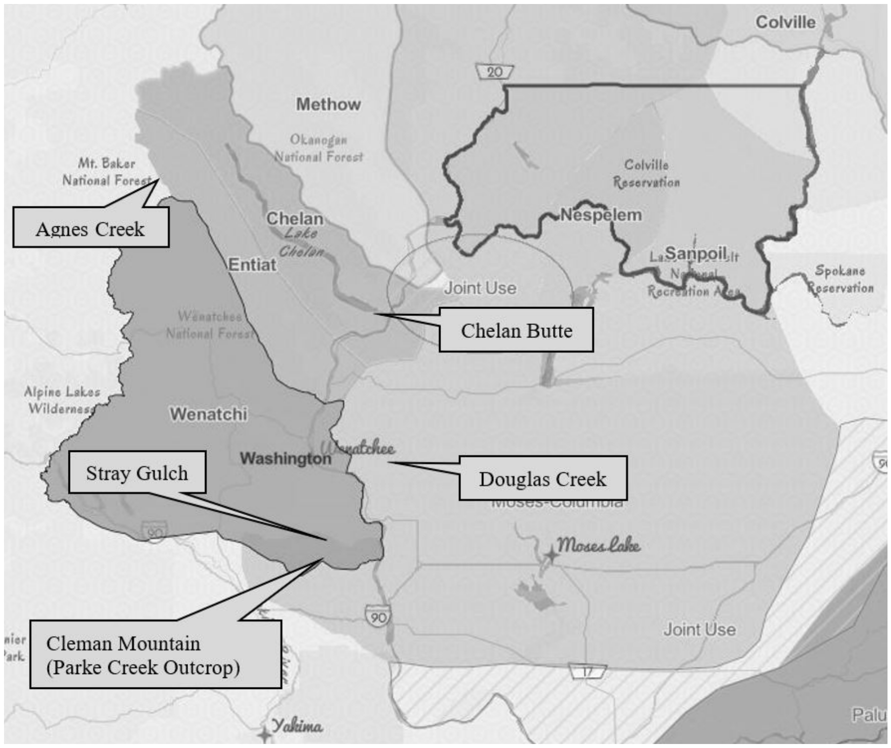


Figure 8. Volcanic glass source locations within Confederated Tribes of the Colville Reservation traditional territories (adapted from Johnson 2021).

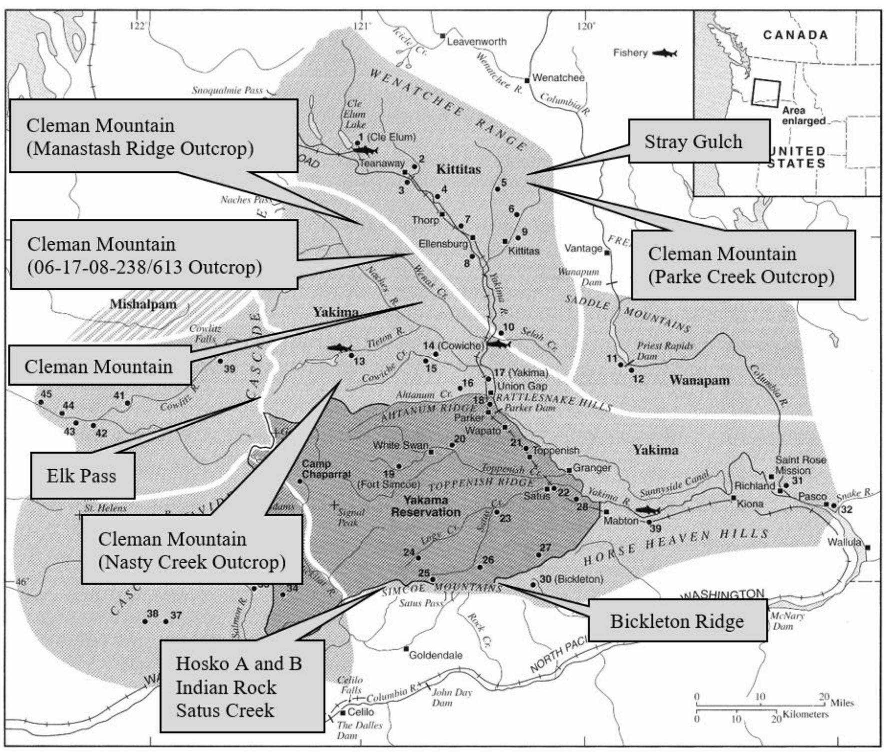


Figure 9. Volcanic glass source locations within Yakama and neighboring groups tribal boundaries (adapted from Schuster 1998:Figure 1).

Trade Networks in the Pacific Northwest

The movement of toolstone throughout the state of Washington, specifically the east side of the Cascades, is pertinent to developing the context of this thesis. Much of the movement of the different toolstones can be explained, at least partially, by the ethnographic and pre-contact trade systems that were present before the appearance of Euro-Americans. The following discussion focusses primarily on the known trade networks that were present in the Northwest during ethnographic times.

A vast trade system spanned the entire Northwest called the Columbia River trade network (Stern 1998:641-643). The heart of this network was centered in the villages between the Cascades and Celilo Falls, near The Dalles, in Oregon near the southern border of Washington on the Columbia River (Hunn 1990:368; Stern 1998:641-642). The trade network had several major hubs throughout the interior Northwest and extended into Wyoming (Figure 10). Goods were brought and traded at The Dalles from all over the region, including high-grade obsidians from Oregon (Hunn 1990). There were several different groups that were utilizing this trade system by the time that Lewis and Clark wrote about it on their expedition (Stern 1998:641). These groups include Native Americans that controlled the portages around the falls and other river passages through the Cascades, the people from the lower Columbia River and coastal areas, and groups from the Western Plateau and eastern foothills of the Rocky Mountains that came seasonally to trade (Stern 1998). Much of what was traded at one place would often be exchanged elsewhere again (Stern 1998:642), this in turn would allow trade items, such as obsidian, to travel long distances through social networks.

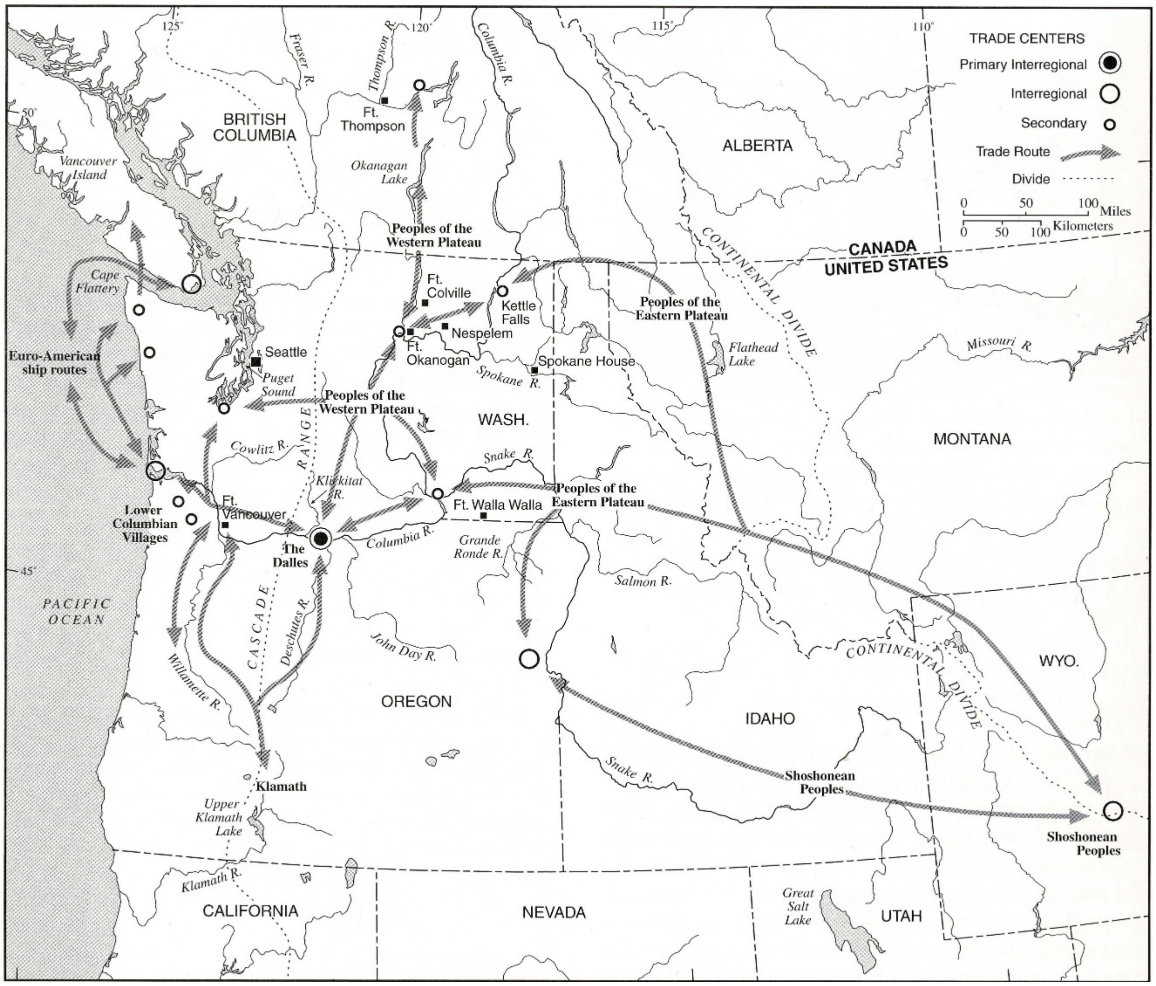


Figure 10. The Columbia River trade network (Stern 1998:642).

In addition to the more generalized Columbia River trade network, there has been suggestion of a Plateau Interaction Sphere (Hayden and Schulting 1997; Minor 2013; Quinn 2006). Originally hypothesized by Hayden and Schulting (1997), the Plateau Interaction Sphere involved a hierarchical group of elites that controlled the acquisition and dispersion of prestige goods such as obsidian, slaves, nephrite, domesticated dogs, etc. and was based out of two large, well-known trade hubs: the Dalles on the Columbia River and the Lillooet-Lytton on the Fraser River. Trade partnerships and control of prestige items amongst the elites accounted for the dispersion of these goods throughout the region and the similarities that are seen between the northern and southern people on the Columbia Plateau (Hayden and Schulting 1997).

Minor (2013) specifically looks at the obsidian from the archaeological sites at the Dalles in order to support the emergence of the Plateau Interaction Sphere around 2500 BP. By using obsidian hydration dating Minor (2013) deduces that obsidian appears in sites at and near the Dalles as early as 9000 BP. However, the sites containing obsidian and other associated prestige goods before 3500 BP are sparse and not frequent enough to claim that the Plateau Interaction Sphere starts before this time (Minor 2013). Based on the occurrence of Great Basin obsidian into the northern reaches of Washington State, it most likely that the Interaction Sphere did not fully take hold until after 2500 BP (Minor 2013).

In contrast to Hayden and Schulting's (1997) and Minor's work, Quinn (2006) speculated that the dispersion of prestige items could be more easily attributed to the evolutionary benefits of an extensive trade and exchange system. By using the appearance of certain trade goods, like obsidian, throughout archaeological sites on the Columbia Plateau, Quinn (2006) emphasized the importance of an extensive trade and exchange network that functioned through "signaling theory." "Signaling theory" is a combination of "costly behavior and public generosity" that can be briefly described as an individual showing off and sharing their wealth with other individuals in order to gain reciprocal relationships and form coalitions (Quinn 2006). Although similar in tone with the idea of the Plateau Interaction Sphere, the "signaling theory" allows for less emphasis on elite control of prestige goods on the Columbia Plateau and emphasizes that the appearance of prestige items in other areas outside of the main trading hubs indicates that costly signaling behavior and public generosity was happening outside of the elite control and that the benefits were seen on all levels of society.

Most of the obsidian that is discussed in the previous four studies (Hayden and Schulting 1997; Minor 2013; Quinn 2006; Stern 1998) is limited to the higher quality obsidians of Oregon and Idaho. The authors' assumptions that the obsidians within these studies are from out-of-state sources from the Great Basin help provide the proof they need in order to support their theories on large trade and exchange systems or trade networks. Although aspects of these theories are likely accurate on a larger scale, there are other studies that have looked at the more localized exchange of Washington glasses. For example, one of the passes commonly used by Native American peoples in the North Cascades is Whatcom Pass (Mierendorf and Baldwin 2015). This pass has been specifically noted as a likely area where Copper Ridge Complex was accessed and transported from its high elevation outcrop (Mierendorf and Baldwin 2015). The Chelan Butte vitrophyric obsidian source has been thoroughly dispersed throughout the middle and upper Columbia River reaches from its source location (Kassa and McCutcheon 2016). Additionally, the outcrop for Elk Pass obsidian was likely accessed and material transported during seasonal hunting forays down the Upper Cowlitz River drainage (McClure 2015).

Archaeological Context of Washington Volcanic Glasses

Previous research concerning Washington State volcanic glasses has primarily focused on single sites or sources of volcanic glass (Adams 2015; Kassa and McCutcheon 2016; McClure 2015; Mierendorf and Baldwin 2015; Parfitt and McCutcheon 2017; Reid et al. 2015; Smits and Davis 2015). In the following sections, I will briefly summarize the research that has been conducted so far concerning the three types of volcanic glass discussed in this thesis: tachylyte, obsidian, and vitrophyric obsidian. Because Chapter VI is a discussion of artifact distribution by volcanic glass source in the state from the NWROSL database, and a synthesis of known work on each source, there is some overlap between the current section and that chapter.

Archaeological Record of Tachylyte in Washington State

Out of the three different material types, tachylyte is the least represented archaeologically. It is not common to find it in archaeological sites which makes it difficult to discuss at length. Further complications on the sparsity of tachylyte in the archaeological record revolve around how difficult it is to distinguish from other stone tool materials. I believe tachylyte is often confused with crypto-crystalline silicate (CCS) artifacts and because CCS cannot be sourced to its original location via XRF analysis, researchers typically dismiss additional data potential from these artifacts past projectile point shape, size, or residue analysis, not knowing that it also has XRF analysis potential. Additionally, there is not enough information in the literature that specifically identifies the differences between CCS, tachylyte, obsidian, and vitrophyric obsidian which unintentionally leaves researchers without the proper resources to make accurate identifications of the stone tool material types within their collections.

Nomenclature is also a significant issue with tachylyte. Oftentimes, tachylyte is called obsidian (e.g., Kassa and McCutcheon 2016; Skinner 2009). While this may be technically correct, given that Merriam Webster's definition of obsidian is "a dark natural glass formed by the cooling of molten lava" (Merriam-Webster 2021), it leads to confusion when trying to describe specific characteristics of rock types that may only vary by silica and water content. Both of these terms are described and defined in the previous chapter. The confusion between tachylyte and obsidian is understandable given the many shared characteristics between the two stones. However, if the difference between these two materials remains obscurely defined in the literature, both academic and field archaeologists alike will continue calling tachylyte a variety of names (e.g. obsidian, basalt glass, black chert).

Previous archaeological analyses discussing tachylyte is limited. Within a recent book on the toolstone geography in the Pacific Northwest (Ozbun 2015), there is only one mention of tachylyte:

> Basaltic glass could also be called obsidian in some instances because of its texture, but is more often called tachylyte or tachylite to distinguish its relatively low silica content and geochemistry. Because its low viscosity melt does not inhibit crystallization during cooling, tachylyte generally forms as thin rinds at the margins of basalt flow sills and dikes where it cools more quickly than crystals can form (James et al. 1996:95). These rinds are often too thin for use as toolstone

but occasionally exceed 5 mm in thickness and are suitable for technological purposes (e.g. Weisler 1990) [Ozbun 2015:4].

One study has discussed the presence of tachylyte in more detail (Parfitt and McCutcheon 2017) and is summarized below. Other than this article, other references to tachylyte are limited to researchers discussing what they received from their XRF analyses with no discernment between the obsidian and tachylyte artifacts (e.g., Mack et al. 2010; Schumacher and Burns 2005). Ultimately, this revelation concerning the lack of information about tachylyte within the archaeological literature is not all that surprising considering how rare tachylyte is on the Columbia Plateau.

Parfitt and McCutcheon (2017) discuss the Grissom archaeological site (45KT301) and how the volcanic glass variation at the site indicates the likely presence of a trade hub. At this site, there were 10 different volcanic glass sources represented, both local (< 50 miles: Douglas Creek and Stray Gulch tachylyte) and nonlocal (> 50 miles: Indian Rock [Unknown Variety A] and Bickleton Ridge obsidians in southern Washington, and six other obsidian sources from Oregon and Idaho). The study compared the abundance and diversity of sourced lithic artifacts from the Grissom site to three other sites in the southern Cascades: Beech Creek (45LE415), Sunrise Borrow Pit Ridge Site (45PI408), and the Tipsoo Lake site (45PI406). Of these four sites, only the Beech Creek and Grissom sites had artifacts from any tachylyte source, only Cleman Mountain from Beech Creek, and two sources from Grissom site (Stray Gulch and Douglas Creek). Parfitt and McCutcheon (2017:49) found that out of the four sites, only data from the Grissom showed a correlation of rank order artifact weight and distance to source, implying the "monotonic decay curve" model, proposed by Renfrew (1977), is correct and "sources farther away from the Grissom site occur in lower weights than closer sources." However, they mention that this correlation was weak and that there was likely something else influencing the data that could not be directly tested.

There has thus far been little research concerning the Cleman Mountain tachylyte source. One study of the Beech Creek site (Mack et al. 2010) listed a piece of Cleman Mountain tachylyte within the archaeological collection. Through XRF and obsidian hydration dating, Mack et al. (2010) observed that volcanic glass source diversity decreases over time at the site and the assemblage is almost exclusively composed of local obsidians. Other than this observation from a single study containing Cleman Mountain tachylyte, there has been no other research specifically involving this source.

Archaeological Record of Obsidian in Washington State

As discussed above, all volcanic glass can technically be described as obsidian; however, in this thesis, I will only be referring to obsidian as the type of volcanic glass that occurs during a rhyolitic eruption that contains a high silica content. All of the obsidian sources are located within areas that would have been frequented by pre-contact peoples and their lack of appearance within the archaeological record is not a reflection on their lack of potential use in the past, but more of a reflection on the need for researchers to submit more volcanic glass for sourcing.

McClure (1989, 2015) published detailed analyses of the Elk Pass obsidian in the Upper Cowlitz watershed. Elk Pass obsidian was likely accessed by the Taytanpan people of this area during seasonal hunting forays. The dispersion of this obsidian is almost exclusively limited to the Upper Cowlitz watershed which is thought to reflect the poor quality of the obsidian which has numerous phenocrysts throughout the matrix. This obsidian also only occurs in small outcrops making intentional forays to obtain this material unlikely given its scattered and sparse geologic context.

Four other obsidian sources, Bickleton Ridge, Hosko B, Indian Rock (Unknown Variety A), and Yakima, are all located within Klickitat County in the Simcoe Mountains near Satus Pass. These sources have seen little to no research conducted concerning their context in the larger toolstone landscape of Washington State. The Yakima source was collected on the Yakama Reservation by Greg Cleveland however the exact location of the source is unknown (Gleason et al. 2017). Bickleton Ridge, Hosko B, and Indian Rock (Unknown Variety A) have also seen little to no research. Geologic source samples from Indian Rock (previously known as Unknown Variety A) were first sent to NWROSL by Dave Powell in 2004 (Craig Skinner, personal communication 2021). More ground truthing of this location was conducted again in 2016 (Gleason et al. 2017). Gleason et al. (2017) presented their fieldwork findings at the 2017 Northwest Anthropological Conference and discussed the widespread occurrence of the Indian Rock source throughout the state of Washington.

Archaeological Record of Vitrophyric Obsidian in Washington State

There are two sources of vitrophyric obsidian that have been found in Washington State: the Copper Ridge Complex and Chelan Butte source. Copper Ridge Complex material is located in the north Cascades near the Canadian border (Mierendorf and Baldwin 2015) while the Chelan Butte source is speculated to be located along the Columbia River, south of Wenatchee (Kassa and McCutcheon 2016). Briefly, vitrophyric obsidian is differentiated from obsidian due to the large amount of phenocrysts present (Bates and Jackson 1984) Additionally, vitrophyric obsidian has sometimes been referred to as ignimbrite or vitrophyre depending on where the archaeology investigations are being conducted (Lee Sappington, personal communication 2020; Craig Skinner, personal communication 2020).

A detailed analysis was conducted on the Copper Ridge source that discussed the dispersal and trade networks associated with the source (Mierendorf and Baldwin 2015). In this study, the authors sought to answer three questions pertaining to the Hannegan Volcanic Complex (vitrophyric obsidian source) and the Hozomeen chert complex. For the sake of this research, I will only be focusing my discussion on the Hannegan Complex and referring to it as Copper Ridge Complex. Through their research, they suggest that the Copper Ridge Complex source was only accessed in the last 4,000 years. The Copper Ridge source is along a high alpine trail that would likely have only been accessed on hunting forays into the area. Vitrophyric obsdian is typically found in small sites within a short distance to the source but has, on occasion, shown up at sites further away suggesting a “down-the-line" transmission (Mierendorf and Baldwin 2015).

The Chelan Butte source was briefly described by Galm (1994) and discussed recently within Kassa and McCutcheon’s (2016) article. The authors chose a sample of 656 volcanic glass artifacts from 18 different sites that represent the Northern reaches of the Mid-Columbia Plateau near Lake Chelan and Brewster in Washington State. Using a variety of statistical tests, XRF analysis, and paradigmatic classifications they found that the use of Chelan Butte, considered the local source to the northern reaches of the Mid-Columbia River, decreased with time. Kassa and McCutcheon (2016) hypothesize that decrease in local source use and increase in non-local source use was likely due to the increase of trade networks and movement of toolstone along the Columbia River as proposed by Hayden and Schulting (1997), Minor (2013), and Quinn (2006). More details on this study are provided in Chapter VI.

CHAPTER IV

METHODS

One of the main goals of this section is to discuss the methods used to answer Objectives 2 and 3 through a macroscopic analysis of tachylyte rock samples (Objective 2) and a field study and survey (Objective 3) of tachylyte. As mentioned in previous chapters, out of the volcanic glasses present in Washington, tachylyte is the least explored or understood, rendering a detailed study involving a macroscopic analysis and field exploration necessary. The different methodologies used to gather the data to address Objectives 2 and 3 are discussed below under Fieldwork and XRF Analyses and Macroscopic Analysis. Additionally, through the Spatial Analyses section I will discuss the methods used to address Objectives 4 (research extent of Washington volcanic glasses) and 5 (analyze volcanic glass distribution of Washington artifacts).

Fieldwork and XRF Analyses

Fieldwork was conducted over several excursions to look for the five different tachylyte source locations examined in this thesis. The goal of this fieldwork was to visit these locations, attempt to find tachylyte on the surface, map the extent of the observed tachylyte distribution, and examine its geological context. Some of the locations were visited with knowledgeable people/informants while others were sought based on a vague latitude and longitude coordinates. A summary of the results is provided in Chapter V.

When arriving at the suspected source location, two people conducted transects approximately 10 m apart in order to cover the most area as efficiently as possible. Once the tachylyte was located, radial transects were walked in concentric circles of increasing size 5 m apart until no more tachylyte material was observed. Using a Garmin eTrex10 GPS unit, the initial find location was plotted as a point, and the final distribution was plotted as a polygon.

Another important aspect of field survey was to examine the geologic context in which the tachylyte was found. When tachylyte material was observed, the nature of the underlying basalt was recorded to determine whether the tachylyte was associated with the top or the bottom of the basalt flow. This assessment involved looking for vesicular basalt, colonnades, etc. as key indicators of location within the flow. This is important information to have because it shows what type of geological context that the rock was emplaced and how we could expect to find tachylyte in other settings.

A total of 13 tachylyte samples were sent to the Northwest Research Obsidian Studies Laboratory (NWROSL) of Corvallis, Oregon. The rocks were subjected to X-ray fluorescence (XRF) analysis to determine the elemental composition and distinguish between the different tachylyte source locations. Since there could be chemical variation in tachylyte samples from a single source location, several samples were submitted from the same presumed source if there was significant spatial separation or significant color variation. The samples selected include one or more rock samples from each visited source, source rock samples obtained by others, and a single archaeological sample. The final sample is described in Chapter V: Tachylyte Sample Analysis.

Macroscopic Analysis and Criteria

I examined 116 tachylyte samples from the Washington State sources of tachylyte to characterize their macroscopic traits. This sample included pieces from all five of the confirmed tachylyte sources. Where and how I obtained these sources are summarized in Table 2 with the results of this examination discussed in Chapter V.

Table 2. Tachylyte Sample for Macroscopic Analysis

Group[1]	Description
Archaeological samples from 45KT301	16 artifacts from 45KT301 (Grissom Site) that had been subject to XRF analysis by NWROSL and reported by Kassa (2014)
Source sample from Wes Hosen	1 sample from a landowner on Wenas Creek who reportedly collected from Cleman Mountain source. Sent to NWROSL for XRF analysis.
Source samples from fieldwork	20 samples I obtained from Cleman Mountain in summer 2019. There were 4 sent to NWROSL for XRF analysis.
Source samples from NWROSL	44 samples sent to me by Alex Nyers from Washington tachylytes. All subject to XRF analysis.
Source samples from Lubinski	10 samples obtained by Lubinski from Stray Gulch, Parke Creek, and a project near Manastash Ridge. There were 4 sent to NWROSL for XRF analysis.
Source samples from Jack Powell	24 samples obtained from Jack Powell's personal collection at potentially three of the sources. There were 3 sent to NWROSL for XRF analysis. (Jack Powell is a retired DNR geologist.)
Source samples from Amy Larsen	1 sample from the Douglas Creek site that Ms. Larsen had collected when she owned the property. Sent to NWROSL for XRF analysis.

[1] archeological samples are artifacts, while source samples are non-cultural

The macroscopic analysis, or Rock Physical Properties Classification, used was adapted from Parfitt and McCutcheon's (2017) work with volcanic glasses at the 45KT301 (Grissom site) in Kittitas County, Washington (Table 3). The goal of using the same macroscopic analysis as previous studies is to capture the same data and make it comparable. Most of the traits chosen revolve around what can be seen with the naked eye and typically do not need the assistance of a microscope or hand lens to identify. If inclusions were not obvious at the macroscopic level, a 10x hand lens or 20x binocular microscope was used to more easily identify these traits.

The Rock Physical Properties Classification (Table 3) is divided into 16 variables (Dimensions) with two to nine categories (Modes) under each Dimension. The Dimensions are further divided into two main groups: cortex (Dimensions I-VI) and groundmass (Dimensions VII-XVI). Cortex refers to the outside of the rock that has been exposed to the elements extensively and has undergone chemical and physical weathering. The groundmass is defined as the fine-grained matrix of the rock that may contain larger inclusions (Bates and Jackson 1984). All the Dimensions attempt to capture as much information as possible about the rock sample using a paradigmatic classification system. The use of a paradigmatic classification system is ideal when describing the variability within a data set and analyzing the frequency of the similarities and differences between the rock samples (Hurt and Rakita 2001:188). The use of the Rock Physical Properties Classification was chosen because the information that I needed to gather related to distinguishing the different traits of the rock samples and for its comparability with Parfitt and McCutcheon (2017).

The first Dimension (I) within the paradigmatic classification system is the Cortex – grain size. This dimension is further divided into five modes: Crypto-Crystalline, Aphanitic, Fine-Grained, Coarse-Grained, and No Cortex Present. A Crypto-Crystalline cortex describes a rock that has a crystalline structure with crystals too small to see with

Table 3. Rock Physical Properties Classification: Dimensions and Modes.[1]

I. Cortex – Grain Size
1. Crypto-Crystalline
2. Aphanitic
3. Fine-Grained
4. Coarse-Grained
5. No Cortex Present

II. Cortex – Solid Inclusions
1. Present
2. Absent
3. No Cortex Present

III. Cortex – Void Inclusions
1. Present
2. Absent
3. No Cortex Present

IV. Cortex – Distribution of Solid Inclusions
1. Random
2. Uniform
3. Structured
4. None
5. No Cortex Present

V. Cortex – Distribution of Void Inclusions
1. Random
2. Uniform
3. Structured
4. None
5. No Cortex Present

VI. Cortex – Color
1. See Munsell
2. No Cortex Present

VII. Groundmass – Groundmass
1. Uniform
2. Bedding Planes
3. Concentric Banding
4. Mottled
5. Only Cortex Present

VIII. Groundmass – Solid Inclusions
1. Present
2. Absent
3. Only Cortex Present

IX. Groundmass – Void Inclusions
1. Present
2. Absent
3. Only Cortex Present

X. Groundmass – Distribution of Solid Inclusions
1. Random
2. Uniform
3. Structured
4. None
5. Only Cortex Present

XI. Groundmass – Distribution of Void Inclusions
1. Random
2. Uniform
3. Structured
4. None
5. Only Cortex Present

XII. Groundmass – Surface Texture
1. Smooth
2. Flawed
3. Matte
4. Grainy
5. Hackly
6. Only Cortex Present

XIII. Groundmass – Surface Luster
1. Chatoyant
2. Earthy
3. Resinous
4. Vitreous
5. Only Cortex Present

XIV. Groundmass – Light Transmittance
1. Opaque
2. Translucent
3. Transparent
4. Only Cortex Present

XV. Groundmass – Patina
1. Entire Specimen[2]
2. Entire Dorsal
3. Partial Dorsal
4. Entire Ventral
5. Partial Ventral
6. Portions of Dorsal and Ventral
7. None
8. Platform Only
9. Only Cortex Present

XVI. Groundmass – Color
1. See Munsell
2. Only Cortex Present

[1] adapted from Parfitt and McCutcheon (2017).
[2] altered from "artifact" to "Specimen" to account for the fact that many of the specimens examined in this thesis are non-cultural rock samples and not artifacts.

the naked eye or microscope (American Geosciences Institute [AGI] 2021). A rock with an Aphanitic cortex has grains so fine that they cannot be distinguished with the naked eye (AGI 2021). A Fine-Grained cortex describes a rock that has grains large enough to see with the naked eye but less than 2 millimeters (mm) in size (AGI 2021). Rock samples characterized as Coarse-Grained are composed of grains larger than 2mm in size (AGI 2021). A rock that is given a "No Cortex Present" designation is typical of rock samples that have either been recently sampled from the parent rock and show no, or few, signs of weathering.

The second Dimension (II) is Cortex – Solid Inclusions with the three modes of Present, Absent, or No Cortex Present. The presence of an inclusion on the cortex typically is expressed as a mineral that is different or distinct from the groundmass, or main body of the rock. It can take a variety of shapes depending on the type of mineral present. When the rock is forming, some minerals can take a crystalline form while others may appear in the form of spheres or bubbles. The lack of inclusions or cortex was noted in the Absent and No Cortex Present modes.

Dimension III is Cortex – Void Inclusions, containing the same three modes as noted in Dimension II: Present, Absent, and No Cortex Present. Void inclusions are noticeable holes or gaps in the cortex. They can be caused in variety of ways from the effects of weathering, the disintegration of inclusions, or the presence of bubbles when the rock was forming.

Dimensions IV and V relate to the distribution of the Cortex – Inclusions and Void Inclusions from Dimensions II and III. These two Dimensions are sub-divided into five modes each: Random, Uniform, Structured, None, and No Cortex Present. A Random distribution is typical when there is no noticeable pattern with the distribution of inclusions or void inclusions. A Uniform distribution was noted when the inclusions or void inclusions are evenly distributed across the cortex of the sample. A Structured distribution of inclusions or void inclusions is typical of samples that have a pattern but may not be evenly or uniformly distributed throughout the sample. A mode of None and No Cortex Present denotes samples that are either free of both inclusions and void inclusions or lack a cortex.

The sixth Dimension (VI) relates to the color of the cortex. The color was noted from the Munsell Book of Rock Colors (Munsell Color 2009). The color that is noted in the dimension was the main color that covers at least 50 percent of the cortex. If there were other colors present, they were discussed in the "Note" section of the label. This designation was necessary because some rock samples have extensive color variation. On samples that do not have cortex present, no Munsell color designation will be made.

The seventh Dimension (VII) moves on from describing the cortex and into describing the groundmass of the rock. This Dimension describes the groundmass overall, and is divided into five groups: Uniform, Bedding Planes, Concentric Banding, Mottled, and Only Cortex Present. A Uniform groundmass is typical of rocks that have a consistent appearance throughout the entirety of the sample without any noticeable changes. Bedding planes are found when the groundmass has a planar appearance. Concentric Banding describes a groundmass with discernible concentric rings. A mottled groundmass is representative of samples that vary in color throughout the rock without any discernible edges.

Dimensions VIII and IX relate to the presence and absent of Inclusions (VIII) and Void Inclusions (IX) within the groundmass. Inclusions within the groundmass are typically characterized by an object or mineral that is not part of the main groundmass and can differ in color, appearance, and shape. Void inclusions within the groundmass are typically pockets or spaces that are formed during the rock-making process or after the rock has weathered and a mineral has disintegrated.

Dimensions X and XI relate to the distribution of the inclusions and void inclusion of Dimensions VIII and IX. Similar to the distribution of the inclusions and void inclusions on the cortex, this dimension is divided into five modes: Random, Uniform, Structured, None, and Only Cortex Present. Random is described as no discernible pattern to the inclusions or void inclusions placement throughout the groundmass. A Uniform designation would be a distribution that has a uniform pattern throughout the groundmass. A Structured distribution is typical of a groundmass that has a pattern to the distribution but may not be evenly distributed throughout. None and Only Cortex Present modes mean that either there are no inclusions or void inclusions in the groundmass (None) or that there is no groundmass visible in order to make any determination (Only Cortex Present).

Dimension XII describes the Groundmass – Surface Texture and is divided into six modes: Smooth, Flawed, Matte, Grainy, Hackly, and Only Cortex Present. A rock sample with a Smooth surface texture is typical of rocks that have a consistent groundmass with a high silica content and or small grain size. A Flawed surface texture defines a texture that has some irregularities but is otherwise smooth. Matte describes a surface that has a bit of resistance to the touch and has a dull, consistent appearance. A Grainy texture describes a rock where the individual grains are either apparent or can be easily felt. A Hackly texture is rough, with grains apparent. Only Cortex Present is used when there is no groundmass is apparent on the sample.

Dimension XIII is the Groundmass – Surface Lustre and is divided into five modes: Chatoyant, Earthy, Resinous, Vitreous, and Only Cortex Present. A Chatoyant surface lustre is normal of rock samples that have a bright band, or multiple bands of reflective light within the stone. An earthy lustre describes a dull appearance that is not reflective. A sample that is Resinous describes a rock that has a resin-like texture that is smooth, reflective, and exhibits a somewhat milky appearance. A Vitreous lustre is typical of rock samples that have high-silica contents and look glassy.

Dimension XIV is Groundmass – Light Transmittance. This dimension is divided into four modes: Opaque, Translucent, Transparent, and Only Cortex Present. An Opaque designation means that no light gets through the sample. A Translucent appearance means that you can see through the sample but that shapes on the other side are not discernible. Transparent samples are see-though and objects on the other side can be seen.

Dimension XVI relates to the Groundmass – Patina and is divided into nine modes: Entire Specimen, Entire Dorsal, Partial Dorsal, Entire Ventral, Partial Ventral, Portions of Dorsal and Ventral, None, Platform Only, and Only Cortex Present. All of the descriptions relate to the location of weathering present on the rock sample or artifact. Patina is essentially the weathering present on the groundmass after a fresh break where the groundmass is beginning to return to a cortex-like state (Edmonds 1997). Patina typically appears as a dulling on the fresh break that gives a rainbow-like appearance.

The sixteenth Dimension (XVI) relates to the color of the groundmass. The color is noted from the Munsell Book of Rock Colors (Munsell Color 2009). The noted color covers at least 50% of the groundmass. This designation was necessary because some rock samples have extensive color variation. On samples that do not have groundmass present, no Munsell color designation was be made. Also, on samples that have more than one predominant color, the main color was noted and used in the paradigmatic classification and the other color(s) were noted in the Note section.

Spatial Analyses

Before an analysis of the spatial patterning of Washington volcanic glass in archaeological sites could be performed, a robust data set of sourced artifacts and their archaeological locations was needed. Craig Skinner, former owner of the NWROSL, agreed to provide the results of 25 years of his volcanic glass sourcing analyses in Excel format for the state of Washington. This spreadsheet listed the NWROSL in-house designation number, the Washington State Forest Service or Smithsonian number, the presence or absence of tachylyte, and all the different sources that are present in the Washington sites from Wyoming to British Columbia. He also provided a second spreadsheet with source location data for all of volcanic sources that have ever been sourced at NWROSL which include the latitude and longitude information for the Washington volcanic glass sources.

The first goal of the spatial analysis was to understand the location of each of the volcanic glass sources present in Washington State, how they were differentiated from each other, and whether the source had any associated artifacts that had been sourced through NWROSL. This information was gathered using the spreadsheet provided by Skinner and a review of source specific literature from McClure (2015) and Mierendorf and Baldwin (2015). If there were any sites that had a questionable location, it was then searched through the Washington Information System for Architectural and Archaeological Resources Database (WISAARD).

Once the Washington volcanic glass sources were identified on the Washington landscape, the sources and any associated archaeological sites were plotted on Google Earth Pro using the latitude/longitude coordinate information provided by Skinner's spreadsheet, WISAARD, or McClure (2015) or Mierendorf and Baldwin (2015). This information was then used to look at the amount of Washington volcanic glass present in the XRF analyzed sites vs. out-of-state glass within the XRF analyzed sites within Washington. The objective was to understand the proportion of Washington volcanic glass present vs. out-of-state glass within Washington's archaeological landscape based on the artifacts that have been sent to NWROSL for XRF analysis. The information was then further divided to look at only the archaeological sites within the state of Washington that had Washington volcanic glass present in order to take a closer look at the spread of Washington glasses exclusively.

The second goal of the spatial analysis was to understand the distribution of the different Washington volcanic glasses throughout the state. The term “local” was used to describe artifacts that were found within 50 miles of their source while the term “non-local” applied to artifacts found further than 50 miles from their source, following the practice of Kassa and McCutcheon (2016), and Parfitt and McCutcheon (2017). The boundary of the study was the Washington border. The site location data was from the dataset that was provided by Skinner. If there were sites that did not have site location data, the latitude and longitude were looked up on WISAARD. If no locational information could be gleaned about a site, either through Skinner’s spreadsheet or WISAARD, it was omitted from the study.

CHAPTER V

RESULTS: TACHYLYTE SAMPLE ANALYSIS

The following chapter details the results from my fieldwork, macroscopic analysis, and chemical analysis of Washington tachylyte sources. Fieldwork was to obtain samples of tachylyte for the following macroscopic analysis I completed and for submission to the NWROSL laboratory for XRF chemical analysis.

Fieldwork Results

Fieldwork was focused exclusively on tachylyte, with the goal to ground truth source locations, try to find exact locations of tachylyte sources within the broadly known source areas, and get better GPS locations of sources if possible. The focus of this part of the study was to address the first part of Objective 3: Relocate, map, and collect samples at the known tachylyte sources and send a selection of samples in for XRF analysis. The fieldwork was carried out over the course of three separate trips. The Douglas Creek trip was limited by landowner access, but a trip was made to discuss the source location with the previous landowner. The trips to the Stray Gulch tachylyte and Parke Creek tachylyte outcrop locations were combined into a single excursion in July 2019. The third trip was to the Cleman Mountain source and was conducted in September 2019. Sources and fieldwork are summarized in Table 4.

Originally, there were seven reported tachylyte locations provided to me by Craig Skinner in October 2018 that were going to be visited. However, since this spreadsheet

Table 4. Summary of Tachylyte Sources and Associated Fieldwork

Tachylyte Source	Fieldwork
06-17-08-238/613	Reported source from NWROSL, but as it is chemically identical to Cleman Mountain, it is combined herein
Cleman Mountain	September 2019 visit to relocate, map, collect samples, and update GPS coordinates
Douglas Creek	Privately owned, access denied, but July 2019 visit with previous landowner provided samples of the source
Manastash Ridge	Reported source from NWROSL, but as it is chemically identical to Cleman Mountain, it is combined herein
Nasty Creek	No visit due to time constraints
Parke Creek	July 2019 visit to relocate reported find by Dr. Lubinski's 2015 field school
Stray Gulch	July 2019 visit to relocate reported find by Dr. Lubinski's 2015 field school

indicated that three of the locations (06-17-08-238/613, Cleman Mountain, and Manastash Ridge) had the same trace element signature, it was considered necessary to visit only one of them. The Nasty Creek (Rocky Coulee) source was not visited due to a lack of time.

Although the Douglas Creek tachylyte was not physically visited at the time of the fieldwork on July 23, 2019, I did meet with the previous landowner, Amy Larson that day. Kat Russell, the Bureau of Land Management (BLM) office archaeologist for the Wenatchee office also met with me at the same time I was meeting with Ms. Larson. Ms. Russell had information on possible collections that the BLM owns that may contain more of the Douglas Creek tachylyte. Given the timeframe and scope of my research I did not follow up with Ms. Russell's leads at this time. Ms. Larson provided me with her entire collection of Douglas Creek tachylyte samples that she gathered while she owned the property. She described the location and context that the tachylyte was in and will be described in more detail below.

From Amy Larson's description, the Douglas Creek tachylyte is located near the intersection of 3 ½ Road SW, 3 Road SW, and Road 4 SW near the grain elevator at Alstown, Washington. All that remains of Alstown is a large grain silo on the BNSF (formerly Burlington Northern-Santa Fe) railroad tracks and several residences along Douglas Creek. Despite its name, this source is located to the south of Douglas Creek itself. The source is located in a drainage that feeds directly into Douglas Creek. According to Ms. Larson, the tachylyte is eroding into the drainage on both sides of the ravine. Considering that the drainage feeding into Douglas Creek is about five miles in length leading west into the Badger Mountains to the reported location, there is a high probability that more of the basalt that contains the Douglas Creek tachylyte may be located further west up the drainage. Based upon the ground location Ms. Larson reported, I used Google Earth and the Alstown 1:24,000, 7.5-Minute Series United States Geological Survey (USGS) quadrangle map (1968) to provide coordinates for the location of the tachylyte, at 47.559440º N, -119.993024º E within Section 19, Township 24 N, Range 23 E (Figure 11).

Information on the location for the Parke Creek and Stray Gulch tachylyte locations came from Dr. Pat Lubinski's fieldwork in 2015 and from coordinates provided by Craig Skinner. In 2015, Dr. Lubinski's summer archaeology field school attempted to find both source locations with multiple crew members over two days of fieldwork. Searches were conducted as pedestrian surveys based on reported UTM locations

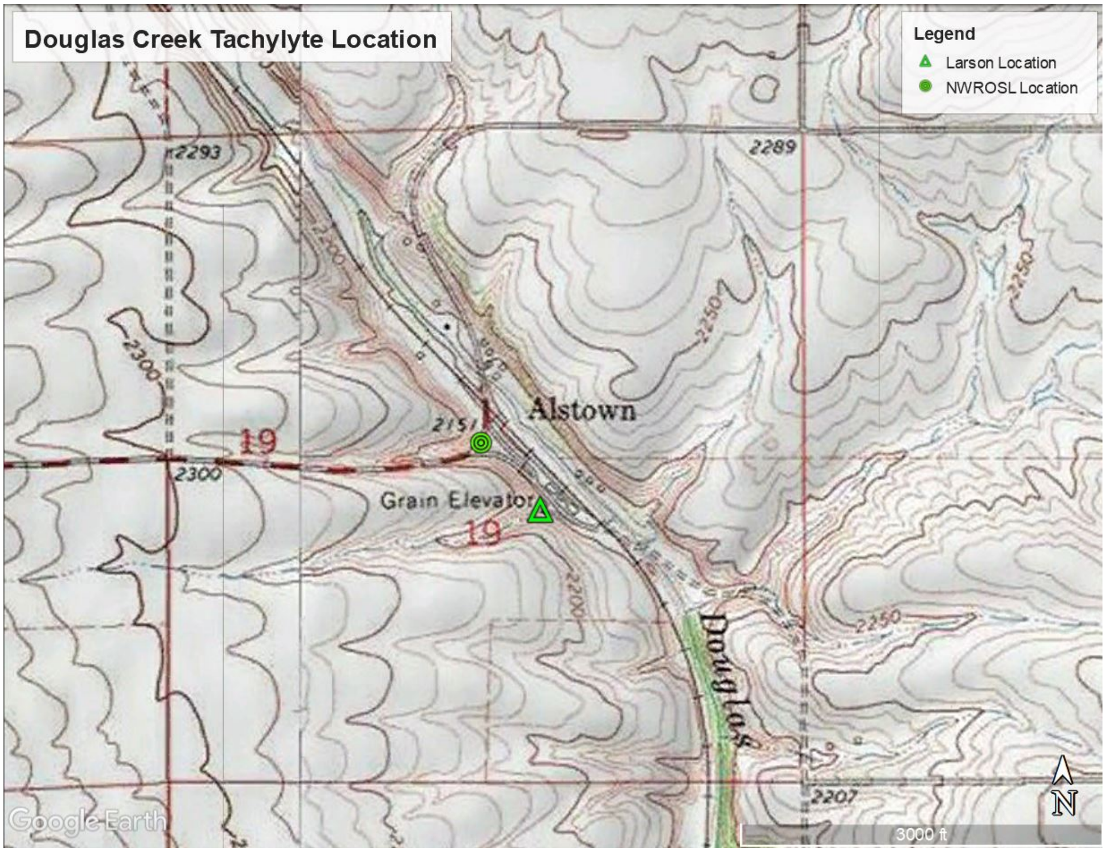


Figure 11. Douglas Creek tachylyte location as reported by Amy Larson and NWROSL. Shown on the Alstown 7.5' Quadrangle (USGS 1968).

provided to the Washington Department of Fish and Wildlife (WDFW) landowner by obsidian sourcing analysts. Dr. Lubinski (personal communication, 2020) notes that the tachylyte found was small pieces, <2 cm in size, scattered within "blisters" of material over exposed basalt bedrock surface areas.

According to Dr. Lubinski, his search for these two sources began from location leads sent by Craig Skinner via email to WDFW Archaeologist Kat Kelly, with whom the field school was working with Summer 2015. In the email, Craig noted that he had not visited either source, but that the samples were sent to him by "reliable collectors." The Stray Gulch tachylyte was reported to have been found on the Stray Gulch 7.5' USGS topographic map (1966a), in the SW ¼ of Section 4, T19N, R21E, at UTM NAD83 Zone 10, 711,345 m E, 5,227,455 m N. Dr. Lubinski and five students checked this location on July 21, 2015 with no success, but Dr. Lubinski returned with 10 students on July 23 and made finds. The tachylyte was found in the SW ¼ as reported, along either side the Green Dot "Cross Over" Road northwest of its crossing of Tekison Creek. The material was black, opaque, and vesicular, found in several discrete scatters atop exposed basalt bedrock. One of these scatters, about 10 m SE of the road, had about 30 fragments of material, all less than 2 cm in maximum dimension, within a 9 x 6 m area. This location was recorded with a Garmin eTrex 10 hand-held GPS, with points taken using waypoint averaging of three samples, each consisting of at least one-minute worth of data points resulting in 100% confidence on the confidence display bar. The location was Zone 10, 711,250 m E, 5,226,927 m N, using NAD27 (Figure 12). (This corresponds with 47.1637356° latitude, -120.2139732° longitude WGS84 using https://tagis.dep.wv.gov/convert/.) Four pieces were collected.

The Parke Creek tachylyte was reported to Skinner to have been found on the Whiskey Dick 7.5' USGS topographic map (1966b), in the SE ¼ of Section 5, T18N, R21E, at UTM Zone 10, 71,1280 m E, 5,217,390 m N. Dr. Lubinski and 10 students visited this locale on July 23 and found material in a single isolated scatter in SE ¼ of Section 5 or close to it. The material was blue and each piece was no more than 2 cm in maximum dimension. The scatter of about 100 fragments in a 5 x 5 m area was on a ridge shoulder overlooking South Fork of Hunt Creek, about 6 m east of a small cairn

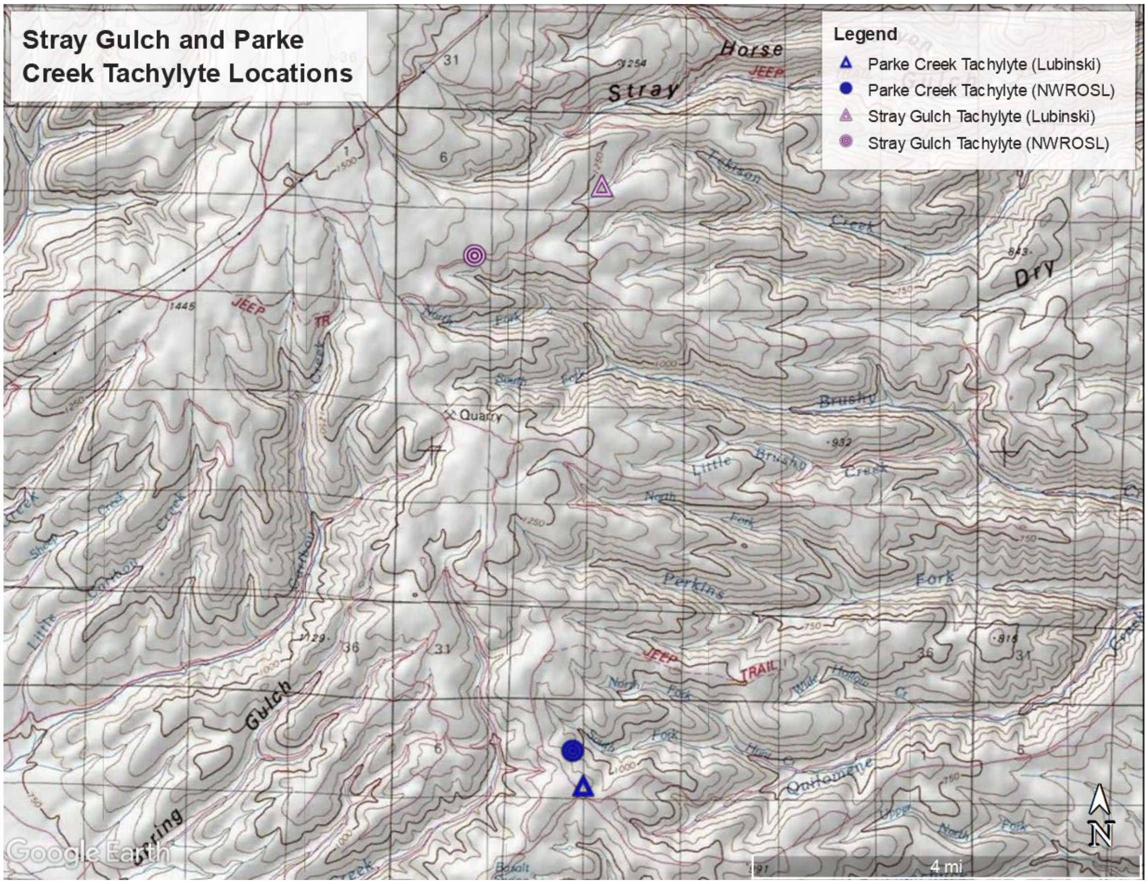


Figure 12. Stray Gulch and Parke Creek topographic locations as reported by Dr. Lubinski and NWROSL database. Shown on the USGS Wenatchee, 1:100,000-scale map (USGS 1975).

with two courses of seven rocks. The GPS location was Zone 10, 711,227 m E, 5,217,241 m N, using NAD27 (Figure 12). (This corresponds with 47.0766856° latitude, -120.2188211° longitude WGS84 using https://tagis.dep.wv.gov/convert/) Four pieces were collected.

During my excursion on July 21, 2019, I was not able to relocate either the Stray Gulch or the Parke Creek sources. My field partner, Josh Allen, and I surveyed both areas spaced approximately 10 m apart. Any areas of the landscape that had exposed basalt outcrops were heavily surveyed with many of the rocks on top of the exposed areas picked up and examined. None of the locations proved fruitful for finding the tachylyte during this trip.

The exposures of basalt were different at each location. The examined location for the Parke Creek tachylyte was on a bare hilltop that had very little vegetation other than sparse clumps of grass, cheat grass, and sagebrush, and was near Spike Spring. There was an extensive amount of what has been dubbed "snot rock" located all over this location with increasing amounts near the Spike Spring locale. "Snot rock," what Jack Powell (1999) calls "opal" is CCS that is a fluorescent yellow to green in color. It contains a high amount of water content and although crystalline in nature, overall makes a poor toolstone material. Typically, CCS erodes out of areas where a spring exposes the underlying bedrock (Miller and Powell 1997) and, given the extensive amount of game trails present, it is likely that it was spread across the landscape by animals more than it was by people. I expected the tachylyte to be strewn about the landscape in this way as well but it was never found. The area was the top of a lava flow based on the vesiculated nature of the rocks.

Almost an entire quarter section of the surrounding area was surveyed by myself and my field partner and we could not locate it. One of the main reasons that we may not have been able to locate the tachylyte was because we were looking for samples that were far larger than what was to be expected from that material type. I took Dr. Lubinski's advice and looked at small exposures of the basalt but still did not relocate the tachylyte source. It is expected that there was either too little of the Parke Creek tachylyte to relocate easily, that it had been picked up by other people, or that we were at the incorrect location. The incorrect location is the most plausible given that I interpreted Dr. Lubinski's coordinates as NAD 83 when in fact they were NAD 27. Additionally, I and my field partner were never able to relocate the rock cairn that was within 6 m of the Parke Creek source, further supporting the likely explanation that I was at the incorrect location.

The location of the Stray Gulch tachylyte varied greatly from that of Parke Creek. Whereas my search locale for Parke Creek tachylyte was on a bare portion on top of one of the flows, my search locale for Stray Gulch tachylyte was within a wooded area on a south facing slope. Two locations were searched for the Stray Gulch tachylyte given that the map I had from Dr. Lubinski differed slightly from the coordinates provided by Craig Skinner at NWROSL. The area provided by the coordinates from Craig Skinner's office proved to not have any or very few exposures of basalt. The coordinates from Dr. Lubinski better matched the location description provided from the field school. The area I examined was wooded with a about a 15-degree slope towards Stray Gulch. Stray Gulch had a sparse amount of water still present during the field visit. Similar to the Parke Creek methods, my field partner and I surveyed the area approximately 10-15 m apart. Any areas with exposed basalt were intensively surveyed and rocks present on top were picked up and checked. There was no tachylyte found at either of the examined Stray Gulch locations although both were extensively surveyed at and beyond the expected source location. It is likely that given how small of an area these sources cover, I did not find it either because we were looking for the wrong size or shape of rock, it was already picked up, or we were at the wrong location.

The reported Cleman Mountain tachylyte source location was surveyed on September 19, 2019 (Figure 13). Information on the location of the source came from two places: a contact of Dr. Hackenberger's and Craig Skinner's coordinates (Zone 10, 664,067 m E,5,187,241 m N, NAD 83) from his volcanic glass database. Dr. Hackenberger's contact, Wes Hosen has a property on Wenas Creek where he has found tachylyte from the Cleman Mountain source. Mr. Hosen also mentioned to Dr. Hackenberger that he had been to the Cleman Mountain source location and that he had a friend that had been there recently.

Figure 13. Overview of Cleman Mountain Source at Location 1; View: SE.

The field crew involved Mr. Hosen, Dr. Hackenberger, Josh Allen, myself, and Mr. Hosen's contact Tom Hibbs. Mr. Hibbs had been the person most recently at the location of the tachylyte, therefore I followed him in my vehicle to the site. The area where we found the tachylyte was near the top of Cleman Mountain. The surrounding vegetation at the first location was cheat grass, clump grasses, and some sagebrush. The source was found over three different areas along the same ridge. The first and most dense toolstone location was primarily found on the road and within about 50 feet of the road on either side. The other two locations were at high points on both the southeast and northwest sides of the main source location (Figure 14).

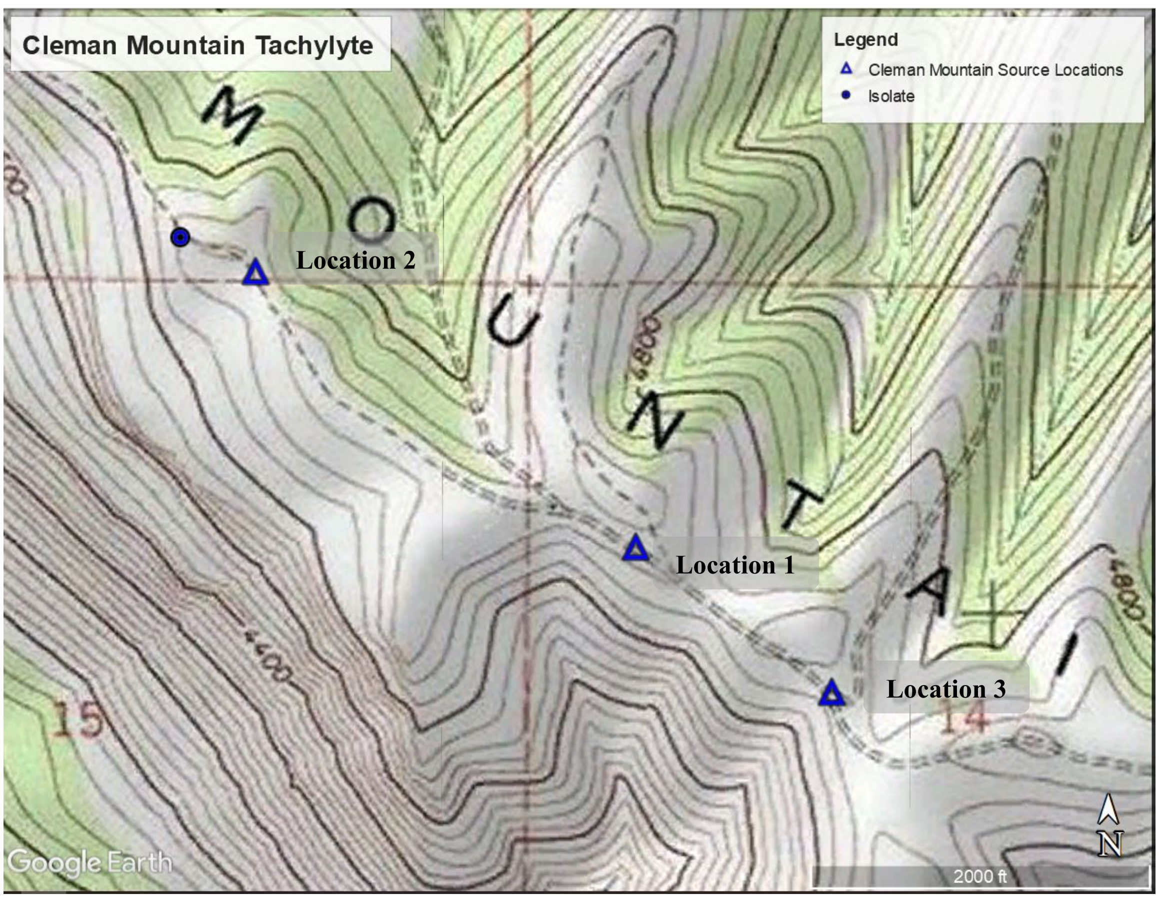


Figure 14. Cleman Mountain Tachylyte locations found through September 2019 fieldwork. Shown on the Milk Canyon 7.5. Quadrangle (USGS 1971).

The three observed locales of exposed tachylyte are described as follows. All locations were recorded using a Garmin eTrex 10 which has up to a 3m accuracy, using UTM coordinates (NAD 83). Cleman Mountain Location 1 (NAD 83, Zone 10T 667,809 m E, 5,184,448 m N): most of the source was within the graded, two-track road. The tachylyte fragments were a dark, denim blue to a light sky blue, and ranged from < 1 cm in width to 4 cm in width. There were many black inclusions within the samples. Cleman Mountain Location 2 (Zone 10T 667,088 m E, 5,184,970 m N): several pieces were found near the road on the side of the slope where the trees were present. Additionally, at Location 2 there was one isolated tachylyte piece located on the southern slope towards the Naches River watershed. The isolate was denim blue with light blue mottling with flake scars present (see Figure 14**)**. The third location of the Cleman Mountain source was found in the median of the graded, two track road on which Source Location 1 materials were found (Zone 10T 668, 174 m E, 5,184,196 m N). I collected 5-10 samples from each of the three of these Cleman Mountain tachylyte locales for submission to NWROSL for source analysis.

XRF Results

XRF analysis was conducted on samples of tachylyte from fieldwork performed in Summer 2019 at the Cleman Mountain source and the collections of Jack Powell, Amy Larson, Wes Hosen, and Dr. Lubinski (Table 5). The focus of this part of the study was to address the second part of Objective 3: Relocate, map, and collect samples at the five known tachylyte sources and send a selection of samples in for XRF analysis. There were no samples of other volcanic glass sent in for XRF analysis. This part of the study, similar to the macroscopic analysis, was solely based on tachylyte. There were 13 samples sent into NWROSL who conducted the analysis during summer 2020. Table 5 summarizes the source locations of the samples that were sent to NWROSL, the number of samples, and who or how the samples were obtained.

Table 5. Summary of Tachylyte Samples Subject to XRF Analysis by Source

Source	No. Analyzed	Source Locations and Description
Stray Gulch Tachylyte	2	1 from Dr. Lubinski's 2015 field school on Stray Gulch 1 from Jack Powell near Stray Gulch
Douglas Creek Tachylyte	1	1 from Amy Larson at tachylyte source
Parke Creek Tachylyte	1	1 from Dr. Lubinski's 2015 field school on Parke Creek
Cleman Mountain Tachylyte	7	1 from Dr. Lubinski's 2016 field school (source uncertain, find located near Manastash Ridge) 1 from Wenas Creek landowner (Wes Hosen) on Cleman Mountain 1 from Jack Powell collection 4 from 2019 personal fieldwork on Cleman Mountain
Nasty Creek	2	2 from Jack Powell's collection near Nasty Creek Flat

Table 6 summarizes the specimen number that was assigned to each source by Alex Nyers at NWROSL, the general collection locale, a brief description of who obtained the specimen and from where, and the geochemical source locations of the specimens as determined by NWROSL (see Appendix A for their full report). Figure 15 is the map of the sourced specimen locations against their established source locations. Most of the tachylyte submitted, with the exception of Specimen #13, was from suspected geologic source locations. Specimen #13 was from Dr. Lubinski's 2016 field school and was found approximately 5 miles NE of the Manastash Ridge outcrop of the Cleman Mountain source. Given that Specimen #13 did not show signs of cultural modification it is unknown how the specimen ended up at this location.

Table 6. Summary of 2020 Tachylyte Sample XRF Results

Spec. #	Collection Locale	Description	Geochemical Source
1	Cleman Mountain	S1: Stetson Timber Sale, Jack Powell Collection, Cleman Mountain	Cleman Mountain
2	Cleman Mountain	S2: Cleman Mountain, Wes Hosen, Cleman Mountain	Cleman Mountain
3	Cleman Mountain	L1S1: Location 1 Sample 1, 2019 Fieldwork, Cleman Mountain	Cleman Mountain
4	Cleman Mountain	L2S1: Location 2 Sample 1, 2019 Fieldwork, Cleman Mountain	Cleman Mountain
5	Cleman Mountain	L3S1: Location 3, Sample 1, 2019 Fieldwork, Cleman Mountain	Cleman Mountain
6	Cleman Mountain	I1; Isolate 1, 2019 Fieldwork, Cleman Mountain	Cleman Mountain
7	Nasty Creek	NCFS1; Nasty Creek Flats, Jack Powell Collection, Nasty Creek Flats	Nasty Creek
8	Douglas Creek	DCS1; Douglas Creek, Amy Larson Collection, Douglas Creek source	Douglas Creek
9	Stray Gulch	SGS1; Stray Gulch Sample 1, Dr. Lubinski 2015 Field School, Stray Gulch Source	Stray Gulch
10	Stray Gulch	SGS2; Stray Gulch Sample 2; Dr. Lubinski 2015 Field School, Stray Gulch Source	Stray Gulch
11	Parke Creek	PCS1; Parke Creek Sample 1; Dr. Lubinski 2015 Field School; Parke Creek Source	Parke Creek
12	Nasty Creek	FRS1; Foundation Ridge Sample 1; Jack Powell Collection, Foundation Ridge	Nasty Creek
13	Between Manastash and South Cle Elum ridges	UNKS1; Unknown Sample 1; Dr. Lubinski 2016 Field School; between South Cle Elum Ridge and Manastash Ridge	Cleman Mountain (Manastash Ridge Outcrop)

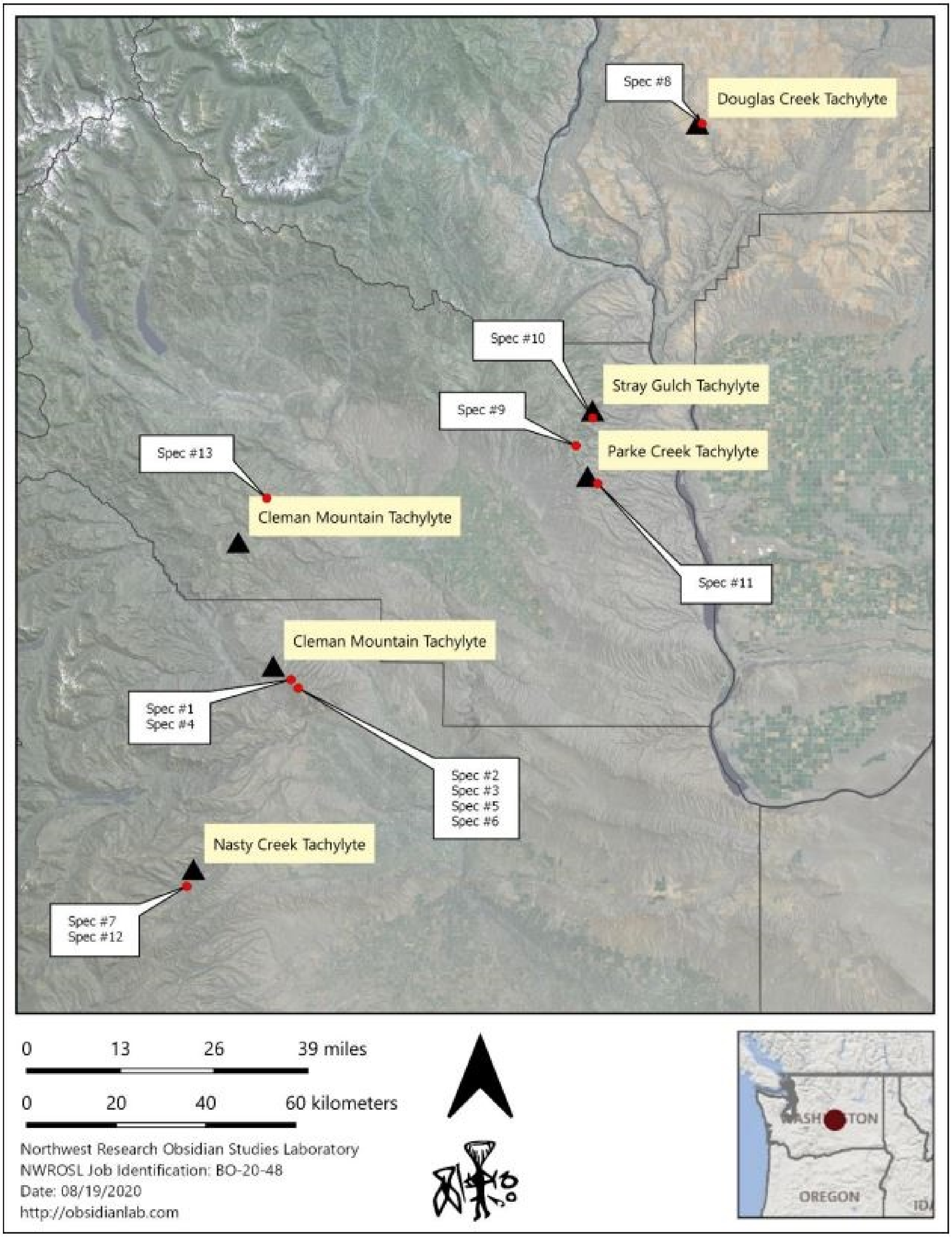


Figure 15. Location of submitted tachylyte (red dots) vs. the established source locations (black triangles) (Nyers 2020:Figure 1).

According to the NWROSL analysis conducted in summer 2020 (Nyers 2020), the most diagnostic of the trace elements that were used to identify different sources of tachylyte were zirconium and yttrium. Submitted samples were assigned to their specific sources if their trace element values "fall within about two standard deviations of the analytical uncertainty of the known upper and lower limits of chemical variability recorded for the source. Occasionally, visual attributes are used to corroborate the source assignments although sources are never assigned solely on the basis of megascopic characteristics" (Nyers 2020:1). During the analysis there was a malfunction with the vacuum and the analysis had to be conducted without it. According to Nyers (personal communication, August 19, 2020), this had no effect on six of the main elements that are used in the analysis (rubidium [Rb], strontium [Sr], yttrium [Y], zirconium [Zr], niobium [Nb], barium [Ba]) but the trace elements for iron (Fe) and titanium (Ti) were less accurately determined. The analysis report provided trace element concentrations for these eight elements.

To further explore the trace element compositions of the tachylyte sources, I wanted to create scatterplots of different trace element pairs, including Zr, Y, and others. I used the trace element data from the 2020 report, and for comparison I also used an Excel spreadsheet with NWROSL trace element data from outcrop source samples provided in December 2018 by Craig Skinner. This dataset included 59 samples with the following listed source names: Cleman Mountain, Nasty Creek, Parke Creek, Stray Gulch, and Douglas Creek. The Cleman Mountain Source was further divided by outcrop locations named: Cleman Mountain, Manastash Ridge, and 06-17-08-238/613.

First, using the combined dataset, I created scatterplots for each tachylyte source based off of their Zr and Y amounts. I chose these trace elements because that is what was used by Nyers (2020) and I wanted my data to be consistent with his work. Figure 16 shows all of the analyzed sources, with a good separation between Stray Gulch and the other sources, but considerable overlap in the other four sources.

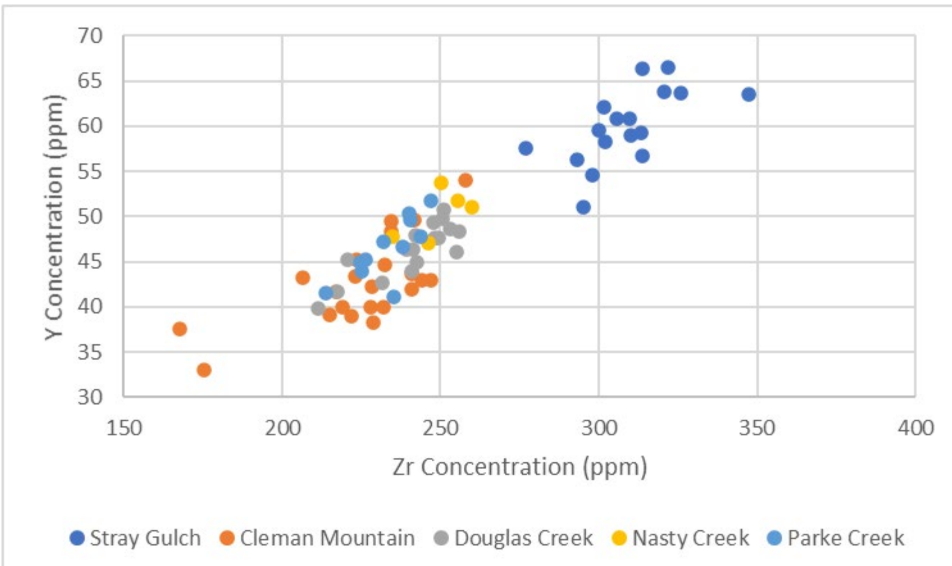


Figure 16. Y vs. Zr scatterplot of all tachylyte outcrop sources analyzed at NWROSL. This dataset includes the NWROSL samples as of 2018 plus my samples from 2020. All are geologic outcrop location samples, not artifacts.

After I discussed this overlap in November 2020 with Craig Skinner, the original creator of the volcanic glass sourcing database that is used at NWROSL and in this thesis, he stated that there may be some better ways to show the data than the scatterplots and that there may be a different element contributing to the differentiation. Additionally, he stated that the database at NWROSL is constantly being developed and added to depending on how many people send in samples. Therefore, a comparison of Zr and Y may have been the best way to differentiate tachylyte sources when he first started the database, but as more samples have been sent in over the course of 30 years, there was or needs to be an adaptation as more is learned about the geochemical components.

Skinner re-ran the tests that he originally used to differentiate the tachylyte sources in order to identify if there were better trace elements to use to compare. After doing this, Skinner recommended three changes for separating tachylyte sources in Washington. First, Parke Creek, Nasty Creek, and Cleman Mountain were all close enough geochemically that they would be combined under a single geochemical source, Cleman Mountain, as of November 2020. Second, the most useful trace elements to use to differentiate Stray Gulch from all other sources are Zr and Barium (Ba). Third, a comparison of Zr and Fe further differentiates Douglas Creek from the other two sources.

After learning this new information from Skinner, I took his advice and compared all of the sources against each other using Zr vs. Ba and Zr vs. Fe. Figure 17 shows the clustering that is seen in the Zr vs. Ba comparison with the Cleman Mountain, Nasty Creek, and Parke Creek samples combined in this graph and hereafter. Similar to the Zr vs. Y comparison in Figure 16, Stray Gulch (blue dots), remains distinguishable from the other sources in the Zr vs. Ba comparison. Douglas Creek, shown in gray, also appears to cluster more towards the top of the Zr vs. Ba scatterplot in Figure 17 rather than clustering within the Cleman Mountain source as seen in Figure 16. There is, however, one Douglas Creek outlier within the Cleman Mountain cluster; this is the one Douglas Creek sample I submitted in 2020.

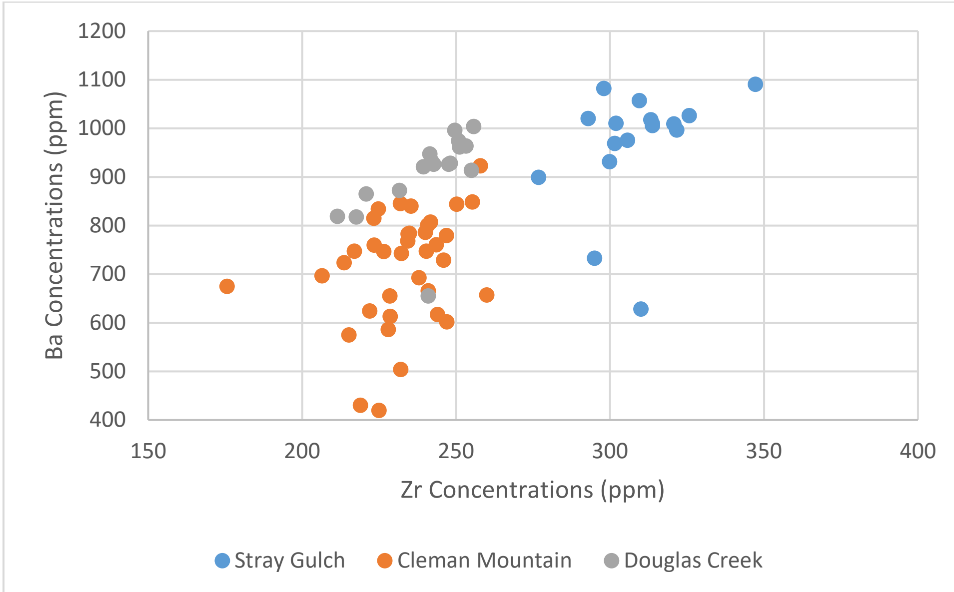


Figure 17. Ba vs. Zr scatterplot of all tachylyte outcrop sources analyzed at NWROSL. This dataset includes the NWROSL samples as of 2018 plus my samples from 2020. All are outcrop location samples, not artifacts. Note that Cleman Mountain in this graph and all following figures is the combination of previously defined Cleman Mountain, Nasty Creek, and Parke Creek sources.

When comparing Fe vs. Zr concentrations, Douglas Creek (gray dots) as well as Stray Gulch (blue dots) solidly stood out from the Cleman Mountain sources (Figure 18). The samples that I sent for analysis in August 2020 were omitted from this scatterplot. This is because Nyers told me that there was a malfunction with the vacuum and that the Fe and Ti concentrations amounts would not be accurately determined. Note that this removes an outlier sample from Douglas Creek in the Fe vs. Zr plot that lies within the Cleman Mountain cluster, making a clearer separation between the two groups, but this same sample is also an outlier in the Ba vs. Zr plot which was not subject to the vacuum error.

Based on the information that Skinner provided and the scatterplots that I created, it appears that the Stray Gulch source can be easily separated from the others using Y vs.

Zr, or Ba vs. Zr, or Fe vs. Zr. In order to differentiate between the Douglas Creek and Cleman Mountain sources, Fe vs. Zr works best. In fact, Fe vs. Zr appears to do a good job of separating all three (Figure 18).

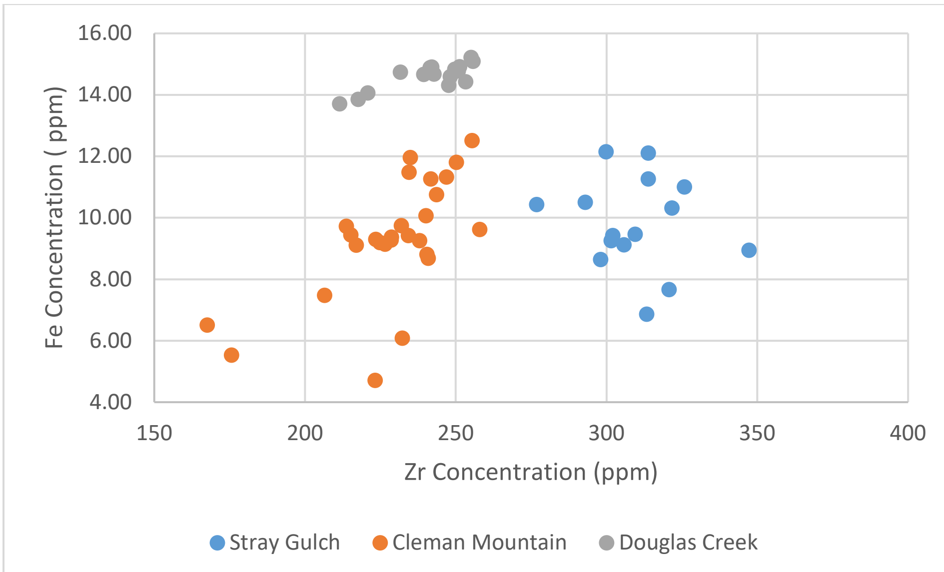


Figure 18. Fe vs. Zr scatterplot of tachylyte outcrop sources analyzed at NWROSL as of 2018. This dataset excludes my samples from 2020. All are outcrop location samples, not artifacts.

To evaluate whether the apparent separation is statistically valid, I created 95% confidence ellipses for these three groups on the data using XLSTAT ver. 2021.1.1 (Addinsoft 2021), a third-party add-on that can be used in Excel. This function takes the dispersion of the trace concentrations of Fe vs. Zr of the different samples and creates a 95% confidence ellipse that best represents the data in each defined group. The ellipses are based upon the data points within my defined groups: Cleman Mountain, Stray Gulch, and Douglas Creek. All points that overlap between the ellipses are within the 95% confidence interval of both groups.

Figure 19 shows the three tachylyte sources with 95% confidence ellipses, while Figure 20 shows the sources with a 90% confidence ellipse. The 95% confidence successfully divides the Douglas Creek sample (Blue) from the Stray Gulch (Green) and Cleman Mountain (Red) samples; however, there is a slight overlap between the Cleman Mountain and Stray Gulch samples indicating samples fall within the 95% confidence ellipse of both sources. Figure 20 shows the three sources with a 90% confidence ellipse.

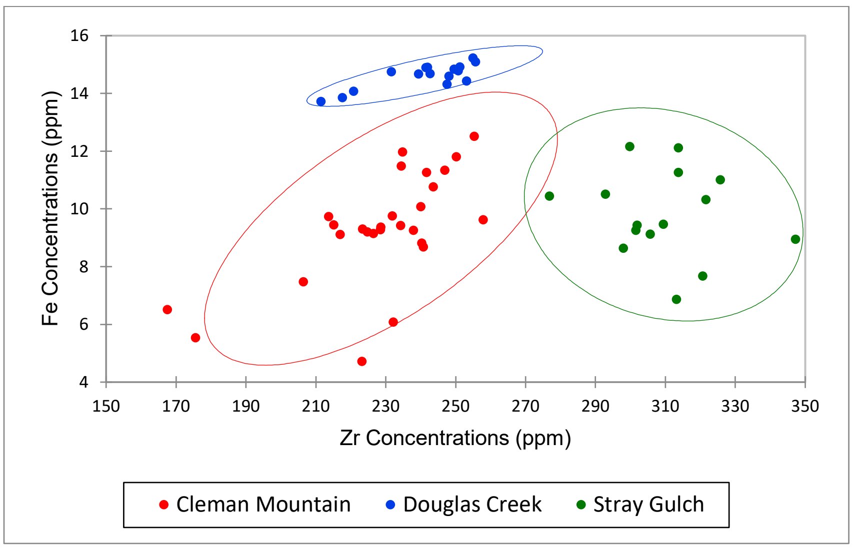


Figure 19. 95% Confidence ellipses for Fe vs. Zr trace element concentrations of Figure 18 dataset.

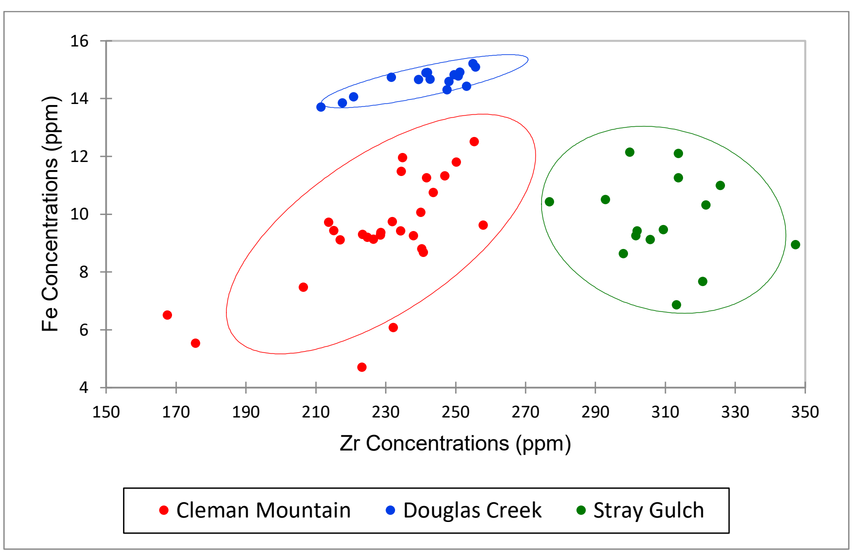


Figure 20. 90% Confidence ellipses for Fe vs. Zr trace element concentrations of Figure 18 dataset.

Macroscopic Analysis Results

The macroscopic analysis was conducted on samples from all five of the tachylyte sources throughout Washington before they were combined into three. The focus of this part of the study was to address Objective 2: Analyze and distinguish the raw material visual characteristics of the five known tachylyte sources through a macroscopic analysis using a 40x microscope and established macroscopic analysis methods (Kassa and McCutcheon 2016). The analyzed samples Table 7 were collected through personal fieldwork, private collections donated to me for my research, samples from Dr. Lubinski's 2015 and 2016 field schools, samples on loan from NWROSL, and an archaeological site curated at CWU (45KT301). In total, 116 samples were analyzed through macroscopic analysis, the results of which are detailed in Table 8 through Table 12.

Table 7. Summary of Tachylyte Samples Subject Macroscopic Analysis by Source

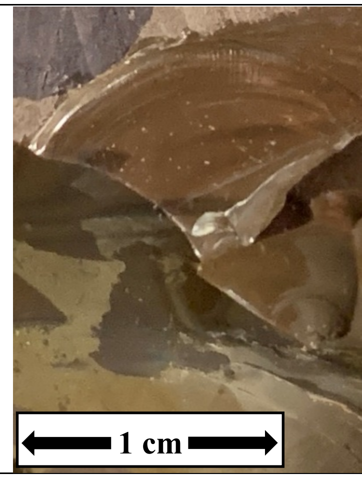
Source	No. Analyzed	Source Locations and Description
Stray Gulch Tachylyte	35	15 from 45KT301, 15 from NWRSOL, 4 from Dr. Lubinski's 2015 field school, 1 from Jack Powell
Douglas Creek Tachylyte	18	16 from NWROSL, 1 from Amy Larson, 1 from 45KT301
Parke Creek Tachylyte	14	10 from NWROSL, 4 from Dr. Lubinski's 2015 field school
Cleman Mountain Tachylyte	31	3 from NWROSL (Manastash Ridge Outcrop); 2 from Dr. Lubinski's 2016 field school Taneum Thinning Project (Manastash Ridge Outcrop); 1 from Wenas Creek landowner, 1 from Jack Powell collection, 24 from personal fieldwork
Nasty Creek	18	18 from Jack Powell's collection

Table 8. Stray Gulch Tachylyte Macroscopic Analysis Summary (n=35)

		
Cat No. 31713 from 45KT301 (groundmass)	A7 from NWROSL (cortex with voids)	A1 from NWROSL, detail (groundmass with inclusions)

Cortex Variables: (if cortex is present)
I: Grain Size: 2. Aphanitic (n=28); 5. No Cortex Present (n=7)
Inclusions & Distribution: **II: Solid Inclusions**: 1. Present (n=20); 2. Absent (n=8); 3. No Cortex (n=7) **III: Void Inclusions**: 1. Present (n=24); 2. Absent (n=4); 3. No Cortex (n=7) **IV: Distribution of Solid Inclusions:** 1. Random (n=20); 4. None (n=8); 5. No Cortex (n=7) **V: Distribution of Void Inclusions**: 1. Random (n=24); 4. None (n=4); 5. No Cortex (n=7)
VI: Cortex Color: 1. Munsell Color – 10YR 4/1 (n=1); 5YR 4/1 (n=1); 5GY 2/1 (n=2); 5PB 3/2 (n=1); 5Y 10/1 (n=1); 5Y 2/1 (n=1); 5Y 3/2 (n=1); 5Y 3/4 (n=1); 5Y 4/1 (n=3); 5YR 2/1 (n=1); N2 (n=2); N3 (n=13); 2. Not Applicable (n=7)
Groundmass Variables: (if groundmass is present)
VII: Groundmass: 1. Uniform (n=25); 4. Mottled (n=6); 5. Cortex Present (n=4)
Inclusions & Distribution: **VIII: Solid Inclusions**: 1. Present (n=26); 2. Absent (n=5); 3. Cortex Present (n=4) **IX: Void Inclusions:** 1. Present (n= 13); 2. Absent (n=18); 3. Cortex Present (n=4) **X: Distribution of Solid Inclusions:** 1. Random (n=26); 4. None (n=5); 5. Cortex Present (n=4) **XI: Distribution of Void Inclusions**: 1. Random (n=13); 4. None (n=18); 5. Cortex Present (n=4)
XII: Surface Texture: 1. Smooth (n=31); 6. Cortex Present (n=4)
XIII: Surface Luster: 3. Resinous (n=31); 5. Cortex Present (n=4)
XIV: Light Transmittance: 1. Opaque (n=31); 4. Cortex Present (n=4)
XV: Patina: 3. Partial Dorsal (n=4); 6. Portions of Dorsal and Ventral (n=4); 7. None (n=27)
XVI: Groundmass Color: 1. Munsell Color – 10YR 2/1 (n=1); 5G 2/1 (n=1); 5GY 2/1 (n=6) 5PB 3/2 (n=1); 5Y 2/1 (n=5); 5Y 3/2 (n=1); N2 (n=13); N3 (n=2); 2. Cortex Present (n=4)
Other Observations:
Size Range of Specimens: 1-3 cm in maximum dimension
Nontechnical Description of Color: The most common color for the cortex was a grayish black with the second most common an olive gray. The groundmass was most commonly a grayish black with the second most common a greenish black.
Characteristics of Inclusions: The inclusions vary greatly in size from <1mm to 1 cm max dimension. The smaller inclusions are typically spherical with a white ring while the larger inclusions are more often irregular shaped with a grainy, black (N2) interior that appears to be a different material than the groundmass.
Use: Reported from seven archaeological sites in Washington (45KI263, 45KT1407 [WEN-54], 45KT301, 45GR630, and Elk Heights, WEN 59) and one site in Oregon (35JE51B)

Table 9. Douglas Creek Tachylyte Macroscopic Analysis Summary (n=18)

		
1891-8 from NWROSL (groundmass and cortex)	1891-3 from NWROSL (groundmass [blue] and cortex)	1891-1 from NWROSL, detail (groundmass with mottling)

Cortex Variables: (if cortex is present)

I: Grain Size: 2. Aphanitic (n=17); 5. No Cortex Present (n=1)

Inclusions & Distribution:

II: Solid Inclusions: 1. Present (n=13); 2. Absent (n=4); 3. No Cortex (n=1)

III: Void Inclusions: 1. Present (n=3); 2. Absent (n=14); 3. No Cortex (n=1)

IV: Distribution of Solid Inclusions: 1. Random (n=13); 4. None (n=4); 5. No Cortex (n=1)

V: Distribution of Void Inclusions: 1. Random (n=3); 4. None (n=14); 5. No Cortex (n=1)

VI: Cortex Color: 1. Munsell Color – 10R 4/6 (n=1); 10YR 4/2 (n=2); 10YR 5/4 (n=2); 10YR 5/6 (n=1); 10YR 6/2 (n=2); 10YR 6/6 (n=1); 5PB 3/2 (n=2); 5Y 7/2 (n=1); 5YR 4/4 (n=1); 5YR 5/6 (n=4); 2. Not Applicable (n=1)

Groundmass Variables: (if groundmass is present)

VII: Groundmass: 1. Uniform (n=14); 4. Mottled (n=4)

Inclusions & Distribution:

VIII: Solid Inclusions: 1. Present (n=14); 2. Absent (n=4)

IX: Void Inclusions: 1. Present (n= 1); 2. Absent (n=17)

X: Distribution of Solid Inclusions: 1. Random (n=14); 4. None (n=4)

XI: Distribution of Void Inclusions: 1. Random (n=1); 4. None (n=17)

XII: Surface Texture: 1. Smooth (n=18)

XIII: Surface Luster: 3. Resinous (n=18)

XIV: Light Transmittance: 1. Opaque (n=15); 2. Translucent (n=2); 4. Cortex Present (n=1)

XV: Patina: 6. Portions of Dorsal and Ventral (n=3); 7. None (n=15)

XVI: Groundmass Color: 1. Munsell Color – 10Y 2/1 (n=1); 10YR 2/2 (n=2); 5GY 2/1 (n=3) 5PB 3/2 (n=3); 5Y 2/1 (n=8); 5YR 2/1 (n=1)

Other Observations:

Size Range of Specimens: 1-12 cm in maximum dimension

Nontechnical Description of Color: Cortex mostly comes in a variety of moderate to dark yellowish browns. The groundmass was mostly an olive gray and greenish black. Some samples had a deep blue present in groundmass with an oxidized, pale blue color present on the cortex.

Characteristics of Inclusions: The inclusions were typically irregular shaped. The color of the inclusions (5Y 2/1, olive black) was typically darker than the groundmass. As seen above in sample 1891-8, there were sometimes striations of brown and yellow on the cortex. The inclusions ranged from <1 mm to >3 cm max dimensions. .

Use: Reported from three sites in Washington (45CH791, 45DO59, 45KT301) and two sites in Oregon (35GM25, 35SH137)

Table 10. Parke Creek Tachylyte Macroscopic Analysis Summary (n=14)

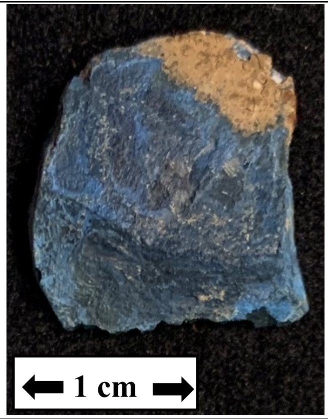
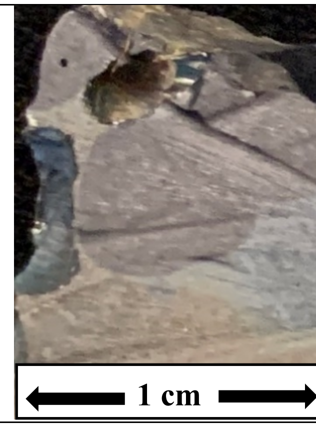
		
1680-4 from NWROSL (cortex)	1680-5 from NWROSL (cortex)	1680-3 from NWROSL, detail (groundmass with inclusions and rock saw marks)
Cortex Variables: (if cortex is present)		
I: Grain Size: 2. Aphanitic (n=14)		
Inclusions & Distribution: **II: Solid Inclusions**: 1. Present (n=10); 2. Absent (n=4) **III: Void Inclusions**: 1. Present (n=5); 2. Absent (n=9) **IV: Distribution of Solid Inclusions:** 1. Random (n=10); 4. None (n=4) **V: Distribution of Void Inclusions**: 1. Random (n=5); 4. None (n=9)		
VI: Cortex Color: 1. Munsell Color – 5B 5/6 (n=3); 5B 6/2 (n=1); 5BG 3/2 (n=3); 5G 5/2 (n=2); 5PB 3/2 (n=2); 5PB 5/2 (n=1); N2 (N=1); N3 (n=1)		
Groundmass Variables: (if groundmass is present)		
VII: Groundmass: 1. Uniform (n=14)		
Inclusions & Distribution: **VIII: Solid Inclusions**: 1. Present (n=8); 2. Absent (n=6) **IX: Void Inclusions:** 1. Present (n= 2); 2. Absent (n=12) **X: Distribution of Solid Inclusions:** 1. Random (n=8); 4. None (n=6) **XI: Distribution of Void Inclusions**: 1. Random (n=2); 4. None (n=12)		
XII: Surface Texture: 1. Smooth (n=14)		
XIII: Surface Luster: 3. Resinous (n=14)		
XIV: Light Transmittance: 1. Opaque (n=13)		
XV: Patina: 3. Partial Dorsal (n=1); 6. Portions of Dorsal and Ventral (n=3); 7. None (n=10)		
XVI: Groundmass Color: 1. Munsell Color – 5B 5/6 (n=1); 5B 6/2 (n=1); 5BG 3/2 (n=7); 5PB 3/2 (n=1); 5Y 2/1 (n=2); 5YR 2/1 (n=1); N1 (n=1)		
Other Observations:		
Size Range of Specimens: 1-2 cm in maximum dimension		
Nontechnical Description of Color: Cortex mostly comes in a variety of moderate blue and dusky blue green with some grayish green and dusky blue. The groundmass is most commonly dusky blue green.		
Characteristics of Inclusions: The inclusions were mostly irregular shapes with some more spherical in appearance. The color of the inclusions (N2, grayish black) were typically darker than the groundmass. The inclusions ranged from 1-3 mm max dimension. (See example inclusions as all dark areas in 1680-3 detail photo above)		
Use: Parke Creek has only ever been found and analyzed in a geological context. No known archaeological sites are associated with the Parke Creek tachylyte source.		

Table 11. Nasty Creek Tachylyte Macroscopic Analysis Summary (n=18)

		
5 from Powell Collection (groundmass)	8 from Powell Collection (cortex)	12 from Powell Collection, detail (cortex with inclusions)

Cortex Variables: (if cortex is present)

I: Grain Size: 2. Aphanitic (n=18)

Inclusions & Distribution:
- **II: Solid Inclusions**: 1. Present (n=14); 2. Absent (n=4)
- **III: Void Inclusions**: 1. Present (n=8); 2. Absent (n=10)
- **IV: Distribution of Solid Inclusions:** 1. Random (n=14); 4. None (n=4)
- **V: Distribution of Void Inclusions**: 1. Random (n=8); 4. None (n=10)

VI: Cortex Color: 1. Munsell Color – 10R 3/4 (n=1); 5B 6/2 (n=2); 5B 7/1 (n=1); 5G 6/1 (n=7); 5GY 6/1 (n=2); 5GY 8/1 (n=1); 5PB 3/2 (n=1); 5Y 8/1 (n=2); 5YR 4/4 (n=1)

Groundmass Variables: (if groundmass is present)

VII: Groundmass: 1. Uniform (n=2); 4. Mottled (n=5); 5. Cortex Present (n=11)

Inclusions & Distribution:
- **VIII: Solid Inclusions**: 1. Present (n=6); 3. Cortex Present (n=12)
- **IX: Void Inclusions:** 1. Present (n= 1); 2. Absent (n=4); 3. Cortex Present (n=13)
- **X: Distribution of Solid Inclusions:** 1. Random (n=6); 3. Cortex Present (n=12)
- **XI: Distribution of Void Inclusions**: 1. Random (n=1); 4. None (n=4); 5. Cortex Present (n=13)

XII: Surface Texture: 1. Smooth (n=14); 6. Cortex Present (n=4)

XIII: Surface Luster: 3. Resinous (n=14); 5. Cortex Present (n=4)

XIV: Light Transmittance: 1. Opaque (n=4); Cortex Present (n=14),

XV: Patina: 6. Portions of Dorsal and Ventral (n=8); 7. None (n=3); 9. Cortex Present (n=7)

XVI: Groundmass Color: 1. Munsell Color – 10YR 2/2 (n=2); 5Y 2/1 (n=8); 5YR 2/1 (n=4); 2. Cortex Present (n=4)

Other Observations:

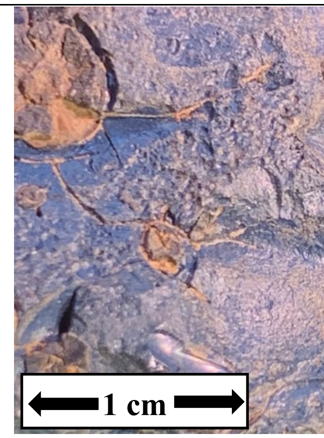
Size Range of Specimens: 1-6 cm in maximum dimension

Nontechnical Description of Color: Cortex mostly comes in a variety of greenish grays with a red oxidized brown as the other most prominent color. The groundmass, when visible, is typically an olive to brownish black.

Characteristics of Inclusions: The inclusions were mostly irregular shapes with some more spherical in appearance. The color of the inclusions (N2, grayish black) were typically darker than the groundmass. The inclusions ranged from 1-3 mm max dimension. (See example inclusions as all dark areas in 12 detail photo above)

Use: Nasty Creek has only ever been found and analyzed in a geological context. No known archaeological sites are associated with the Nasty Creek tachylyte source.

Table 12. Cleman Mountain Tachylyte Macroscopic Analysis Summary (n=31)

		
7 from Cleman Mtn. #1 (cortex)	6 from Cleman Mtn #3 (groundmass)	4 from Cleman Mtn #1, Detail (cortex with inclusions)
Cortex Variables: (if cortex is present)		
I: Grain Size: 2. Aphanitic (n=31)		
Inclusions & Distribution: **II: Solid Inclusions**: 1. Present (n=27); 2. Absent (n=4) **III: Void Inclusions**: 1. Present (n=8); 2. Absent (n=23) **IV: Distribution of Solid Inclusions:** 1. Random (n=27); 4. None (n=4) **V: Distribution of Void Inclusions**: 1. Random (n=8); 4. None (n=23)		
VI: Cortex Color: 1. Munsell Color – 5B 5/1 (n=1); 5B 5/6 (n=4); 5B 6/2 (n=6); 5BG 5/2 (n=2); 5G 3/2 (n=1); 5G 4/1 (n=1); 5GY 6/1 (n=1); 5PB 3/2 (n=6); 5Y 4/1 (n=1); 5YR 5/6 (n=1); N2 (n=2); N3 (n=2); N4 (n=1)		
Groundmass Variables: (if groundmass is present)		
VII: Groundmass: 1. Uniform (n=8); 4. Mottled (n=16); 5. Cortex Present (n=7)		
Inclusions & Distribution: **VIII: Solid Inclusions**: 1. Present (n=19); 2. Absent (n=4); 3. Cortex Present (n=8) **IX: Void Inclusions:** 1. Present (n= 2); 2. Absent (n=21); 3. Cortex Present (n=8) **X: Distribution of Solid Inclusions:** 1. Random (n=19); 4. Absent (n=4); 5. Cortex Present (n=8) **XI: Distribution of Void Inclusions**: 1. Random (n=2); 4. None (n=21); 5. Cortex Present (n=8)		
XII: Surface Texture: 1. Smooth (n=23); 6. Cortex Present (n=9)		
XIII: Surface Luster: 3. Resinous (n=23); 5. Cortex Present (n=9)		
XIV: Light Transmittance: 1. Opaque (n=7); 4. Cortex Present (n=24),		
XV: Patina: 2. Entire Dorsal (n=1); 6. Portions of Dorsal and Ventral (n=16); 7. None (n=5); 9. Cortex Present (n=9)		
XVI: Groundmass Color: 1. Munsell Color – 5B 5/6 (n=3); 5B 7/6 (n=1); 5G 4/1 (n=2); 5GY 2/1 (n=1); 5PB 3/2 (n=13); 5Y 2/1 (n=2); 5YR 2/1 (n=1); N1 (n=1); N2 (n=1); 2. Cortex Present (n=6)		
Other Observations:		
Size Range of Specimens: 1-10 cm in maximum dimension		
Nontechnical Description of Color: Cortex mostly comes mostly in pale blue and dusky blue with a range of blue color variation in between. The groundmass, when visible, was most commonly a dusky blue with couple as a moderate blue.		
Characteristics of Inclusions: The inclusions were mostly irregular shapes with some more spherical in appearance. The color of the inclusions (N2, grayish black) were typically darker than the groundmass. The inclusions ranged from 1-3 mm max dimension. (See example inclusions as all dark areas in 4 detail photo above)		
Use: Reported from two sites in Washington (45CL654, 45YA638)		

In this analysis, there were several Dimensions that were typically consistent throughout every sample and source location. These dimensions were Grain Size (I), Surface Texture (XII), and Surface Luster (XIII). When cortex was present, the Grain Size (I) was 2. Aphanitic on all of the samples. When the samples had enough groundmass present, the Surface Texture (XII) and the Surface Luster (XIII) of were 1. Smooth and 3. Resinous, respectively.

Most of the variation between the different tachylyte sources and their Dimensions were based on the colors of the cortex (Dimension VI) and the groundmass (Dimension XVI). Although all of the sources had some type of blue variation, Parke Creek and Cleman Mountain were more consistently found in hues of blue than the others. Douglas Creek was typically yellowish brown on the cortex and olive black for the groundmass, Stray Gulch was characterized by shades of gray and olive, and Nasty Creek commonly had greenish gray cortex with oxidation and the groundmass was brown to olive black.

Solid Inclusions in the cortex and groundmass (Dimensions II and VIII) were typically present on most of the samples in the form of spherical and irregular shaped bubbles; however, they came in a variety of shapes and sizes depending on the source. Some of the inclusions were bubbles that appeared different than the groundmass with a different texture (e.g., see upper right photographs in Table 10 and Table 12). These inclusions were either isolated bubble-like spheres or irregular shapes made up of multiple bubbles massing together. Some of the spherical bubbles were encompassed by white rinds (see upper right photograph in Table 8). Other variations between the sources were present but none as noticeable as the color and the type of inclusions.

Although there can be some distinctions between the sources of tachylyte and the appearance of their associated colors and inclusions, there is also a significant amount of overlap. A lot of the tachylyte sources contain the same colors even if one has more of an abundance of one color than the other. Stray Gulch, for example, is typically shades of gray and olive but there were also a few occurrences of blue which was more commonly found in the Cleman Mountain and Parke Creek sources. The inclusions can vary from one source to the other (e.g. Stray Gulch typically has bubbles while Parke Creek has irregular shaped clusters), but the inclusions can also vary within a source and should not be considered a defining characteristic of one source from the other. Based off of these results, I would hesitate to definitively assign a source of tachylyte based solely on macroscopic appearance.

CHAPTER VI

RESULTS: VOLCANIC GLASS ARTIFACT DISTRIBUTION

This section will address Objectives 4 and 5. The goal of Objective 4 is as follows: investigate the occurrence of Washington's volcanic glasses in Washington archaeological assemblages to establish the distribution of identified Washington volcanic glass toolstones in relation to each other and to out-of-state volcanic glasses. The goal of Objective 5 is as follows: analyze the distribution of Washington artifacts subject to XRF source analysis by NWROSL and their volcanic glass sources. The dataset that I will be using to conduct this analysis is from the August 2020 spreadsheet from Craig Skinner that details all of the Washington sites that NWROSL had analyzed up until that time.

Washington Volcanic Glass Source Distribution

Within the state of Washington there are 16 geochemically distinct volcanic glass sources, 12 of which are found within archaeology sites throughout the state. There are 3 tachylyte sources (Cleman Mountain, Douglas Creek, and Stray Gulch), 5 vitrophyric obsidian sources (Chelan Butte, Copper Ridge A, B, C, and D), and 8 obsidian sources (Agnes Creek, Bickleton Ridge, Elk Pass, Hosko A, Hosko B, Indian Rock [Unknown Variety A], Satus Creek, and Yakima) (Figure 21). Three of the obsidian sources (Agnes Creek, Hosko A, and Satus Creek) and one vitrophyric obsidian source (Copper Ridge Variety C) have been located geographically and samples have undergone XRF analysis at NWROSL, but they have not yet been found within an archaeology site.

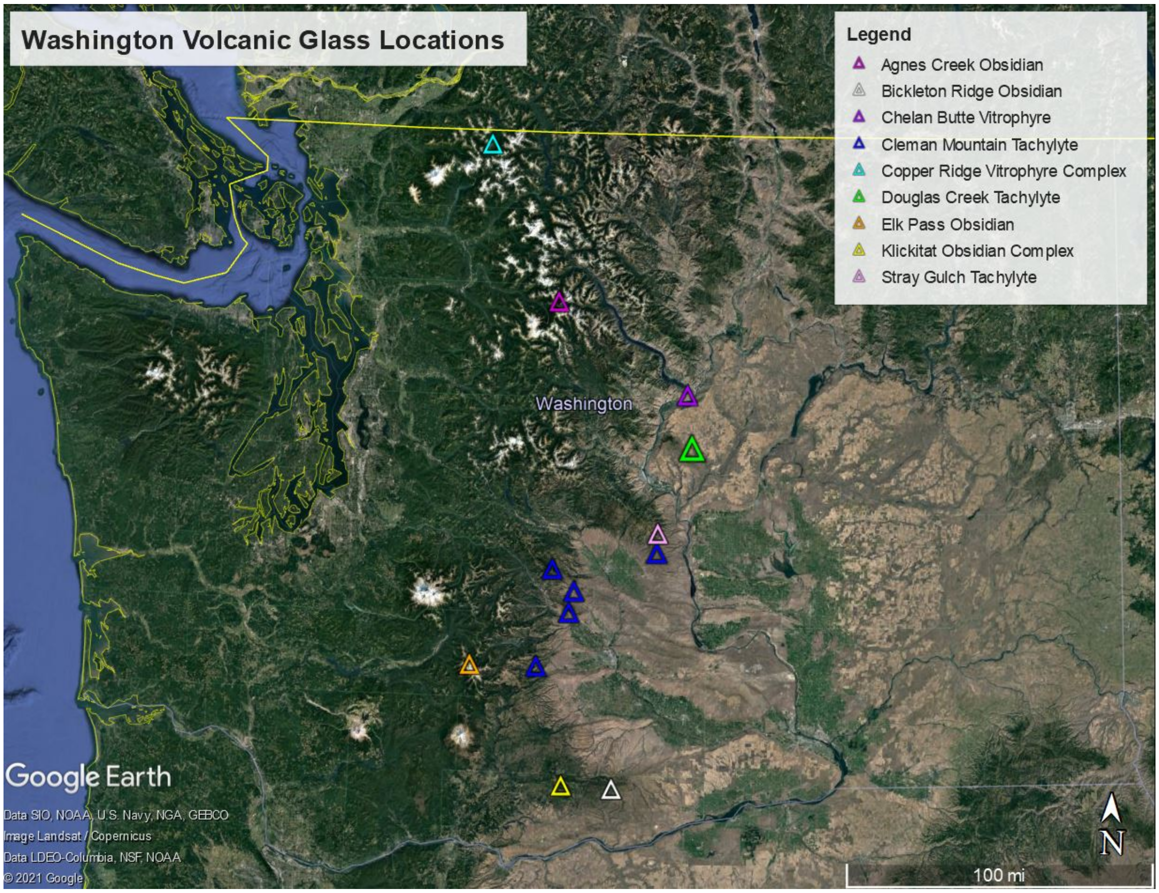


Figure 21. Washington volcanic glass sources used in this thesis. Locations ground-truthed and mapped from NWROSL latitude/longitude data, except for Chelan Butte (see below). Note that "vitrophyre" on the map refers to vitrophyric obsidian.

A source not shown in Figure 21 is named the Yakima source. The "Yakima" source has only been identified a few times from different archaeological sites (Craig Skinner, personal communication 2021). The source was initially identified by Greg Cleveland as a secondary streambed source on the south Fork of Logy Creek which is located in both Klickitat and Yakima counties; however, an exact location is unknown (Gleason et al. 2017). The Chelan Butte source has never been ground truthed and has been named for its proximity to sites in which characterized artifacts have been geochemically distinguished (Craig Skinner, personal communication 2020).

Figure 22 shows the Klickitat County obsidians in more detail. Within the Klickitat County obsidians, the name "Klickitat Complex" was created for use in this thesis to simplify the geographic area that Hosko A and B, Satus Creek, and Indian Rock (Unknown Variety A) represent in Klickitat County, Washington. All three recorded obsidian source locations of the "Klickitat Complex" are within a 3.5-mile extent of each other trending SW/NE. Hosko A and B are recorded at the same geographical location while having different geochemical signatures. Bickleton Ridge is within Klickitat County however it is far enough away from the other three sources that it is easy to represent it separately on the map. (Note that the Indian Rock source was known as "Unknown Variety A" in the NWROSL dataset for years until the source location was discovered and named "Indian Rock;" I will use both names together following NWROSL practice.)

The Copper Ridge Complex is composed of four geochemically distinct sources of vitrophyric obsidian, varieties A, B, C, and D, all located in close proximity of each other on Copper Ridge in North Cascades National Park. The ridge is between Copper Mountain and the Chilliwack River near the north end of the Park. One latitude/longitude location is given for all four varieties from the NWROSL source location database. The exact locations of Variety A and B outcrops are provided in Mierendorf and Baldwin (2015:95) while Variety C and D locations are noted in text as in the vicinity as Variety A, without providing an exact location (Mierendorf and Baldwin 2015:91). Figure 23 shows the source locations for Variety A and B as provided by Mierendorf and Baldwin (2015).

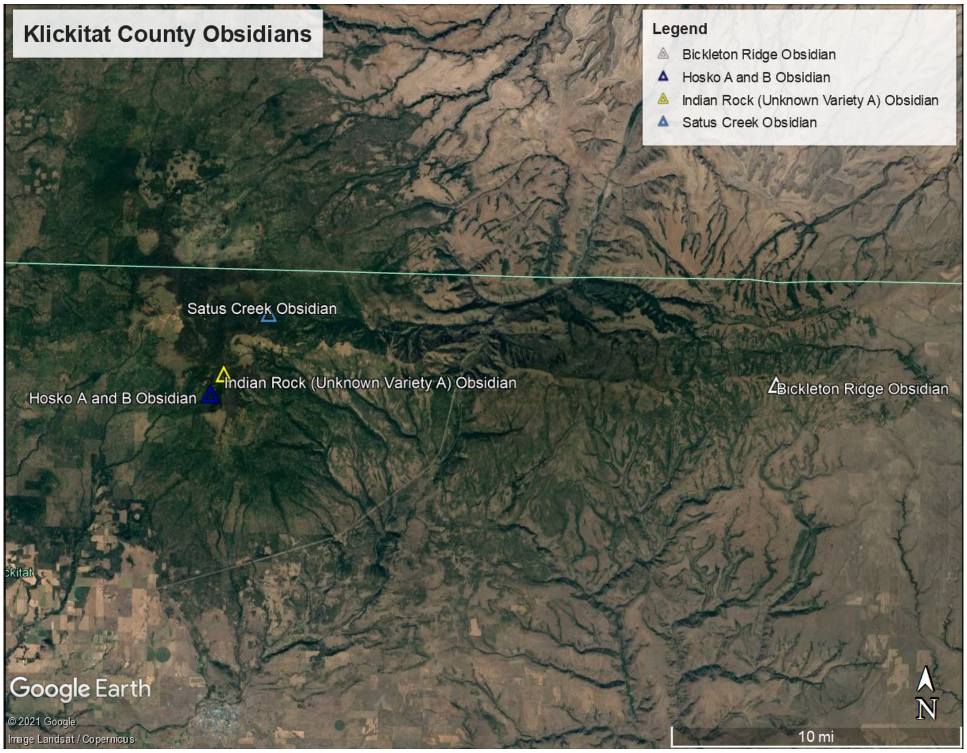


Figure 22. Klickitat County obsidian sources detail map. This includes the Klickitat Complex (Satus Creek, Indian Rock [Unknown Variety A], Hosko A, Hosko B), and Bickleton Ridge.

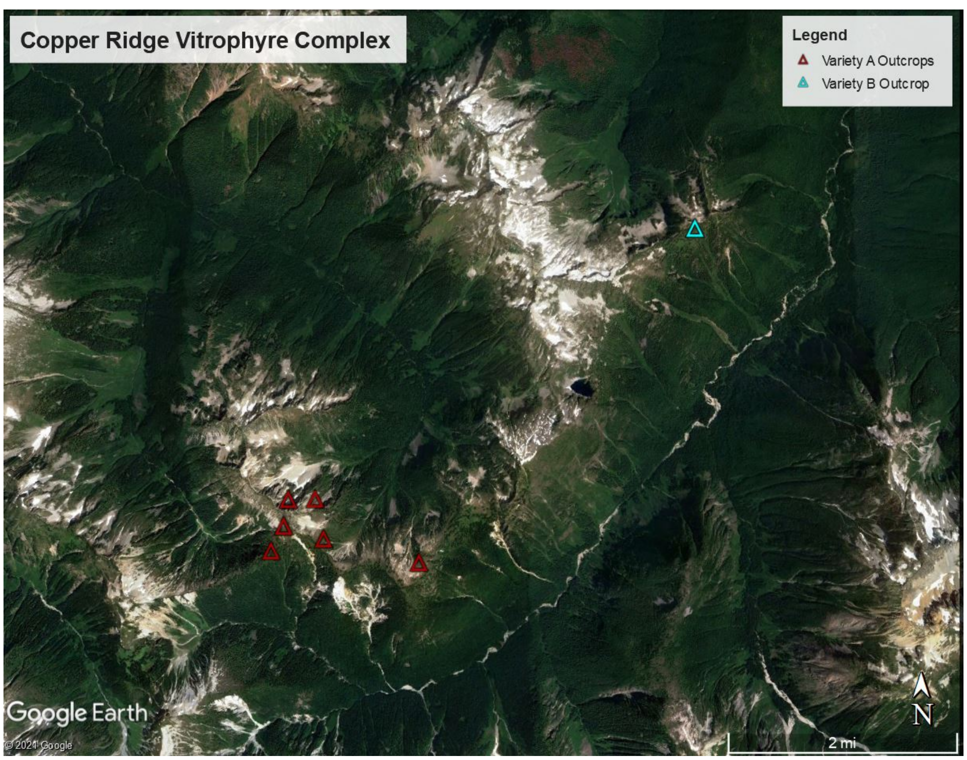


Figure 23. Copper Ridge vitrophyric obsidians sources detail map. Location data from Mierendorf and Baldwin (2015:91). Note that "vitrophyre" on the map refers to vitrophyric obsidian.

Cleman Mountain Tachylyte is composed of five known (ground-truthed) outcrops whose distribution ranges 50 miles NE/SW by 20 miles NW/SE in Kittitas and Yakima counties (Figure 24). Prior to this thesis, the Cleman Mountain geochemical source included three outcrops (Cleman Mountain, Manastash Ridge, and 06-17-08-238/613); however, research conducted in this thesis revealed that two more outcrops, Parke Creek and Nasty Creek (Rocky Coulee), could be added to the Cleman Mountain Tachylyte distribution after it was discovered that they were not geochemically distinct enough to differentiate (see XRF Results above). Although Stray Gulch Tachylyte is only 6 miles north of the Parke Creek outcrop, it is geochemical distinct from the Cleman Mountain Tachylyte group and is therefore separated as a distinct source.

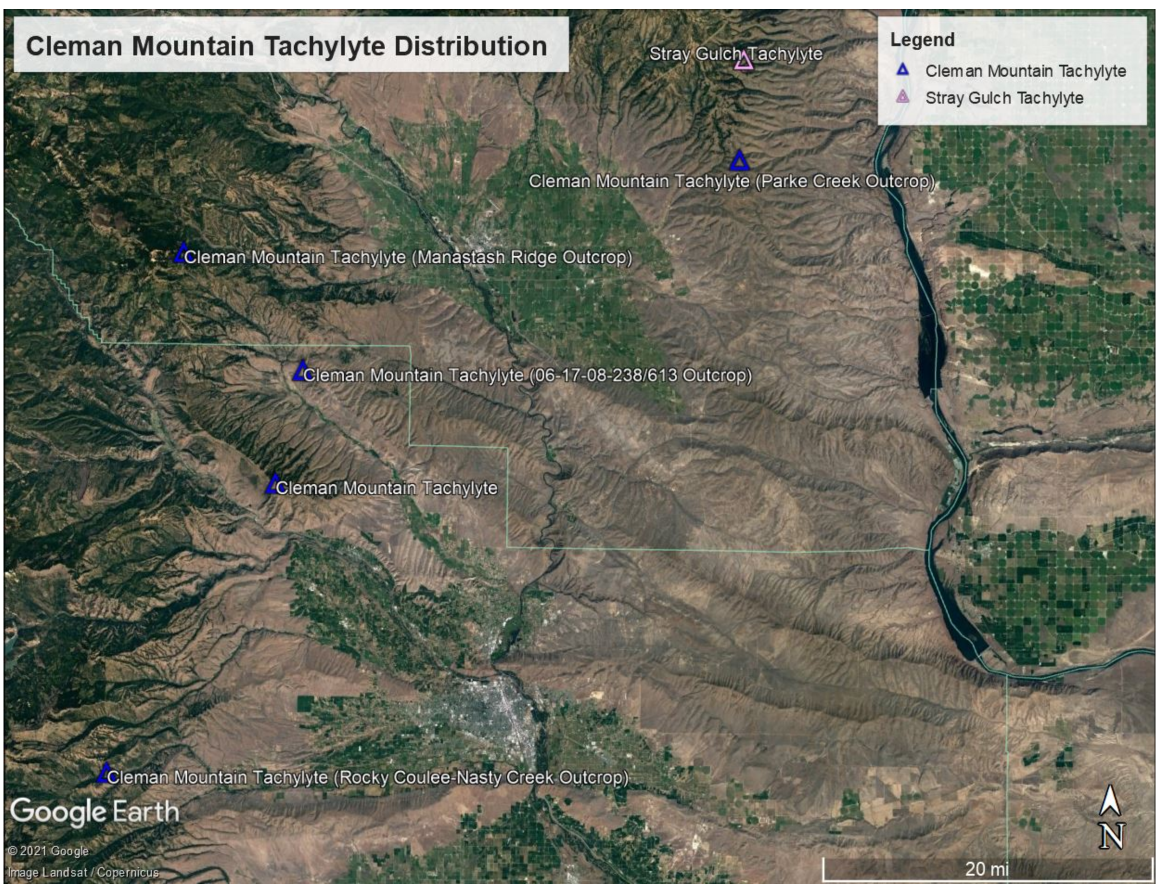


Figure 24. Cleman Mountain tachylyte source distribution map.

Volcanic Glass Spread in Washington Sites

Figure 25 represents the sites that have undergone formal XRF analysis at the NWROSL as of August 2020 (personal communication, Craig Skinner 2020). The sites represented in this map are limited to what has been sent to NWROSL and are by no means a complete representation of all pre-contact sites in the state of Washington. Out of the 1,663 artifacts analyzed, 323 or 19.3% have been from Washington volcanic glass sources while the remaining 1,342 or 80.7% have come from out of state sources. Out of the 260 sites that have been analyzed, 70 sites or 26.9%, contain Washington glasses. Within the 70 sites with Washington sources that have been analyzed, 43 sites or 61.4% contain only Washington glasses and no out of state glasses.

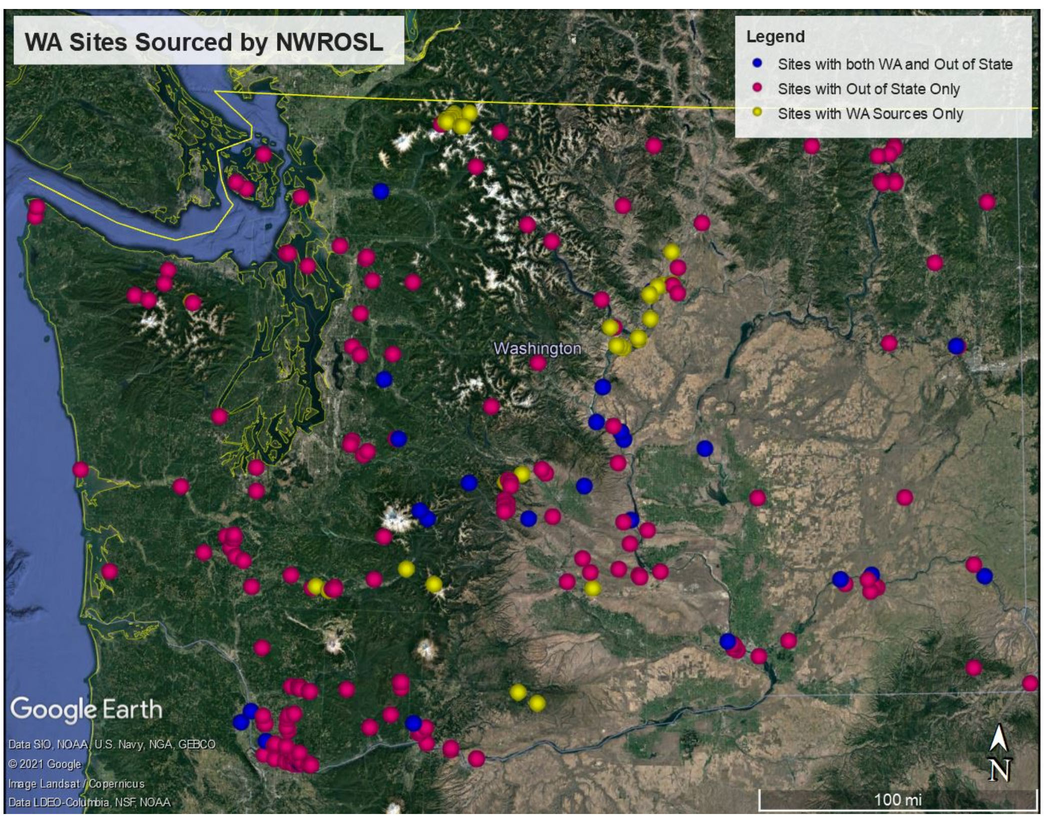


Figure 25. Washington archaeological sites with volcanic glasses sourced by NWROSL, sorted into three categories. Site locations mapped from NWROSL latitude/longitude data for this and following maps, unless otherwise noted.

Table 13 represents the 70 sites in Washington that contain Washington glasses. Most of these sites also contain out of state sources. The total count analyzed at each site and the percent that come from a Washington source is provided. The sites that are highlighted in gray contain two or more Washington glasses.

Table 13. Summary of Washington Sites with Washington Glasses Present[1]

Site	Washington Source	Count	Out of State Count	Total	% WA Sources
45-BN-583	Bickleton Ridge	2	11	13	15%
45-CA-271	Copper Ridge Variety B	1	0	1	100%
45-CH-216	Chelan Butte	13	0	13	100%
45-CH-57	Chelan Butte	3	0	3	100%
45-CH-58	Chelan Butte	3	0	3	100%
45-CH-61	Chelan Butte	7	0	7	100%
45-CH-204	Unknown Tachylyte	1	5	6	17%
45-CH-217	Chelan Butte	1	0	1	100%
45-CH-782	Chelan Butte	2	0	2	100%
45-CH-791	Douglas Creek	3	5	8	38%
45-CL-1 (Cathlapotle)	Indian Rock (Unknown Variety A)	2	301	303	<1%
45-CL-463	Indian Rock (Unknown Variety A)	1	1	2	50%
45-CL-654	Cleman Mountain	1	10	11	6%
45-DO-387	Chelan Butte	2	2	4	50%
45-DO-409	Chelan Butte	3	0	3	100%
45-DO-417	Chelan Butte	2	0	2	100%
45-DO-59	Douglas Creek	3	1	4	75%
45-DO-917	Unknown Tachylyte	1	1	2	50%
45-FR-5 (Strawberry Island/Miller)	Unknown Tachylyte	1	15	16	6%

[1] sites in gray have two or more Washington sources

Table 13. Summary of Washington Sites with Washington Glasses Present[1] (Continued)

Site	Washington Source	Count	Out of State Count	Total	% WA Sources
45-FR-39	Bickleton Ridge	3	2	6	67%
	Indian Rock (Unknown Variety A)	1			
45-FR-50 (Marmes Rockshelter)	Unknown Tachylyte	1	30	31	3%
45-GR-630	Stray Gulch	1	4	5	20%
45-KI-1080	Indian Rock (Unknown Variety A)	2	7	9	22%
45-KI-263	Bickleton Ridge	1	2	4	50%
	Stray Gulch	1			
45-KL-1675	Hosko B	1	0	1	100%
45-KT-1407 (WEN-54)	Stray Gulch	2	0	2	100%
45-KT-301 (Grissom)	Bickleton Ridge	19	36	110	67%
	Douglas Creek	31			
	Indian Rock (Unknown Variety A)	5			
	Stray Gulch	17			
	Unknown Tachylyte	1			
	Yakima WA	1			
45-KT-991	Bickleton Ridge	1	1	2	50%
45-LE-286	Elk Pass	6	0	6	100%
45-LE-415 (Beech Creek Site)	Elk Pass	50	0	50	100%
45-LE-425	Elk Pass	1	0	1	100%
45-OK-69	Chelan Butte	1	0	1	100%
45-OK-113	Chelan Butte	1	1	2	100%
45-OK-382	Bickleton Ridge	2	1	3	67%
45-OK-419	Chelan Butte	5	0	5	100%
45-OK-422	Chelan Butte	9	0	9	100%
45-OK-424	Chelan Butte	4	0	4	100%

[1] sites in gray have two or more Washington sources

Table 13. Summary of Washington Sites with Washington Glasses Present[1] (Continued)

Site	Washington Source	Count	Out of State Count	Total	% WA Sources
45-OK-426	Chelan Butte	2	0	2	100%
45-PI-406 (Tipsoo Lake Site)	Bickleton Ridge	2	27	32	16%
	Elk Pass	3			
45-PI-408 (Sunrise Ridge Borrow Pit)	Bickleton Ridge	1	56	57	2%
45-SA-11	Indian Rock (Unknown Variety A)	2	123	125	2%
45-SA-444 (Powerhouse Bridge)	Indian Rock (Unknown Variety A)	1	7	8	13%
45-SK-258	Copper Ridge Variety A	1	12	16	25%
	Copper Ridge Variety B	3			
45-SP-342	Bickleton Ridge	1	5	6	17%
45-WH-455	Copper Ridge Variety A	5	0	5	100%
45-WH-462	Copper Ridge Variety B	9	0	9	100%
45-WH-478	Copper Ridge Variety A	1	0	1	100%
45-WH-479	Copper Ridge Variety A	5	0	5	100%
45-WH-480	Copper Ridge Variety A	5	0	5	100%
45-WH-481	Copper Ridge Variety A	5	0	5	100%
45-WH-482	Copper Ridge Variety B	1	0	1	100%
45-WH-484	Copper Ridge Variety B	11	0	11	100%
45-WH-486	Copper Ridge Variety A	1	0	1	100%
45-WH-503	Copper Ridge Variety B	6	0	6	100%
45-WH-505	Copper Ridge Variety B	4	0	5	100%
	Copper Ridge Variety D	1			
45-WH-515	Copper Ridge Variety B	1	0	1	100%
45-WH-549 (FS 262)	Copper Ridge Variety A	1	0	2	100%
	Copper Ridge Variety B	1			
45-WH-554 (FS 261)	Copper Ridge Variety A	5	0	5	100%
45-WH-555 (FS 265)	Copper Ridge Variety A	4	0	4	100%

[1] sites in gray have two or more Washington sources

Table 13. Summary of Washington Sites with Washington Glasses Present[1] (Concluded)

Site	Washington Source	Count	Out of State Count	Total	% WA Sources
45-WH-631	Copper Ridge Variety B	3	0	3	100%
45-WT-41 (Granite Point)	Unknown Tachylyte	1	14	15	7%
45-YA-638	Cleman Mountain	1	3	4	25%
AAR-1271-39	Bickleton Ridge	1	0	1	100%
Elk Heights	Stray Gulch	2	0	2	100%
FS 06-17-08-491 (Lotsa Lost Flakes)	Indian Rock (Unknown Variety A)	9	7	16	56%
IF 112	Copper Ridge Variety B	1	0	1	100%
Indian Rock NE	Indian Rock (Unknown Variety A)	1	0	1	100%
Isolate 44	Indian Rock (Unknown Variety A)	1	0	1	100%
Reflection Pond Site	Chelan Butte	1	0	1	100%
WEN-59	Stray Gulch	1	0	1	100%
	TOTAL	323	690	1013	

[1] sites in gray have two or more Washington sources

Washington Volcanic Glass Artifact Distribution

Figure 26 shows the distribution of sites that contain artifacts with Washington sources based on XRF analyses conducted by NWROSL. Some of the sources have a localized spread (e.g. Elk Pass obsidian) while other sources have artifacts found in sites throughout the state (e.g. Bickleton Ridge obsidian). Analyzed artifacts are within 100 miles of the source location except for one site with Cleman Mountain tachylyte, two sites with Bickleton Ridge obsidian, one site with Copper Ridge Complex, and one site with Klickitat complex obsidian. The distribution within or outside of a 50-mile buffer will be discussed under “local” and “nonlocal” below.

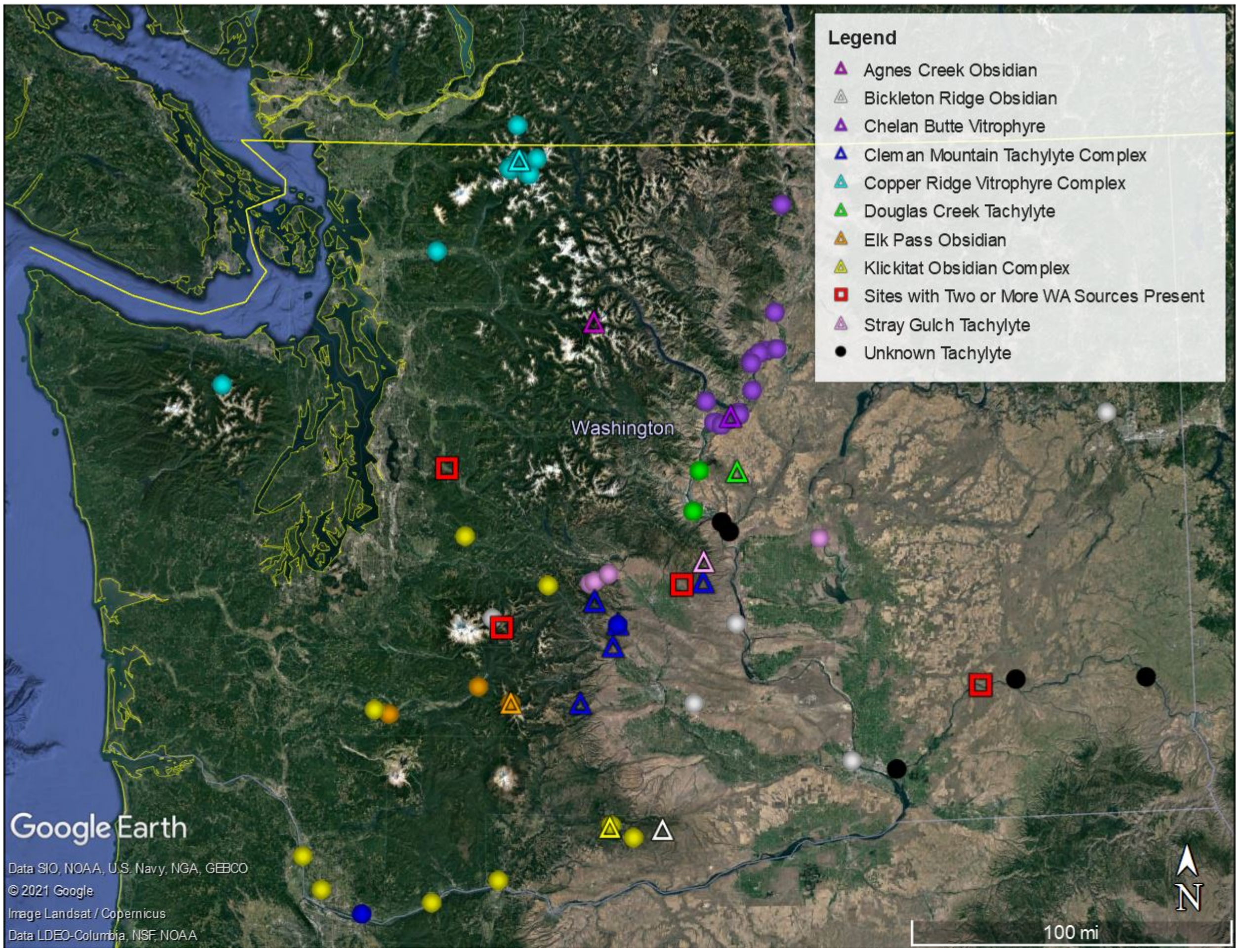


Figure 26. Washington archaeological sites with Washington volcanic glasses sourced by NWROSL. The data for this map is in Table 14. The "two or more WA sources" group excludes sites with multiple sources in the same geographic complex. Note there no sites with artifacts matched to the Agnes Creek source. For the Cleman Mountain source, which has five known outcrop locations, only the Cleman Mountain outcrop location is shown on this map. Note that "vitrophyre" on the map refers to vitrophyric obsidian.

It should be noted that the thesis artifact data includes a very uneven sample, in that materials have been submitted irregularly to NWROSL for sourcing, and some sites have had many samples submitted, while other sites have had only one sample submitted. NWROSL sample sizes per site vary from 1 to 303 artifacts from any volcanic glass source in these 70 sites, with 1 to 74 artifacts from Washington sources. The vast majority of sites (n=52, 74%) have <5 Washington source samples present while only 2

Table 14. Summary of Artifacts Sourced to Washington Volcanic Glass Outcrops from NWROSL

Source	Material[1]	Artifact Count	Artifact %	Site Count[2]	Site %
Bickleton Ridge	Obsidian	33	10.2	10	14.3
Chelan Butte	Vitrophyre	59	18.3	16	22.9
Cleman Mountain	Tachylyte	2	<0.1	2	2.9
Copper Ridge	Vitrophyre	75	23.2	19	27.1
Douglas Creek	Tachylyte	37	11.5	3	4.3
Elk Pass[3]	Obsidian	60	18.6	4	5.7
Klickitat Complex	Obsidian	26	8.0	11	15.7
Stray Gulch	Tachylyte	24	7.4	6	8.6
Unknown	Tachylyte	6	1.9	6	8.6
Yakima	Obsidian	1	<0.1	1	1.4
	Total=	323	--	70	--

[1] Note that material listed as vitrophyre are vitrophyric obsidian and those listed as obsidian are non-vitrophyric
[2] Site Count includes all sites with this source. Since some sites have multiple sources, the same site may be counted multiple times. Since there are 70 sites total, that is listed here and used for % calculations, even though the column would add to 78.
[3] Note that Elk Pass has only 4 sites in the NWROSL database but has also been sourced by Richard Hughes XRF analyses (McClure 2015:112), bringing the total number to 13 sites. This illustrates a limitation of the thesis dataset.

sites (3%) have >20 Washington source samples submitted. These two sites with the largest samples containing Washington sourced artifacts are 45LE415 (n=50) and Grissom (45KT301, n=74).

With this in mind, the number of artifacts sourced to each Washington volcanic glass are summarized in Table 14. Obsidian artifacts compose 120 (37%) of the 323 sourced artifacts, vitrophyric obsidian 134 (42%), and tachylyte 69 (21%). The most abundant Washington sourced artifacts are made of Chelan Butte vitrophyric obsidian, Copper Ridge Complex, and Elk Pass obsidian, but this may tell us more about research agendas than patterns of use. Chelan Butte and Copper Ridge also are found in the highest proportion of sites with sourced artifacts, but Elk Pass is less common than Klickitat Complex obsidians, Bickleton Ridge obsidian, Stray Gulch tachylyte, and unknown tachylyte when utilizing the NWROSL dataset. Cleman Mountain tachylyte is the least encountered source material, which is interesting given that it has the widest outcrop distribution. Perhaps this reflects the low quality and/or small size of the nodules.

Obsidian Dispersal

The sites containing artifacts from the Elk Pass obsidian are within a limited range of the source (<40 miles) (Figure 27). McClure (2015) discusses this trend in his research surrounding the Elk Pass obsidian outcrops and the material dispersion into the surrounding archaeology sites. Out of the 11 sites containing Elk Pass obsidian noted in McClure's (2015) study, 2 were submitted for XRF analysis at NWROSL and 9 were submitted for XRF analysis with Richard Hughes (McClure 2015:111). Two of the sites included on Figure 27 are exclusively from the NWROSL data and were not included in McClure's (2015) study. These additional sites fall within the <40 miles from source range although one is outside of the upper Cowlitz River watershed on the eastern flank of Mount Rainier. McClure's research observed that this source of obsidian is almost exclusively found in the upper Cowlitz River watershed. This is thought to the be the result of the Taytanpan people's hunting patterns in pre-contact and ethnohistoric times (McClure 2015:109). Hunting mountain goats in this area was an annual occurrence for the Taytnapam people and the Elk Pass obsidian source is located in the immediate vicinity of a known "goat hunters trail" (McClure 2015). The most frequent tool type at these sites are projectile points made of CCS rather than the local Elk Pass obsidian source, suggesting that the procurement of the obsidian was likely a secondary objective compared to hunting activities (McClure 2015: 110).

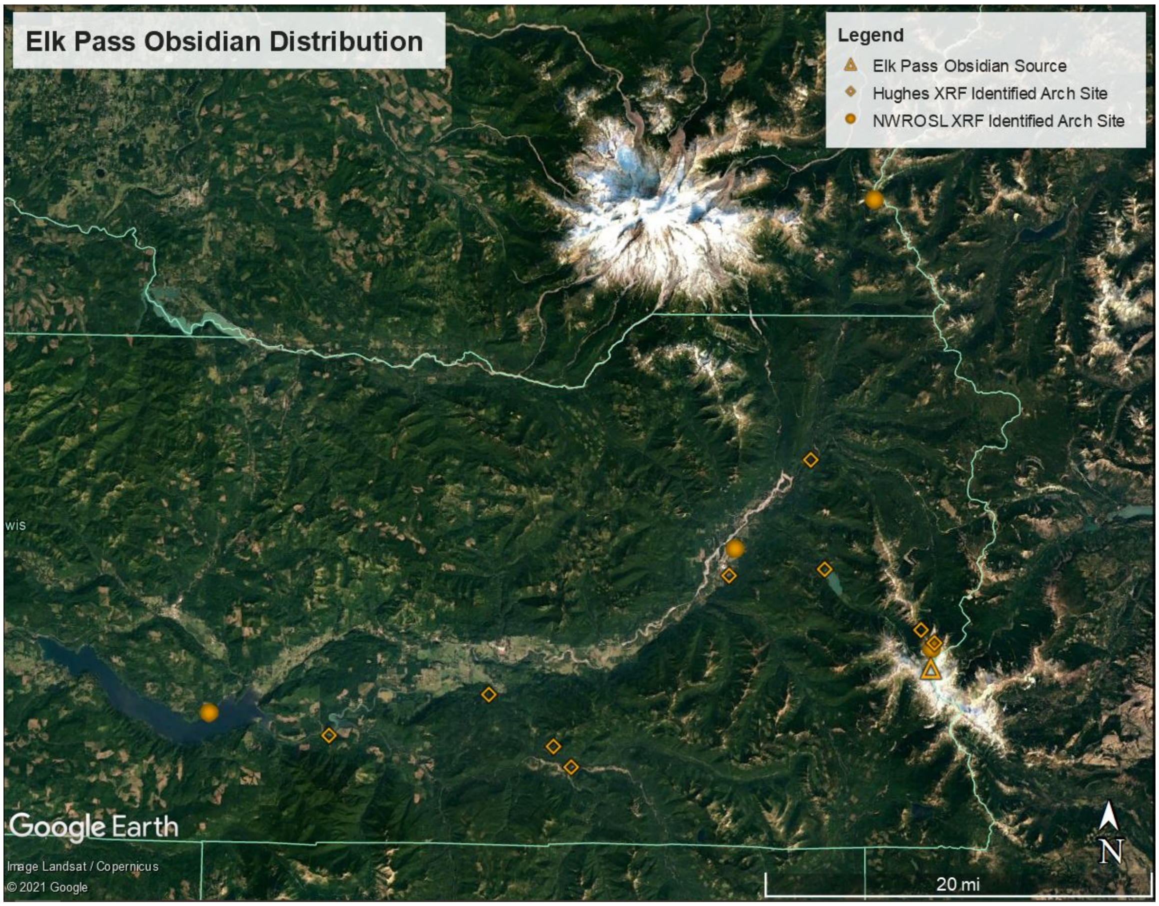


Figure 27. Archaeological sites with Elk Pass obsidian. Hughes location data based on McClure (2015:112) and validated through DAHP's WISAARD locations.

The Klickitat County obsidians are composed of five different geochemical sources of obsidian: Bickleton Ridge, Hosko A and Hosko B, Indian Rock (Unknown Variety A), and Satus Creek. The obsidians from Klickitat County are spread throughout the entire state of Washington, with most of the associated sites surpassing the "local" range of 50 miles (Figure 28) which will be discussed in more detail below. Hosko A and Satus Creek have not been found in the archaeological record and will not be included in this discussion. Hosko B has only been found in one archaeological site (45KL1675), and it was a single fragment of obsidian in a surface site otherwise dominated by CCS (Komen 2009). Interestingly, the Klickitat Complex obsidian artifacts are all mostly from western Washington, while the Bickleton Ridge obsidian artifacts are mostly in eastern Washington.

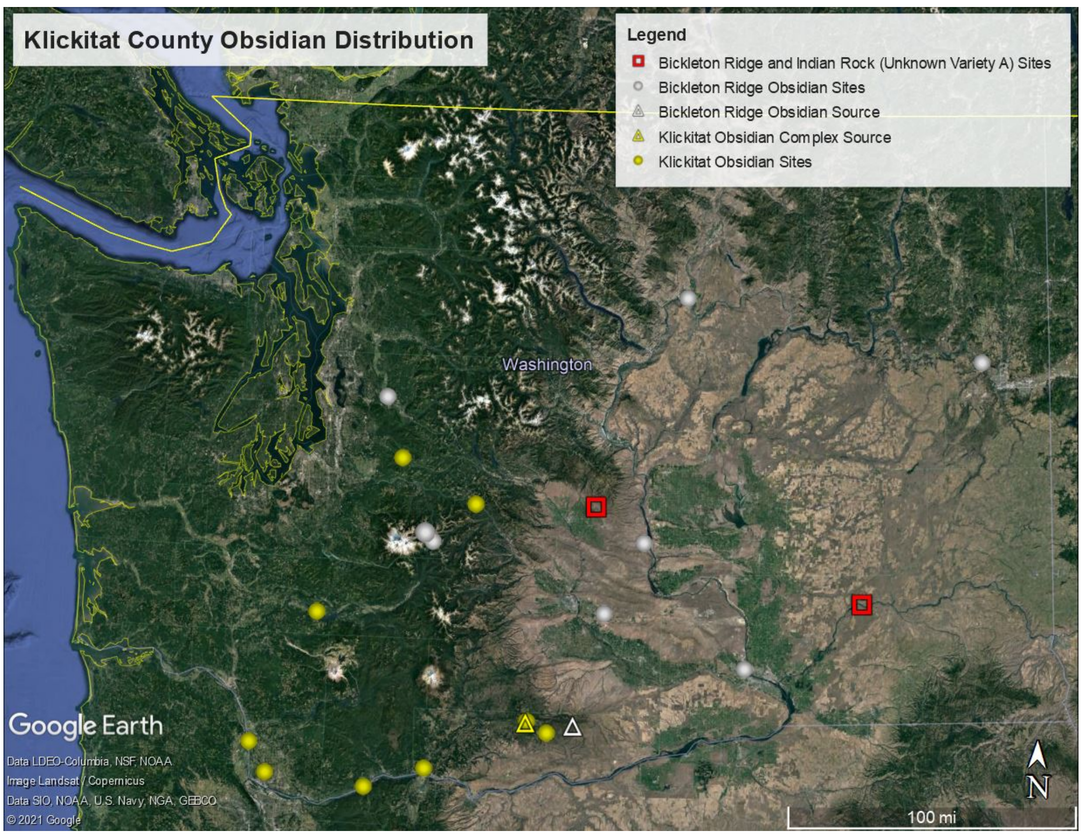


Figure 28. Archaeological sites with Klickitat County obsidians. Hosko B has one site associated with the source: the yellow circle immediately SE of the yellow triangle. All other yellow circles are associated with the Indian Rock (Unknown Variety A) source.

Indian Rock (Unknown Variety A) has only been discussed on two separate occasions in the last decade (Gleason et al. 2017; Parfitt and McCutcheon 2017). Parfitt and McCutcheon's (2017:54) study concerning a collection from the Grissom site (45KT301), noted that the fragments from Indian Rock (Unknown Variety A) consistently contained inclusions, similar to the amount seen in low quality, local glasses, which differed from what they were seeing with non-local obsidians. A more in-depth study of the Indian Rock (Unknown Variety A) source was conducted by a group of archaeologists in 2017 who presented on their findings at the Northwest Anthropological Conference (NWAC) (Gleason et al. 2017). Curious as to the source location of two fragments of glass in a 2015 excavated site (45LE291), the authors of this study set out to find the suspected location of the source in the Simcoe Mountains of south-central Washington. In November 2016, the authors relocated the Indian Rock (Unknown Variety A) source as well as Hosko A and B (Gleason et al. 2017) and submitted samples to NWROSL for geochemical analysis. Additionally, the group looked at the macroscopic characteristics of the source as well as the outcrop characteristics (Gleason et al. 2017). Other than these two studies (Gleason et al. 2017; Parfitt and McCutcheon 2017), there has not been any additional in-depth research on the Indian Rock (Unknown Variety A) source.

The Bickleton Ridge obsidian source appears to have the greatest dispersal throughout the state of Washington with artifacts from this source showing up as far away as Spokane or about 186 miles northeast of the source. It is located about 19 miles east of the other Klickitat County obsidians. Parfitt and McCutcheon (2017) discuss the appearance of Bickleton Ridge source material in the Grissom site (45KT301), the Sunrise Borrow Pit site (45LE408), and the Tipsoo Lake site (45LE406). Bickleton

Ridge is also present in 45KI263, *Yuetswabic*, a known Snoqualmie village site located in Fall City (130 miles NW of source). Schumacher and Burns (2005:57-58) briefly discuss appearance of distant obsidian at the site as indication of pre-contact and ethnohistoric trade and exchange systems that spanned the region. Other than 45KT991, a small lithic scatter, the Bickleton Ridge source appears across the state mostly within large habitation sites (45FR39, 45KT301, 45OK382, 45SP342) potentially indicating a certain regard for this volcanic glass material.

Vitrophyric Obsidian Dispersal

Chelan Butte is considered a vitrophyric obsidian based on the amount of phenocrysts present in its groundmass and was originally noted in the NWROSL database as “Unknown Vitrophyre 1” (Craig Skinner, personal communication 2021). Chelan Butte has a regional distribution that almost exclusively follows the northern Mid-Columbia River Valley (Figure 29). Kassa and McCutcheon (2016) identified 612 pieces of Chelan Butte in their sample of 656 volcanic glass fragments from 18 sites in the northern Mid-Columbia River Valley. There were 53 pieces of the Chelan Butte material verified using XRF sourcing by either NWROSL or the Archaeometry Laboratory at the University of Missouri Research Reactor. The remaining 559 pieces of Chelan Butte vitrophyric obsidian in their sample were macroscopically identified based on the greenish/blue-gray groundmass and abundant phenocrysts present (Kassa and McCutcheon 2016:86). Their study sought to determine if raw material quality played a role in the occurrence, tool form, and use of a volcanic glass source in the 18 sites they studied in the northern Mid-Columbia River Valley (Kassa and McCutcheon 2016:87). Although their study statistically tested many different aspects of raw material source selection and both WA and out of state sources, I am only concerned with the testing that was done on the source-to-site dispersal of Chelan Butte. Kassa and McCutcheon (2016:94) found that the Chelan Butte source was abundant in all flake size classes from these 18 sites, supporting the theory that local, low quality glass would occur at higher frequencies across all size classes compared to non-local, high quality glasses. Other than the discussion on the Chelan Butte source by Kassa and McCutcheon (2016), there has been no additional research on the source.

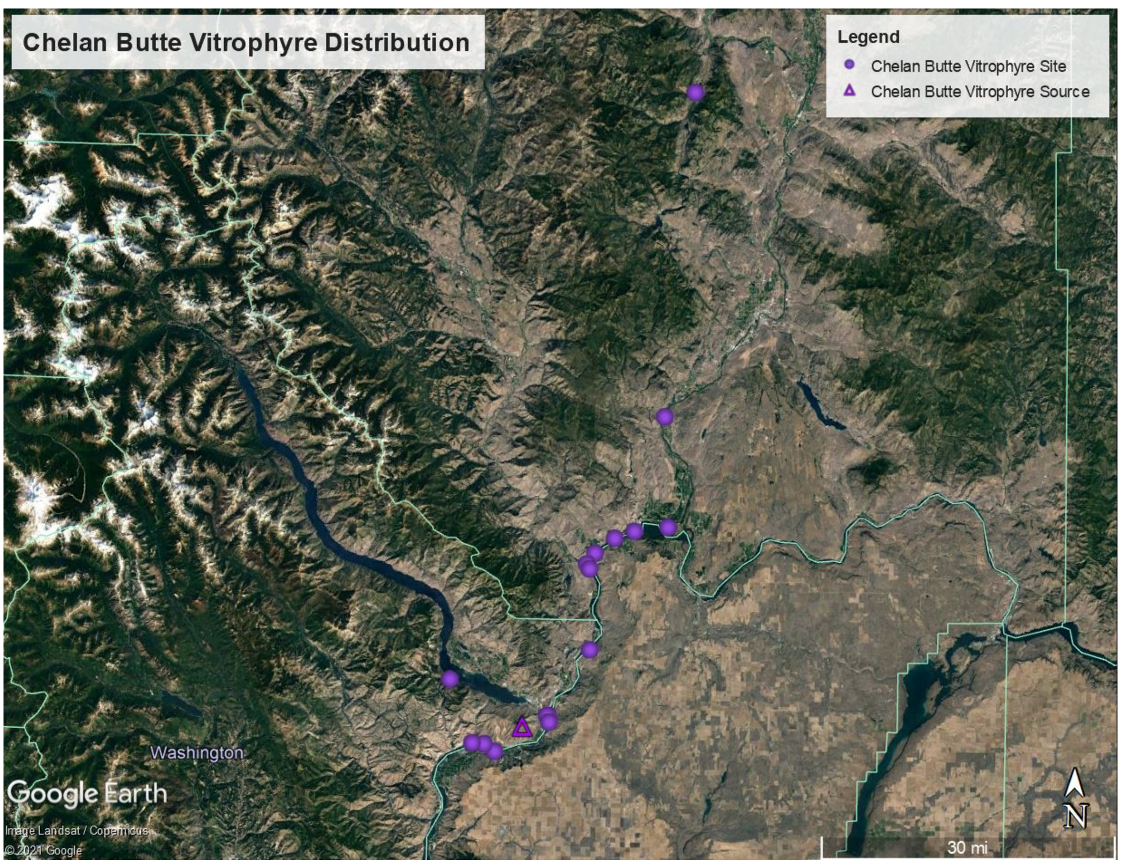


Figure 29. Archaeological sites with Chelan Butte vitrophyric obsidian. The location of the Chelan Butte source is assumed (Craig Skinner, personal communication 2021). Note that "vitrophyre" on the map refers to vitrophyric obsidian.

The Copper Ridge Complex material is almost exclusively limited to sites on Copper Ridge and in a couple of the surrounding drainages within 13 miles of the source outcrops; however, there is one exception with one artifact located at an archaeology site in the Olympic National Forest, 112 miles southwest of the source (see Figure 25). From the NWROSL database there are 19 sites that have been analyzed that contain the Copper Ridge varieties. Out of those 19 sites, there are 3 sites that contain two varieties. Mierendorf and Baldwin (2015) have two sites present in their tables that were not on the list from NWROSL and were not included in this research. The sites listed as "Macro ID" in Figure 30 are directly from the map in Mierendorf and Baldwin (2015:Figure 6-10) and site numbers were not provided for those locations in text but have been included in the map to show the dispersion of the toolstone on Copper Ridge. One site, 45WH486, is listed as having samples from both Variety A and B (Mierendorf and Baldwin 2015:Table 6-3); however, the data from NWROSL lists only Variety A present which is how it is represented on my map.

The use of the Copper Ridge source along Copper Ridge and the surrounding vicinity is thought to reflect the pre-contact land-use patterns of the people living in the populated lowland areas along the Skagit River valley (Mierendorf and Baldwin 2015:97). Copper Ridge is within the upper Skagit River valley, used consistently over millennia as a seasonal hunting and foraging ground by the populations living in the lowlands (Mierendorf and Baldwin 2015:97). This location of the valley is within one of only two rain shadows in this area making it prime as a hunting and gathering grounds

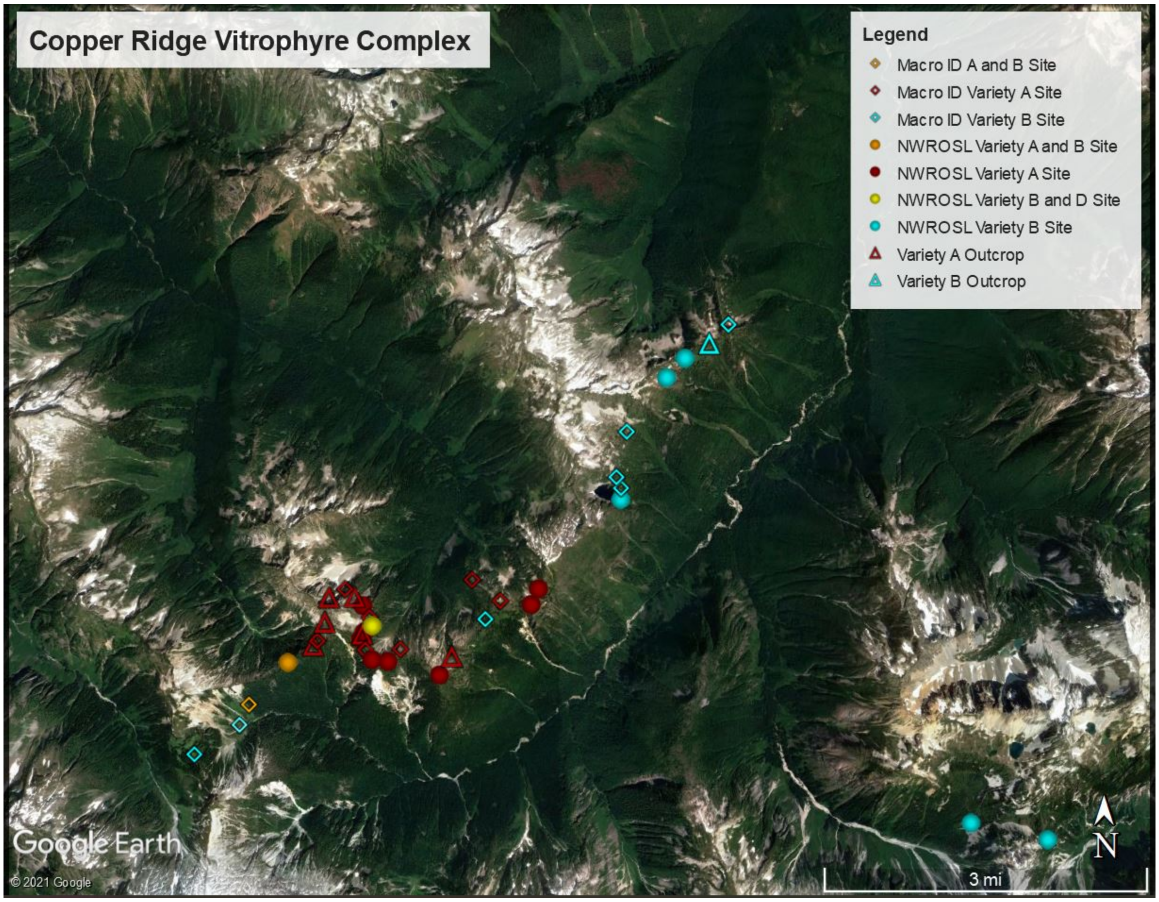


Figure 30. Archaeological sites within the Copper Ridge vicinity containing Copper Ridge vitrophyric obsidian. Macroscopic ID sites and outcrop locations are from Mierendorf and Baldwin (2015:95); NWROSL site locations validated through DAHP's WISAARD location data. Note that "vitrophyre" on the map refers to vitrophyric obsidian.

within the mountainous regions of the Northern Cascades (Mierendorf and Baldwin 2015:97). The site located in the Olympic National Forest (45CA271) is data exclusively from NWROSL and was not included in Mierendorf and Baldwin's (2015) study. The appearance of the Copper Ridge source at this distant site (112 miles southeast of source) suggests that there may have been some trade and exchange of this toolstone.

Tachylyte Dispersal

As mentioned before in this thesis, the discussion of tachylyte and its subsequent distribution throughout the state of Washington has been limited thus far (Mack et al. 2010; Parfitt and McCutcheon 2017). Based on observations through research presented in this thesis, it is apparent that tachylyte use is somewhat localized but not compared to the tighter grouping of the Elk Pass obsidian and most artifacts of the Copper Ridge Complex. Artifacts made from the Douglas Creek source range up to ~40 miles from the source while Stray Gulch artifacts range up to ~ 80 miles and Cleman Mountain artifacts up to ~ 110 miles (see Figure 21).

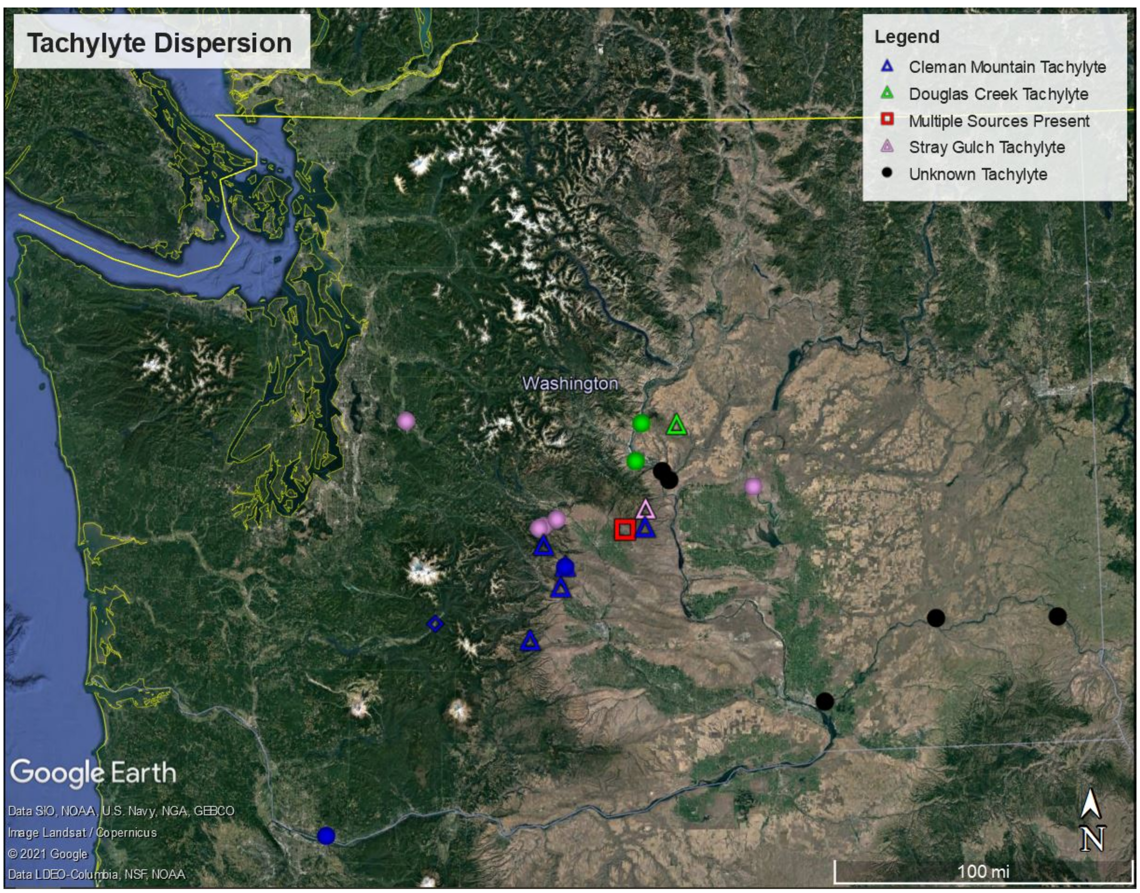


Figure 31. Archaeological sites with tachylyte. Triangles denote source locations, circles and diamond denotes sites. Data from NWROSL, except for the blue diamond, which is from Mack et al. (2010:127, 140).

Parfitt and McCutcheon (2017) discuss the abundance and diversity of obsidian (tachylyte is lumped with the term "obsidian" in their study) with regards to the Grissom site (red square in Figure 31) which is speculated to be the location or near the location of an ethnohistoric, tertiary, trade hub (Parfitt and McCutcheon 2017:60-61). In Table 13, there are 49 sourced tachylyte artifacts from the Grissom site: 17 Stray Gulch, 31 Douglas Creek, and 1 from an unknown source . Interestingly, although the site lies within the distribution of Cleman Mountain source outcrops, there are no Cleman Mountain tachylyte artifacts from the site.

Stray Gulch tachylyte has been found at six sites in Washington. Parfitt and McCutcheon's research on the Grissom site indicated the abundance of the low-quality (greater amount of inclusions) Stray Gulch tachylyte aligned with the predicted expectations of Eerkens et al. (2007). Eerkens et al. (2007) speculate cores and larger flakes should be made principally from local sources (Stray Gulch tachylyte is <10 miles northeast of the site). Other research surrounding the use and movement of Stray Gulch tachylyte has been limited. Only latitude/longitude coordinates are available for two of the sites (WEN-59 and Elk Heights, see Table 13); no further research or information has been found regarding those two sites. The final three sites containing Stray Gulch tachylyte were found on WISAARD and had some additional information associated with them. Based on site forms, sites 45GR630 and 45KI263 (*Yuetswabic*) were large, data recovery excavations that recovered thousands of lithics while 45KT1407 is noted as a small lithic scatter. Site 45KI263 (*Yuetswabic*) is the location of a Snoqualmie Village located in Fall City (Schumacher and Burns 2005). Although not as detailed as the study conducted by Parfitt and McCutcheon (2017), Schumacher and Burns (2005) speculate that the appearance of not only the Stray Gulch tachylyte but also obsidian from southern Idaho/northern Nevada indicate that a far-reaching, trans-Cascade trade and exchange system that was likely being utilized at this site (Schumacher and Burns 2005:57-58).

Cleman Mountain tachylyte has been sourced to only three sites in Washington despite its large geographic spread over five different outcrops. Mack et al. (2010:127, 140) recovered a single piece of Cleman Mountain sourced tachylyte from the Beech Creek Site (45LE415). Site 45LE415 has been included in Figure 31 as a blue diamond because the piece was part of a different XRF study and not included in the NWROSL database. Of the 111 artifacts that have been sent in from 45LE415 over the course of 20 years, only 1 piece (<1%) has come from the Cleman Mountain tachylyte source. The other two sites, 45CL654 and 45YA638, have both had XRF sourcing conducted although a more thorough investigation of either site has not taken place.

The Douglas Creek tachylyte source has only been recently identified (post 2013) and has seen some research mostly in the form of macroscopic observations. A large midden was excavated along the Columbia River in 2013 (45CH791) which turned up five pieces of tachylyte from the Douglas Creek source, three of those were sent in for XRF analysis at NWORSL while the other two were macroscopically identified. All the pieces that were noted in the site were considered to be of a better quality than expected for tachylyte (Davis et al. 2013:39-40). The Grissom site (45KT301), discussed above also contained 31 pieces of Douglas Creek tachylyte. At the time of Parfitt and McCutcheon's (2017) study only a single piece of Douglas Creek was sourced from the

Grissom site; however, as of the August 2020 database from NWROSL an additional 30 pieces of Douglas Creek tachylyte have been sourced from the Grissom site. An analysis of this data has recently been completed by Nik Simurdak (2021) for a Farrell Scholarship project and will not be included or discussed in this thesis. The final site that contains the Douglas Creek tachylyte that has been sourced is the Orondo Rockshelter (45DO0059). The Orondo Rockshelter contains pictographs and human remains, however information about the Douglas Creek artifact could not be obtained.

There is tachylyte from unknown sources distinct from Stray Gulch, Cleman Mountain, and Douglas Creek found in six archaeology sites throughout Washington. Based on their trace elements there appear to be four to five geochemically distinct sources (Craig Skinner, personal communication 2021). Five of the sites contain only unknown tachylyte as their sole, potentially Washington based volcanic glass while one of them, the Grissom site in Kittitas county, contains six different Washington volcanic glasses. Three of the six sites that contain unknown tachylyte all follow along the Snake River on the Washington/Oregon border. The remaining two sites are along the banks of the Columbia River in Chelan and Douglas counties, about 10 miles southeast of Wenatchee. Given that three of the sites containing the unknown tachylyte follow the Snake River, two are on the banks of the Columbia River, and the sixth is from a site expected to be an ethnographic trading center in Kittitas County, there is a strong potential that the source of the unknown tachylyte from these sites is located somewhere along a well-known and well-used Native American corridor likely in the state of Washington.

Local vs. Non-Local Site Distribution of Washington Volcanic Glasses

Employing the 50-mile cutoff for local vs. nonlocal use after Kassa and McCutcheon (2016) and Parfitt and McCutcheon (2017), patterns of use vary widely for Washington volcanic glasses, with some sources widely dispersed and others used entirely locally (Table 15, Table 16). Given the generally low quality of tachylyte and vitrophyric obsidian, it is expected that they would be used locally which is borne out with these sources. The proportion of sites reflecting local use (also calculated as Local Source Index in Table 15) is 0.50 to 0.95 for these material types individually, and 0.82 and 0.95 when pooled. The same is true for some of the obsidian sources: Elk Pass (1.00) and Hosko B (1.00). The only widely distributed materials in this sense are Bickleton Ridge obsidian (0.10) and Indian Rock (Unknown Variety A) obsidian (0.20). This difference in obsidian distribution could be due to the fact that the Bickleton Ridge and Indian Rock (Unknown Variety A) obsidians are a higher quality than the Hosko B or Elk Pass obsidians and therefore were more likely to be traded farther than the other two obsidians. When all obsidians are pooled, the greater number of sites that are non-local far outweigh the sites that are local making the Local Source Index for obsidian 0.32

Table 15. Summary of Local and Nonlocal Occurrence of Washington Volcanic Glasses.[1]

Source	Local Use (Sites < 50 mi away)	Nonlocal Use (Sites > 50 mi away)	Local Source Index[2]
Bickleton Ridge Obsidian	1	9	0.10
Chelan Butte Vitrophyric Obsidian (Unknown Vitrophyre 1)	15	1	0.94
Cleman Mountain Tachylyte	1	1	0.50
Copper Ridge Vitrophyric Obsidian Complex	21	1	0.95
Douglas Creek Tachylyte	3	0	1.00
Elk Pass Obsidian	4	0	1.00
Hosko B Obsidian	1	0	1.00
Indian Rock (Unknown Variety A) Obsidian	2	8	0.20
Stray Gulch Tachylyte	5	1	0.83
All Obsidians	8	17	0.32
All Tachylytes	9	2	0.82
All Vitrophyric Obsidians	36	2	0.95

[1] sources without ground-truthed locations (unknown tachylyte, Yakima) are excluded except for Chelan Butte, which for the sake of this analysis is assumed to be located at or near Chelan Butte. Sources with no archaeological use are omitted. Data for this summary is from Table 16.

[2] Calculated as (Local Use sites) / (Local Use sites+ Nonlocal Use sites)

Table 16. Details for Local and Nonlocal Occurrence of Washington Volcanic Glasses[1]

Source	Sites <50 mi away	Artifact Count	Sites> 50 mi away	Artifact Count
Bickleton Ridge Obsidian	AAR-1271-39	1	45BN583	2
			45FR39	3
			45KI263	1
			45KT301	19
			45KT991	1
			45KT382	1
			45PI406	2
			45PI408	1
			45SP342	1

[1] sites listed in bold and shaded have other Washington volcanic glass present

Table 16. Details for Local and Nonlocal Occurrence of Washington Volcanic Glasses[1] (Continued)

Source	Sites <50 mi away	Artifact Count	Sites> 50 mi away	Artifact Count
Chelan Butte Vitrophyric Obsidian	45CH216	13	Reflection Pond Site, Okanogan County	1
	45CH57	3		
	45CH58	3		
	45CH61	7		
	45CH217	1		
	45CH782	2		
	45DO387	2		
	45DO409	3		
	45DO417	2		
	45OK69	1		
	45OK113	1		
	45OK419	5		
	45OK422	9		
	45OK424	4		
	45OK426	2		
Cleman Mountain Tachylyte	45CL654	1	45YA638	1
Copper Ridge Vitrophyric Obsidian Variety A	45SK258	1	-	-
	45WH455	5		
	45WH478	1		
	45WH479	1		
	45WH480	1		
	45WH481	1		
	45WH486	1		
	45WH549 (FS 262)	1		
	45WH554 (FS 261)	5		
	45WH555 (FS 265)	4		
Copper Ridge Vitrophyric Obsidian Variety B	45SK258	3	45CA271	1
	45WH462	9		
	45WH482	1		
	45WH484	11		

[1] sites listed in bold and shaded have other Washington volcanic glass present

Table 16. Details for Local and Nonlocal Occurrence of Washington Volcanic Glasses[1] (Concluded)

Source	Sites <50 mi away	Artifact Count	Sites> 50 mi away	Artifact Count
Copper Ridge Vitrophyric Obsidian Variety B (Continued)	45WH503	6		
	45WH505	4		
	45WH515	1		
	45WH549 (FS 262)	1		
	45WH631	1		
	IF 112	1		
Copper Ridge Vitrophyric Obsidian Variety D	45WH505	1	-	-
Douglas Creek Tachylyte	45CH791	3	-	-
	45DO59	3		
	45KT301	31		
Elk Pass Obsidian	45LE286	6	-	-
	45LE415	50		
	45LE425	1		
	45PI406	3		
Hosko B Obsidian	45KL1675	1	-	-
Indian Rock (Unknown Variety A) Obsidian	Indian Rock NE	1	45CL1 (Cathlapotle)	2
	45SA444	1	45CL463	1
			45FR39	1
			45KI1080	2
			45KT301	4
			45SA11	2
			FS 06-17-08-491 (Lotsa Lost Flakes)	9
			Isolate 44	1
Stray Gulch Tachylyte	45GR630	1	**45KI263**	1
	45KT1407 (WEN 54)	2		
	45KT301	17		
	Elk Heights	2		
	WEN 59	1		

[1] sites listed in bold and shaded have other Washington volcanic glass present

CHAPTER VII

CONCLUSIONS

Through my thesis research I have conducted fieldwork, a macroscopic analysis and XRF analysis on a unique, and not widely known, volcanic glass: tachylyte. Additionally, I have looked into and analyzed the distribution of Washington volcanic glass sources throughout Washington sites that have been analyzed through NWROSL. The following discussion is broken into four parts, each reviewing and discussing a different aspect of my research and what my results potentially mean with regards to Washington volcanic glasses and future research regarding the topic.

Fieldwork and XRF Analysis

Originally, the goal of the fieldwork was to relocate all five of the then-defined tachylyte sources (Cleman Mountain, Douglas Creek, Nasty Creek, Parke Creek, and Stray Gulch) in order to meet my third objective: relocate, map, and collect samples at the known tachylyte sources and send a selection of samples in for XRF analysis. I was able to visit and relocate the Cleman Mountain source and visit but not relocate the location of the Stray Gulch and Parke Creek sources. Douglas Creek was located on inaccessible private property and I did not get to visit the Nasty Creek source. Based on XRF analyses, which will be discussed in greater detail below, Cleman Mountain, Parke Creek, and Nasty Creek sources were all combined into a single source: Cleman Mountain. So, although I did not visit or was unable to locate all of the outcrops associated with the Cleman Mountain source, one of the Cleman Mountain outcrops was visited. Additionally, samples of all the sources were found or provided to me from all of the sources and outcrops (other than 06-17-08-238/613) so I was ultimately able to successfully meet my objective of collecting samples to conduct a macroscopic analysis with based on fieldwork. Overall, through my fieldwork, I was able to characterize one out of five of the Cleman Mountain outcrops, and compile ground-truthed information for the Stray Gulch and Douglas Creek sources based on information from the previous landowner of the Douglas Creek source and the fieldwork of Lubinski's 2015 field school.

It is apparent through my research that to relocate these sources is somewhat difficult. Even through Dr. Lubinski's work, it took him several tries with a crew of seven or more people in order to relocate either the Stray Gulch or the Parke Creek source. This lends me to believe that the unobtrusive nature of the sources may have also been difficult in the past to relocate and could explain their lack of presence in the archaeological record – to some extent. Other possible reasons for the lack of use include generally poor knapping quality and/or small, unusable nodule size. Most of the tachylyte samples that were collected had a large amount of inclusions which makes knapping quality poor and potentially not a commonly sought-after material type. Additionally, the size of the nodules may have limited the types of tools that could be produced, again making tachylyte a less than desirable stone to relocate, knap, and use. These are all suppositions about tachylyte, of course, and not true at all times, especially in light of the data that is available concerning the Grissom site, which contains over 30 pieces of the Douglas Creek source and 17 pieces of the Stray Gulch source, some of which are heavily used cores.

My investigation of XRF sourcing data showed that there was not a drastic difference between the Parke Creek, Cleman Mountain, or Nasty Creek tachylyte sources – enough that it was decided by Craig Skinner, founder of NWROSL to combine them as a single Cleman Mountain source in the fall of 2020. Together we agreed that a comparison of Fe vs. Zr is the best way to tease out all three sources (Cleman Mountain, Stray Gulch, and Douglas Creek) when solely looking at the trace element characteristics of the data. We did find that there would be some overlap in between Stray Gulch and Douglas Creek at the upper end of the Fe range. This overlap could lead the researcher to seek out other ways to determine the likely source of the tachylyte or accept that it was within the indeterminate range of Stray Gulch and Douglas Creek.

Considering the spread of the CRBG across the entirety of central Washington, the geochemical appearance of the Cleman Mountain source in five different outcrop locations, some over 50 miles apart, is not all that surprising. Given the chemical composition of the different flows that make up the CRBG, it is likely that the Cleman Mountain tachylyte all came from a flow that spread out across the entire landscape and mixed in similar ways with either water or silicates in order to create the Cleman Mountain outcrops of tachylyte. Using a similar logic, the Douglas Creek and Stray Gulch tachylyte, also from within the CRBG, likely came from separate, distinct flows.

Macroscopic Analysis

The goal of the macroscopic analysis was to analyze and distinguish the raw material characteristics of the known tachylyte sources. At the point in time when I was macroscopically analyzing tachylyte samples, there were still five, distinct sources: Cleman Mountain, Douglas Creek, Nasty Creek, Parke Creek, and Stray Gulch. Since then, Cleman Mountain has been combined with Nasty Creek and Parke Creek.

A look at my macroscopic analysis results shows variation within a single geochemically-distinct tachylyte source. Cleman Mountain and Parke Creek outcrop samples from the Cleman Mountain source more consistently have distinct blue shades associated with them than any of the other sources. Nasty Creek, although geochemically similar to Parke Creek and Cleman Mountain, did not have any samples with the blue shades.

The macroscopic analysis appears to not be the best way to differentiate the sources. Stray Gulch, for example, has several pieces that have blue hues, but because the blue is not the largest part of the groundmass they were typically recorded as olive gray or grayish black. The nature of inclusions could potentially be a useful characteristic to tell sources apart, but was not helpful for these tachylytes because the shapes of the inclusions also vary within the individual sources. Additional complications of proper groundmass characterization stem from the fact that many of the samples analyzed had rock saw marks on them, making certain aspects of characterizations difficult if not impossible to identify at times. In addition to these complications, the relatively small number of samples from each source, and the uncertainty about whether these samples indicate the full range of variation within each source, both limit the applicability of the macroscopic analysis results.

Volcanic Glass Distribution

Overall, it was found that there was a higher occurrence of out-of-state volcanic glasses in Washington archaeological assemblages compared to Washington volcanic glasses. Only 19.3% of the artifacts submitted to NWROSL for analysis are from Washington sources. There are also four Washington sources lacking any evidence of archaeological use. These data potentially show us that there was a preference for out-of-state glasses which tend to be a higher quality obsidian. However, this does not take into account trade patterns of pre-contact peoples or sampling biases. Many of the sites that have been tested in Washington come from areas that are on the border of Washington and Oregon near large pre-contact trade centers such as the Dalles, so the appearance of out-of-state glasses would not be uncommon in these areas and may explain the higher density of out-of-state glasses and their distribution throughout the state.

Additionally, there is a sampling bias due to individual researcher choice about whether to submit samples, and also due to a bias in the area of archaeological research. Areas that see more development are likely to trigger archaeological mitigation efforts and field projects. Development projects that initiate data recovery excavations tend to take place along river corridors due to the sensitive nature of pre-contact use of these areas. This attention to river corridors is imperative to protecting Native American resources however it does skew the data and ignores the pre-contact land use of other areas, particularly farmland and rugged, inaccessible terrain, which have largely remained unrecorded and un-surveyed.

The dispersal of artifacts made from Washington glasses was looked at through the lens of a Local Source Index, with a score of 0.0 being completely non-local and a score of 1.0 being completely local. The index showed that the tachylytes and vitrophyric obsidians, when counts were pooled, had a strong tendency for a local use, 0.95 and 0.82 respectively while the obsidians tended to have a stronger non-local use, 0.32 The difference between the three types could be as simple as a preference for one type of stone over another for toolmaking, or a limited archaeological dataset skewing the results. Another potential explanation for the more prevalent occurrence of obsidian in non-local sites vs. tachylyte and vitrophyric obsidian is the location of the sources on the landscape and their proximities to trade routes, villages, hunting trails, root/berry gathering areas, or the many other activities practiced by pre-contact people, both known and unknown.

Future Research

Future research would benefit from a macroscopic analysis of all the different types of Washington volcanic glasses – not tachylytes exclusively. In order to make claims that the tachylytes and vitrophyric obsidians of Washington State are more or less preferential to the obsidians in the state, these materials would need to actually be analyzed. A look at some of the more common out-of-state obsidian sources would also be a great addition to this aspect of the study. In addition to material quality, it would be useful to more clearly understand material nodule size, as the available size of source pieces will affect potential uses and desirability of a source material. The asystematic nature of the geochemically-sourced dataset would be improved if more researchers from both academia and cultural resource management firms sent in volcanic glass any time it is found. The source data would also be improved with submission of more outcrop samples as found, to identify additional sources and better define the spatial extent of outcropping. Further analysis into the trade patterns and routes of pre-contact people would greatly add to the conversation on the dispersal of the different sources throughout the landscape. Both McClure (2015) and Mierendorf and Baldwin (2015) address the local use of their discussed glass sources with significant detail on the pre-contact movement of the people in their areas and the other glasses in the state would benefit from similar attention in future work.

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APPENDIX A

ORIGINAL NWROSL SOURCING REPORT

X-Ray Fluorescence Analysis of Geologic Tachylyte Samples from Kittitas and Yakima Counties, Washington

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Thirteen geologic source tachylyte samples from Kittitas and Yakima counties, Washington, were submitted for energy dispersive X-ray fluorescence trace element provenance analysis. The samples were prepared and analyzed at the Northwest Research Obsidian Studies Laboratory under the accession number 2020-48.

Analytical Methods

X-Ray Fluorescence Analysis. Nondestructive trace element analysis of the samples was completed using a Thermo NORAN QuanX-EC energy dispersive X-ray fluorescence (EDXRF) spectrometer. The analyzer uses an X-ray tube excitation source and a solid-state detector to provide spectroscopic analysis of elements ranging from sodium to uranium (atomic numbers 11 to 92) and in concentrations ranging from a few parts per million to 100 percent. The system is equipped with a Peltier-cooled Si(Li) detector and an air-cooled X-ray tube with a rhodium target and a 76 micron Be window. The tube is driven by a 50 kV 2mA high voltage power supply, providing a voltage range of 4 to 50 kV. During operation, the tube current is automatically adjusted to an optimal 50% dead time, a variable that is significantly influenced by the varying physical sizes of the different analyzed samples. Small specimens are mounted in 32 mm-diameter sample cups with mylar windows on a 20-position sample tray while larger samples are fastened directly to the surface of the tray.

For the elements that are reported in Table A-1, we analyzed the collection with a 3.5 mm as well as an 8.8 mm beam collimator installed with tube voltage and count times adjusted for optimum results. Instrument control and data analysis are performed using WinTrace software (version 7) running under the Windows 7 operating system.

The diagnostic trace element values used to characterize the samples are compared directly to those for known obsidian and fine-grained volcanic (FGV) sources reported in the literature and with unpublished trace element data collected through analysis of geologic source samples (Northwest Research 2020a). Artifacts are correlated to a parent obsidian, FGV, or basalt source (or geochemical source group) if diagnostic trace element values fall within about two standard deviations of the analytical uncertainty of the known upper and lower limits of chemical variability recorded for the source. Occasionally, visual attributes are used to corroborate the source assignments although sources are never assigned solely on the basis of megascopic characteristics.

Results of Analysis

X-Ray Fluorescence Analysis. The tachylyte source samples analyzed by X-ray fluorescence methods were correlated with five known tachylyte sources. The collection locations and identified sources are shown in Figure 1. Analytical results are presented in Table A-1 in the Appendix and are summarized in Table 1 and Figure 2. Analyzed samples are shown in Figure 3.

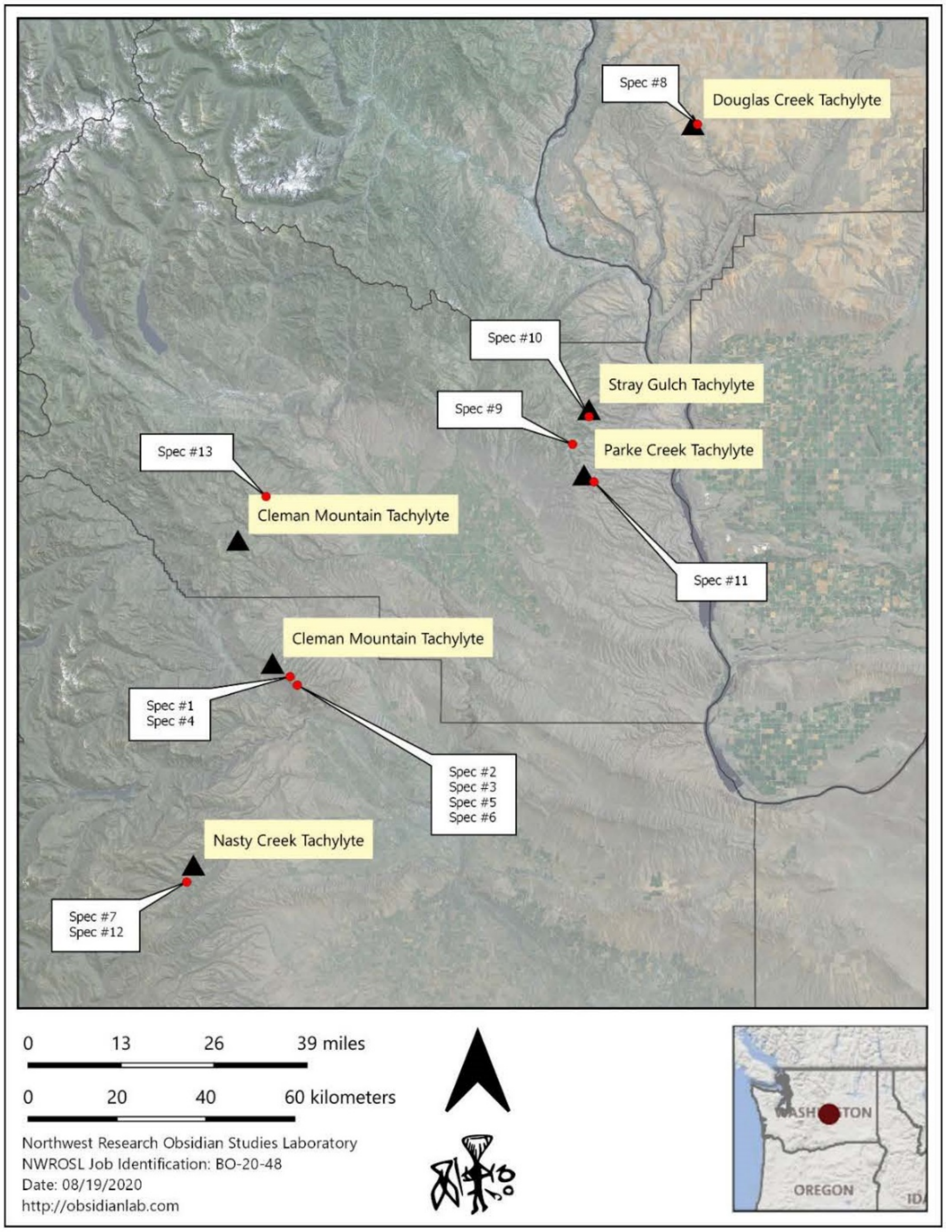

Figure 1. Locations of submitted tachylyte samples (red dots). The black triangles in the map above designate the locations of established tachylyte sources.

Table 1 - Summary of results of trace element analysis of the project specimens.

GEOCHEMICAL SOURCE	N=	PERCENTAGE
Cleman Mountain	7	54
Douglas Creek	1	8
Nasty Creek Tachylyte	2	15
Parke Creek	1	8
Stray Gulch	2	15
TOTAL	**13**	**100**

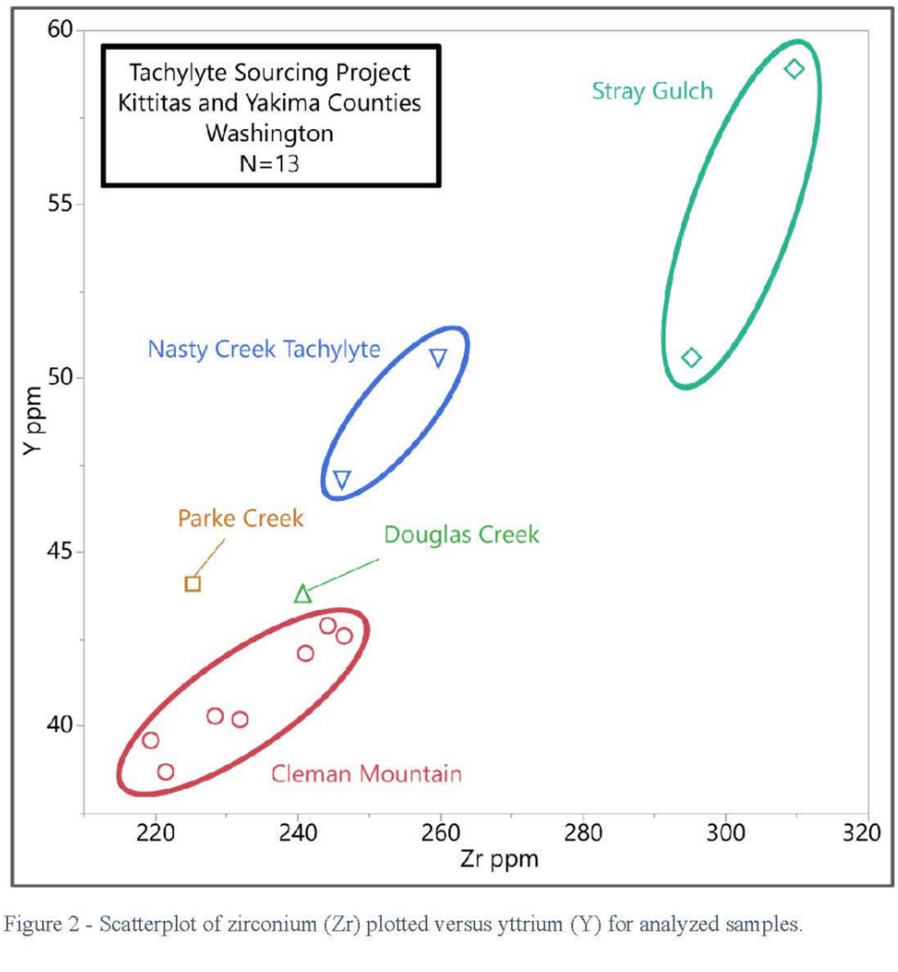

Figure 2 - Scatterplot of zirconium (Zr) plotted versus yttrium (Y) for analyzed samples.

Figure 3 - Analyzed tachylyte samples.

Information concerning the location, geologic setting, and prehistoric use of obsidian and tachylyte sources identified in the current investigation may be found at www.sourcecatalog.com (Northwest Research 2020b).

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Northwest Research Obsidian Studies Laboratory

2020a Northwest Research Obsidian Studies Laboratory World Wide Web Site (www.obsidianlab.com).

2020b Northwest Research U. S. Obsidian Source Catalog (www.sourcecatalog.com).

Appendix

Results of X-Ray Fluorescence Analysis

Northwest Research Obsidian Studies Laboratory

Table A-1. Results of XRF Studies: Tachylyte Sourcing Study, Kittitas and Yakima Counties, Washington

Site	Specimen No.	Catalog No.		Trace Element Concentrations Rb	Sr	Y	Zr	Nb	Ba	Ti	Fe203 (%)	Geochemical Source
Cleman Mountain	1	S1		65	258	42	241	19	666	9650	7.74	Cleman Mountain
			±	3	5	2	4	3	43	480	0.01	
Cleman Mountain	2	S2		57	279	43	247	18	602	13360	5.63	Cleman Mountain
			±	2	4	2	4	3	43	340	0.01	
Cleman Mountain	3	L1S1		67	304	43	244	19	617	15280	8.71	Cleman Mountain
			±	3	5	2	4	3	40	370	0.01	
Cleman Mountain	4	L2S1		52	277	40	219	15	430	11890	6.47	Cleman Mountain
			±	2	5	2	4	3	34	310	0.02	
Cleman Mountain	5	L3S1		56	265	40	228	15	586	9000	7.20	Cleman Mountain
			±	2	4	2	4	3	37	220	0.01	
Cleman Mountain	6	I1		50	261	39	222	16	624	5660	3.72	Cleman Mountain
			±	2	4	2	4	3	47	150	0.01	
Nasty Creek	7	NCFS1		61	273	47	246	18	657	15370	8.42	Nasty Creek Tachylyte
			±	3	5	2	4	3	43	220	0.01	
Douglas Creek	8	DCS1		56	275	44	241	17	655	7860	6.25	Douglas Creek
			±	2	4	2	4	3	41	180	0.01	
Stray Gulch	9	SGS1		67	305	51	295	20	733	12730	8.12	Stray Gulch
			±	3	5	2	4	3	40	190	0.02	
Stray Gulch	10	SGS2		77	300	59	310	27	628	19060	4.94	Stray Gulch
			±	3	5	2	4	3	39	400	0.01	
Parke Creek	11	PCS1		60	282	44	225	21	420	11730	3.67	Parke Creek
			±	4	6	4	6	0	44	390	0.01	
Nasty Creek	12	FRS1		61	289	51	260	23	729	15250	8.74	Nasty Creek Tachylyte
			±	3	5	2	5	3	38	270	0.02	
Unknown	13	UNKS1		53	284	40	232	19	504	13310	6.61	Cleman Mountain
			±	2	4	2	4	2	39	250	0.01	
NA	RGM-1	RGM-1		144	109	27	220	12	801	1730	1.65	RGM-1 Reference Standard
			±	3	3	2	3	2	27	290	0.01	

Trace element values reported in parts per million except where specifically designated; ± = analytical uncertainty estimate (in ppm).
NA = Not available; ND = Not detected; NM = Not measured; * = Small sample; FGV = Fine-grained volcanic specimen.