

THE ARCHAEOLOGY OF OBSIDIAN OCCURRENCE IN STONE
TOOL MANUFACTURE AND USE ALONG THE
MID-COLUMBIA RIVER, WASHINGTON

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ABSTRACT

THE ARCHAEOLOGY OF OBSIDIAN OCCURRENCE IN STONE TOOL MANUFACTURE AND USE ALONG THE MID-COLUMBIA RIVER, WASHINGTON

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Archaeologists have documented the relatively unique co-occurrence of local, low-quality and nonlocal, high-quality obsidian in Washington stone tool assemblages. I employed an evolutionary archaeology approach to generate explanations for the presence of 656 obsidian artifacts from 18 archaeological sites in the Mid-Columbia River Valley. To document occurrence, I used a model comprised of cost and performance variables. Once inter-variable relationships were identified, paradigmatic classifications were used to measure stone tool provenance, material, technological, and functional attributes. Gathered data was evaluated using a stepwise statistical analysis to test the null hypothesis: *Obsidian source occurrence is random across stone tool manufacture and use*. In many cases the null hypothesis was rejected because occurrence was non-random across obsidian source, space, and time, identifying the statistically significant attributes sorting obsidian occurrence in my sample. Results indicated that selective conditions predominately favored local, low-quality obsidian sources, which occurred across all object types. Also favored were the minimally represented nonlocal,

high-quality sources, which occurred principally as flakes. Spatial distributions of source diversity and reduction trajectories varied between the northern and southern reaches of my study area. Over time, source diversity increased while frequencies of local sources decreased.

Keywords: Archaeology, Stone tool geography, Obsidian sourcing, Statistical modeling

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CHAPTER I

INTRODUCTION

Obsidian, a silicic volcanic glass, flakes predictably producing sharp edges; consequently, when available, precontact people incorporated obsidian into chipped stone tool industries (Cotterell et al. 1985; Phillips 2011). Archaeologists studying stone tool geography have used the unique geochemical signatures of obsidian sources to trace artifacts recovered from archaeological sites to their parent source in order to understand aspects of stone tool procurement, manufacture, use, and discard (Shackley 2005). In the Mid-Columbia River Valley of Washington State, numerous archaeological investigations have noted obsidian of various qualities and relative geographic sources as components of the diverse stone tool assemblages (Chatters 1986; Galm and Masten 1985; Grabert 1968; Gunkel 1961; Schalk and Mierendorf 1983). Though it is fairly unique to have local, low-quality and nonlocal, high-quality obsidian sources occur simultaneously in stone tool assemblages in Washington, the quantity and degree of source occurrence in the Mid-Columbia region has yet to be studied.

To understand these co-occurrences, I employed an evolutionary archaeology approach to explain how sources were selected and incorporated into stone tool industries. In order to identify the selective conditions, a model of cost and performance was used to identify the inter-variable relationship between stone tool manufacture and use variables. Once identified, paradigmatic classifications were employed to gather data on lithic attributes. Observed data were then statistically analyzed to test hypotheses on

the selective conditions sorting obsidian occurrence in the Mid-Columbia River Valley across source, space, and time.

Problem

Previous researchers (Andrefsky 1994; Cadena 2012; Eerkens et al. 2002; Eerkens et al. 2007; Mack et al. 2010; Renfrew 1977; Shackley 2005) have noted that technological, functional, material, and provenance studies can elucidate patterns of obsidian consumption in precontact lithic industries. Though obsidian is well documented in archaeological sites in the Mid-Columbia River Valley, a systematic study, such as those noted above, can help clarify the variables influencing material selection. While it is known that precontact peoples used local and nonlocal obsidian (Chatters 1986; Galm 1994a), the quantity and degree to which obsidian sources were incorporated into stone tool manufacture and use remains unknown. Once the occurrence is documented, I was able to, as in other areas of the Pacific Northwest (Eerkens et al. 2007; McClure 2014; Parfitt 2013; Vaughn 2010), study the selective conditions under which local and nonlocal obsidian was utilized in precontact stone tool manufacture and use.

Numerous patterns have been suggested to explain obsidian occurrence variability. First, according to the Law of Monotonic Decrement or distance decay, as the distance from a source increases the abundance of a material should decrease (Renfrew 1977). Second, bifaces and small flakes should have greater and near equivalent source diversity, whereas large flakes should have lower source diversity (Eerkens et al. 2007). Additionally, archaeologists have suggested that over time source diversity in some areas of the Pacific Northwest decreased and exploitation became focused on local sources (Cadena 2012; Mack et al. 2010). I want to know how these patterns compare to obsidian occurrence in the Mid-Columbia River Valley.

Purpose

The purpose of this study was to evaluate the occurrence of obsidian in precontact archaeological assemblages from the Mid-Columbia River Valley. I accomplished this using an evolutionary archaeology informed model to explain difference and change in obsidian artifact frequencies recovered from 18 archaeological sites. I achieved this purpose by:

1. Adapting an evolutionary archaeology theoretical model of stone tool manufacture and use to determine the selective conditions under which obsidian was consumed.

Numerous stone tool analytical models employed cost and performance variables to understand how lithic raw materials were incorporated into stone tool manufacture and use (Andrefsky 1994; Eerkens et al. 2007; Kornbacher 2001; Renfrew 1977; Wilhelmsen 2001). My research was guided by an evolutionary archaeology based model of stone tool cost and performance from which difference and change in artifact frequencies could be documented through the inter-relationships among four sub-variables: provenance, material, technological, and functional properties (McCutcheon 1997). This approach provided the means to investigate and explain the relative relationship between attributes of cost and performance in order to identify the selective conditions structuring obsidian occurrence. It was expected that obsidian consumption was a function of natural selective conditions (Dunnell 1978a, b).

2. Operationalizing the material, technological, and functional sub-variables in the form of paradigmatic classifications.

Each cost and performance sub-variable documents attributes of obsidian consumption according to the underlying theory of reduction that is at the base of all stone tool investigations (Cotterell and Kamminga 1990; McCutcheon 1997). Paradigmatic classifications were designed to relatively measure the dimensions of each sub-variable by a number of mutually exclusive, predetermined modes. These modes were used to understand the selective conditions structuring obsidian occurrence. An example of cost and performance variables in lithic research is the expectation that nonlocal, high-quality material occurs as high energy, curated tools; whereas, local, low-quality material occurs as low energy, expedient tools (Andrefsky 1994, 2009). However, findings from recent obsidian research near my study area, which also employed the lithic approach used in this thesis (McCutcheon 1997), did not align with these expectations (Parfitt 2013). Rather, results indicated that nonlocal obsidian was used across all tool types. These studies demonstrate variability in archaeological obsidian source occurrence. Accordingly, to understand the conditions structuring occurrence in the Mid-Columbia region my first task was to document the stone tool attributes present in my sample.

3. Utilizing the techniques of artifact classification, data observation, and resampling to measure and describe dimensions of obsidian artifacts from my sample.

I measured and described 656 obsidian artifacts from 18 archaeological sites using McCutcheon's (1997) paradigmatic classifications. The counts of measured dimensions were resampled to determine if data were representative by assessing evenness and richness across the filled modes. Resampling indicated if dimensions

were either representative or unrepresentative. Only representative data was statistically analyzed.

4. Employing a stepwise statistical strategy to identify non-random associations between cost and performance classificatory data to assess the null hypothesis: *Obsidian source occurrence is random across stone tool manufacture and use*. If the null hypothesis could be rejected because obsidian does not occur randomly in these assemblages, then observed data could be used to assess the alternative hypothesis: *Obsidian source occurrence is not random across stone tool manufacture and use*.

My statistical strategy began with the cross tabulation cost and performance sub-variables using chi-square analysis or a Fisher's exact test to evaluate if dimensions were randomly or non-randomly associated. Where the cross tabulation of dimensions were non-random, investigations continued to examine the nature of the association. If data met assumptions of chi-square, Cramer's V was calculated to understand the strength of the association and an analysis of adjusted residuals was achieved to further explore selective conditions by examining which modes of intersected representative dimensions were significantly contributing to the rejection of the null hypothesis. Analysis of the non-random associations between cost and performance revealed the possible selective conditions of obsidian occurrence for my sample from the Mid-Columbia River Valley and allowed me to form arguments for why particular partitions of gathered data were representative and significant. Doing so also aided in determining if patterns of obsidian occurrence identified by other researchers

(Eerkens et al. 2007; Cadena 2012; Mack et al. 2010; Parfitt 2013; Renfrew 1977) were observed in my sample assemblages.

Significance

The significance of my thesis research is two-fold. First, my research provided an initial synthesis of the selective conditions under which my sample of obsidian from the Mid-Columbia River Valley was incorporated into stone tool technology. In the past, archaeologists have discussed the benefits of understanding obsidian occurrence in this region (Galm 1994a; Galm and Masten 1985; Schalk and Mierendorf 1983); however, a comprehensive study of the obsidian present had yet to be implemented.

Second, my thesis demonstrated the effectiveness of a theoretically based paradigmatic and statistical approach to stone tool analysis that has the ability to explain difference and change in a population across time and space. I employed McCutcheon's (1997) model which aims to understand stone tool cost and performance through paradigmatic classifications based on empirical representations of stone tool provenance, material, technological, and functional attributes. This model employs variables analogous to those used in other lithic studies from which comparable data can be generated. Similar to other researchers, I acknowledged that documenting these lithic variables is insufficient and suggest a stepwise statistical analysis used to test hypotheses as well as assess the significance and the strength of the non-random associations between variables. From this approach, results could be clearly explained using the broader theoretical framework. Ultimately, such a model provides archaeologists with an

approach to stone tool analysis that can be used to explicitly document and analyze the relationship between attributes stone tool cost and performance.

CHAPTER II

STUDY AREA

Study Area

The geographic boundary of this research is based on the documented archaeological occurrence of obsidian within the Mid-Columbia River Valley located within Chelan, Douglas, and Okanogan Counties, Washington (Chatters 1986; Craig Skinner, personal communication 2013; Daughtery 1956; Galm 1994a; Galm and Masten 1985; Grabert 1968; Gunkel 1961; Schalk and Mierendorf 1983; Skinner and Thatcher 2010). For the purposes of this thesis, the Mid-Columbia River Valley was defined as the land adjacent to the banks of the Columbia River from the town of Entiat north to Bridgeport and extending just north of the mouth of the Okanogan River (Figure 1). The direct linear distance between the northern and southern limits of the study is 87 kilometers.

Physical and Cultural Context

The Mid-Columbia River Valley is located at the convergence of three physiographic provinces: the Northern Cascades, the Okanogan Highlands, and the Columbia Basin (Franklin and Dyrness 1973). The Northern Cascades are topographically variable ranging from mature mountains (~3,000 meters) trending north-south, to deep valleys (~1,800 meters) and low gradient streams flowing east-west. The Okanogan Highlands differ from the Northern Cascades and are characterized by broad,

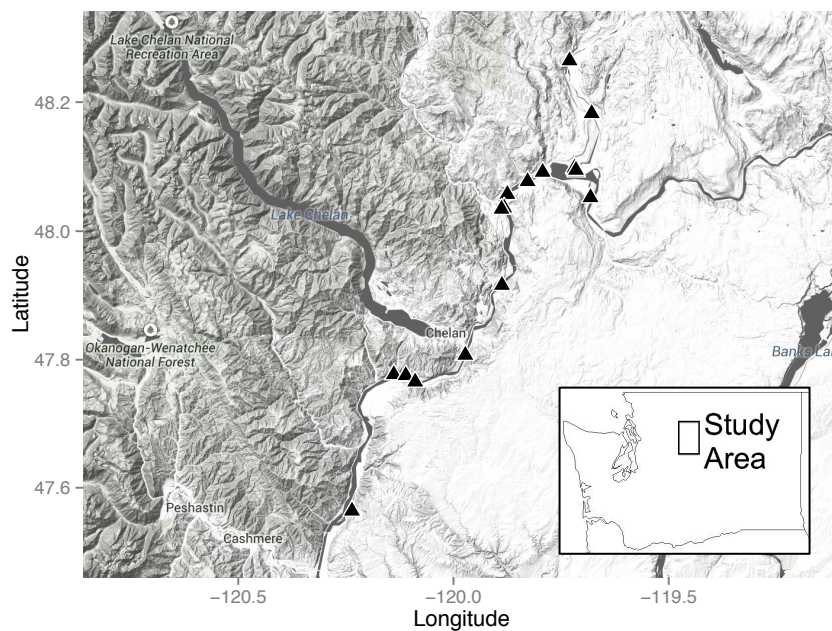


Figure 1. Map of the Study Area Illustrating the 18 Archaeological Sites (Base Map Provided by Google Maps 2014).

rounded ridges and hills, between approximately 1,500-365 meters in elevation; moderate slopes; and upland areas, separated by broad south-flowing river valleys. The Columbia Basin is located between approximately 300 and 600 meters and consists mainly of stratified Miocene-aged basalt flows overlain by loess. Here, the topography is defined by gently rolling to moderate hilly plains periodically interrupted by basaltic buttes and canyons.

Various geomorphic processes, namely glaciation and erosion from numerous Pleistocene and later fluvial episodes, shaped the topography of study area (Atwater 1986; Bretz 1919; Chatters and Hoover 1986; Waitt and Thorson 1983; Waters 1933). These episodes succeeded in down cutting the Columbia River with floodwaters

redepositing unconsolidated gravels, sands, and silts which created step terraces and flood bars within the river valley (Galm 1994b). As a result of these physiographic differences and geomorphic processes, the study area varies considerably in topography. The west bank of the Columbia River is generally represented by hilly terrain incised with numerous small drainages, coulees, and the Entiat, Chelan, Methow, and Okanogan rivers. In contrast, the east bank is characterized by cliff and bench topography; unlike the west side, it is drier and lacks tributaries.

Knowledge of the physical environment is central to understanding precontact land use and settlement. Like the east and west, the northern and southern reaches of the study area are also dissimilar in topography as well as resource availability, which likely affected human utilization of the landscape. The northern reach is generally steep, with the exception of low-lying river terraces and floodplains (Chatters 1986). In this reach, the Methow and Okanogan rivers converge with the Columbia. Chatters (1986) describes this as a diverse environment with accessible resources for procurement and favorable for human habitation. The topography of southern reach has been described as a steep sided gorge that is interspersed by low relief terraces (Mierendorf 1983); here, the deeply incised Chelan River converges with the Columbia River. According to Schalk and Mierendorf (1983), the extreme relief of this reach likely restricted human habitation and resource procurement by constraining the movement of peoples in and around this area.

The Mid-Columbia River Valley was traditionally home to six Native American Indian groups: the Chelan, Entiat, Wentachi, Southern Okanogan (Sinkaietk), Methow, and Moses Columbia (Sinkayuse), collectively referred to as the Middle Columbia River

Salishans (Cline et al. 1938; Miller 1998; Ruby and Brown 1992; Spier 1936; Teit 1928). The Chelan, Entiat, and Wenatchi lived primarily west of the Columbia River to the Cascade Range along Lake Chelan, the Entiat River, and the Wenatchee River, respectively (Miller 1998). The Southern Okanogan peoples lived from the Columbia-Okanogan River confluence in the south to the Okanogan-Similkameen River confluence in the north (Ruby and Brown 1992; Spier 1936; Teit 1928). The Methow utilized areas of the Okanogan River as well as the Columbia River from the modern day town of Brewster to the Methow Rapids. While the Moses Columbia (Sinkayuse) inhabited areas from the Columbia Plateau south and east of the Columbia River, south to Priest Rapids, and east of the Columbia River to approximately the present-day town of Creston (Miller 1998; Ruby and Brown 1992; Spier 1936).

The broad context of Columbia Plateau archaeology has been synthesized and discussed in numerous archaeological studies (Ames et al. 1998; Campbell 1985; Chatters 1986, 1989, 1995; Grabert 1968; Schalk and Mierendorf 1983). Due to the nature of this thesis, I chose to focus on the local context of the Mid-Columbia River Valley. Based on excavations of the Wells Reservoir, Chatters (1986) refined Grabert's (1968) original cultural phases for the Okanogan Highlands region (Table 1). The age ranges of archaeological sites were determined based on radiocarbon dating (charcoal and shell), stratigraphy, and/or projectile point style comparisons (Lohse 1986). Analysis of this data revealed distinct clusters of occupations separated by discontinuities, and described as cultural phases (Chatters 1986).

Table 1. Okanogan Highlands Cultural Phases (Chatters 1986; Grabert 1968).

Phase	*WRAP Occupation Period Cluster (B.P.)	Associated Cultural Phase (Grabert 1968)	WRAP Cultural Phase Time Span (B.P.)
Period 1	7800-6000	Late Okanogan–Early Indian Dan	Okanogan (ca. 8000-6000)
Period 2	4350-3800	Mid-Late Indian Dan	Indian Dan (4400-3500)
Period 3	3300-2200	Early Chliwist	Chliwist (3300-2200)
Period 4	<900	Cassimer Bar	Cassimer Bar (1000-historic)

* Wells Reservoir Archaeological Project (WRAP)

The purpose of defining phases is to identify patterns in archaeological sites and facilitate discussion of those patterns synchronically or diachronically. Chatters' concept of occupation phases (1986:85) follows Dunnell (1973); however, the definition of occupation was altered to “an assemblage that is vertically and/or horizontally distinguishable and of sufficient and comparable size.” This includes occupations that may constitute an assemblage from a single period of residency to multiple single periods of residency, which may not be separable. Thus, artifacts may be assigned to multiple phases, thereby making discrete changes over time undetectable.

The following overview of the Columbia Plateau cultural chronology, adapted from Chatters (1986), indicates broad patterns of environmental and cultural change that facilitates an understanding of how alterations in subsistence and landscape use may have affected the selective conditions shaping obsidian source occurrence. During the Okanogan Phase (c.a. 8000 – 6000 B.P.), the climate became relatively warmer and drier. Housepits were absent; however, evidence of pit ovens and some milling stones were

present. Stone tools were mainly crafted from basalt and the predominant projectile point types were large leaf and lozenge shapes. During this time, it was suggested that people typically lived in small groups traveling regularly from the rivers to the uplands for fishing and hunting activities, respectively.

In the Indian Dan Phase (6000 – 3500 B.P.) basalt was the primary lithic material, but was not used in the same capacity as in the Okanogan Phase. Nonlocal toolstone and shell began to appear in the archaeological record and evidence of extensive trading activity was most prominent in this period. Around 4500 B.P., semi-subterranean houses appeared on river terraces. Researchers believe this period was characterized by a shift to a more logistic subsistence strategy whereby resources were collected and processed before being brought to residential sites for storage and consumption.

During the Chliwist Phase (3500 – 1000 B.P.) the climate was relatively cooler and moister. Semi-subterranean houses became larger and more widespread. A wider variety of raw materials were used for chipped stone tool technology, including volcanic glassy materials such as obsidian, perlite, and pitchstone. Projectile points became larger and were typically in the style of leaf-shaped points, corner- and basal-notched, and stemmed points. These point styles, along with bone tools and ground stone adzes, were commonly recovered. Evidence of regional trade was present through items such as marine shell. This phase was characterized by a logistic subsistence strategy and evolved to include central bases, extractive camps, and special-use localities.

The contemporary sagebrush-steppe environment was the setting for the Cassimer Bar Phase (1000 - 250 B.P.). Cassimer Bar settlements appeared to be large, site densities

increased, and locations were used repeatedly. A variety of lithics were used including obsidian, opal, agate, and petrified wood. Obsidian and other cryptocrystalline lithics were predominant material types with basalt occurring less frequently. These materials were crafted into projectile points, which often occurred as corner and side-notched and corner-removed points, and were smaller than in earlier periods.

Criteria of Site Selection

Obsidian occurrence in the Mid-Columbia River Valley was informed by local scholarly literature (Chatters 1986; Daugherty 1956; Galm 1994a; Galm and Masten 1985; Grabert 1968; Gunkel 1961; Schalk and Mierendorf 1983), which identified silicic glass (e.g. obsidian, vitrophyre, and tachylyte) as part of the diverse stone tool assemblages. In order to study the occurrence of obsidian in this area, assemblages needed to be available. As a result, collections on loan from The Confederated Tribes of the Colville Reservation were used for this research. The identification of material was achieved through a review of cultural resource reports and site forms. In addition, Jacqueline Cook, Repatriation Specialist, of the Colville Tribal Repository provided guidance by identifying additional artifacts through database queries and hand selection of material with visual characteristics of silicic glass. Table 2 contains the archaeological site, related excavation, and report references from the 18 assemblages selected for analysis. A number of sites containing obsidian were identified and were unavailable for analysis (see 45OK74, 45CH216, 45CH782, 45DO68, 45CH62, 45CH254, and 45CH409). When these collections as well as others yet to be identified

Table 2. Identified Archaeological Sites.

Archaeological Site	Excavation Year	Report Reference
45CH57	1959, 1981	Gunkel (1961), Schalk and Mierendorf (1983)
45CH58	1981	Schalk and Mierendorf (1983)
45CH61	1959	Gunkel (1961)
45DO372	1983	Chatters (1986)
45DO387	1983	Chatters (1986)
45DO409	1981	Schalk and Mierendorf (1983)
45DO417	1982	Schalk and Mierendorf (1983)
45DO59	1959	Gunkel (1961)
45OK113	1963	Grabert (1968)
45OK382	1981, 1984	Chatters (1986)
45OK383	1983, 1984	Chatters (1986)
45OK419	1981, 1983, 1984	Chatters (1986)
45OK422	1980, 1981, 1983	Chatters (1986)
45OK424	1981, 1983, 1984	Chatters (1986)
45OK426	1983	Chatters (1986)
45OK69	1981, 1983, 1984	Chatters (1986)
45OK92	1963	Grabert (1968)
45OK94	1963	Grabert (1968)

through a literature review or examination of curated artifacts become available, they will likely provide additional insight into obsidian occurrence in the Mid-Columbia River Valley.

CHAPTER III

LITERATURE REVIEW

The structure of this literature review aligns with the objectives outlined in Chapter I. Pertinent research within the study area and Pacific Northwest region was examined to contextualize the theoretical assumptions and observed patterns of obsidian occurrence. In addition, review of archaeological and statistical analytical models provided methods and techniques for documenting the selective conditions under which obsidian was incorporated into stone tool manufacture and use. Identified patterns were used to orient hypotheses for obsidian occurrence in my study area, which could then be statistically tested.

Analytical Models in Stone Tool Analysis

This section describes the analytical models of stone tool manufacture and use that were adapted to understand the conditions selecting for obsidian occurrence. The relatively recent adoption of X-ray fluorescence spectroscopy (XRF) into archaeology in the 1970s ushered in a new era of studying stone tool geography (Galm 1994a). Without XRF, a technique used to geochemically identify certain lithic materials, many obsidian studies and models could not have been achieved. Varying concentrations of trace chemical elements remain in obsidian during its formation, giving each geologic source a unique signature that can be characterized using XRF (Shackley 2005). This technique coupled with attributes of stone tool of stone tool manufacture and use has led researchers to define models on archaeological occurrence of lithic raw materials.

A number of models have been developed to understand decreasing frequencies of raw materials as the distance from a source increases (Ericson 1977; Findlow and Bolognese 1982; Renfrew 1977; Wood and Wood 2005). One of the earliest is the Law of Monotonic Decrement discussed by Renfrew (1977) and founded on previous stone tool spatial distribution research (Renfrew et al. 1968). Based on studies regarding obsidian trade in the Mediterranean, Renfrew (1977) observed that as the distance from a quarry source increased the archaeological occurrence of obsidian decreased. This model reflects a decline in the size and abundance of lithic materials based on stone tool reduction and incurred costs of transporting material.

Eerkens et al. (2002) and Eerkens et al. (2007) extended this concept to examine how source-to-site distances and artifact types reflect source diversity. Eerkens et al. (2007) employed a simple model of lithic raw material procurement, reduction, and use to describe patterns of source diversity and average source-to-site distance measurements in northern California and central Idaho. This model is based on the following assumptions: 1) raw materials are distributed unevenly across the landscape and encountered during seasonal movements and, 2) as humans move over the landscape they acquire and discard raw materials causing artifact types and sources to have different disposal patterns. Therefore, it is expected that artifact types and raw materials be patterned as follows. First, cores and flakes should be primarily from local sources, while formal tools should generally be from exotic sources. Second, raw materials represented as large flakes should be local and less diverse, and small flakes/formal tools should be from both local and nonlocal sources. Accordingly, artifacts were aggregated into three

categories: formal tools such as bifaces; small flakes, produced from pressure flaking or retouch; and large flakes, characteristic of primary or percussion reduction. Artifacts from unknown sources were eliminated as source-to-site distances could not be calculated and unknown sources from different studies could have been the same source.

The results of Eerkens et al. (2007) study indicated a relationship between artifact type, distance from source, and source diversity. The average distance to a source and source diversity was nearly the same for formal tools and small flakes, while small flakes were on average farther away from a source than larger flakes. Eerkens et al. (2002, 2007) demonstrated that choosing specific artifact types or sizes of flakes for XRF may not present an accurate representation of the source diversity at a site. The authors noted that while this model proved effective, it does not take into account the following: recovery and geochemical analysis of small flakes, state of traded raw material (nodules or finished tools), or raw material quality.

The significance of considering raw material quality when studying material incorporation into lithic technology has been demonstrated by Andrefsky (1994). He identifies two critical variables for understanding the organization of raw material procurement and lithic technology: the amount of effort expended for the creation of high and low energy tools, and the quality and abundance of raw materials which may influence the types of tools produced. He proposes a model based on the premise that quality and availability aid in determining the production of high and low energy stone tools (Figure 2).

		Lithic Quality	
		High	Low
Lithic Abundance	High	Formal- and informal-tool production	Primarily informal-tool production
	Low	Primarily formal-tool production	Primarily informal-tool production

Figure 2. Andrefsky's Model: Lithic Quality and Abundance (1994: Figure 2).

In this model, the extent to which local materials are utilized is dependent upon quality and abundance (Andrefsky 1994; Luedtke 1992). Raw material quality is described as the ease in which chipping is controllable during tool production. Low-quality materials are often crafted into informal tools, while formal tools tend to be produced from high-quality material. For example, if high-quality materials are scarce and low-quality materials are abundant, low-quality material may be used for both formal and informal tools. Regarding abundance, if local material is scarce, then nonlocal resources must be procured and if easy to attain, these materials may be equally as abundant as plentiful local materials.

McCutcheon (1997) provides a more comprehensive approach for understanding the selective conditions under which stone tool variability is produced. He used an evolutionary archaeological framework to combine material, technological, and functional attributes into paradigmatic classifications. These classifications were

designed to collect data to test stone tool cost and performance hypotheses regarding the selective conditions influencing stone tool manufacture and use (Figure 3). This approach is relatively unique as it synthesizes variables of cost and performance discussed by other researchers into a single model that defines those variables in the form of paradigmatic classifications (composed of dimensions and modes), from which lithic variation can be documented.

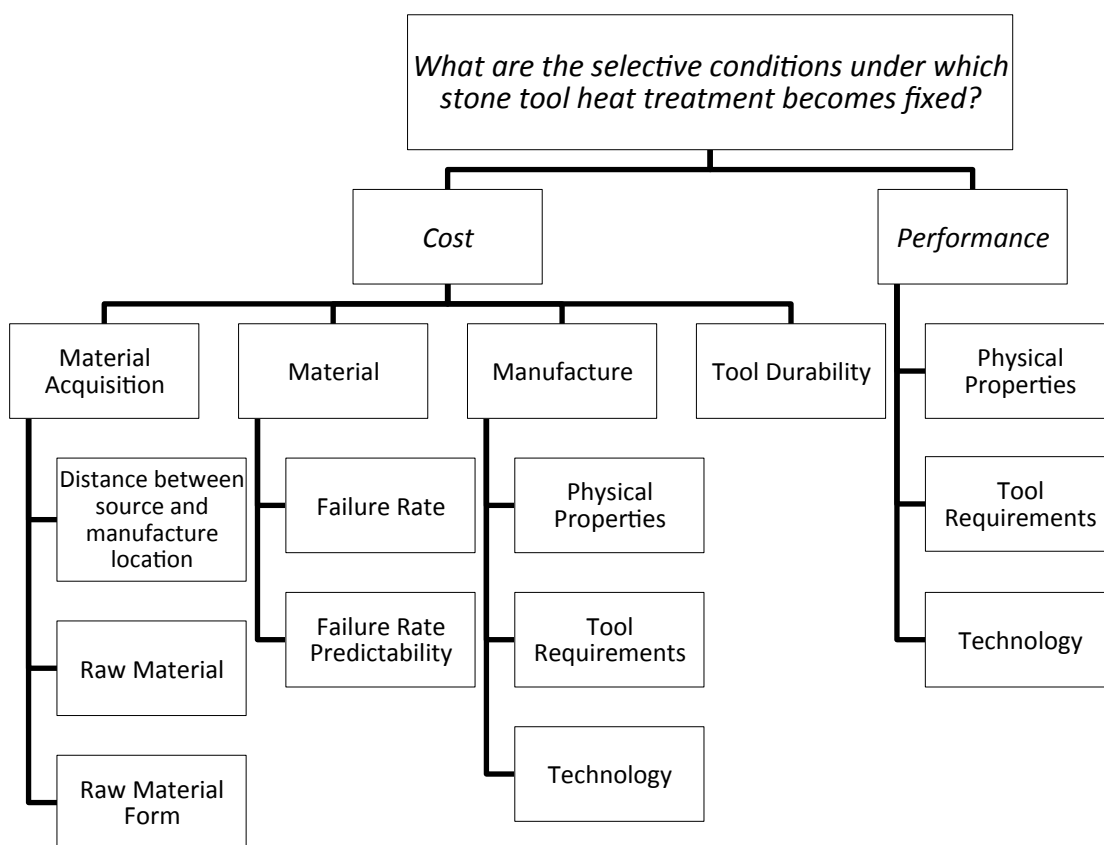


Figure 3. McCutcheon's Model: Cost and Performance (1997: Figure 60).

Evolutionary archaeology seeks to address how and why a particular population came to be represented by constructing explanations of how selective conditions

structured the archaeological record (Lyman and O'Brien 2000). McCutcheon (1997) used Endler's (1986) model of natural selection to illustrate three ways natural selection can affect stone tool manufacture and use. Endler (1986) discusses the location of individuals in a population within a distribution centered on a mean: 1) directional selection in which individuals at one end of a distribution are favored, 2) stabilizing selection in which individuals around the mean are favored over individuals at either end of the distribution, 3) disruptive selection in which individuals at either end of the distribution are favored. The techniques employed by McCutcheon (1997) have been used in the Pacific Northwest and elsewhere (Campbell 1981; Dancey 1973; Dunnell 1978; Sullivan and Rosen 1985; Vaughn 2010) to explain variation in stone tool raw material consumption.

Obsidian Occurrence in the Pacific Northwest

As in other geographic regions where obsidian assemblages are present, the archaeological occurrence of obsidian has been at the center of discussions regarding tool stone geography and social interaction spheres in the Pacific Northwest (Carlson 1994; Galm 1994a; Grabert 1968; Minor 2013). The archaeological evidence of obsidian in regional trade and exchange systems begins approximately 9000 years B.P. (Carlson 1994; Minor 2013). The observed spatial distribution of obsidian has led researchers to suggest several trade routes extending north-south through the interior of Washington (Minor 2013), via the Pacific Northwest Coast (Carlson 1994), and east-west linking the Northwest Coast and Plateau (Carlson 1994; Galm 1994a).

Washington has only 12 known obsidian sources compared to the 134 sources in Oregon (NROSL 2014); many of these sources are considered to be relatively small and/or low-quality (Galm 1994a). Only recently have archaeologists begun to characterize the intra-source variability and the archaeological distribution of Washington obsidian (Galm 1994a; McClure 2014; Schalk and Baldwin 2014). The archaeological distribution of Washington sources and inclusion into exchange systems appears to have been limited (Galm 1994a; McClure 2014; Mierendorf and Baldwin 2014) and many obsidian artifacts recovered in Washington are understood to have been procured through trade networks from sources in British Columbia, Oregon, northern California, and Idaho (Carlson 1994; Galm 1994a; Minor 2013).

Early Mid-Columbia River Valley Obsidian Studies

Geochemical sourcing techniques, such as XRF, currently facilitate the majority of obsidian research. However, many early studies along the Mid-Columbia River relied on macroscopic (visual) sourcing because techniques like XRF were not readily available. Thus, source-to site-distances were understood only on ordinal levels (e.g., local, regional, or exotic) (Chatters 1986; Schalk and Mierendorf 1983). While such studies offer a lower resolution of obsidian occurrence, they aid in contextualizing broad distribution patterns and identifying areas for further research.

Analysis of obsidian occurrence in the Mid-Columbia River Valley has been accomplished through macroscopic source identification and inter-site comparisons. In the Interior Plateau, obsidian represents less than one percent of the total chipped stone tool assemblages (Chatters 1986; Galm 1994a). Spatially, higher frequencies of obsidian

are generally found in riverine sites likely because many trade routes were along rivers (Chatters 1986); however, obsidian has been documented in both riverine and upland environments with sites in the lower Columbia River generally containing more obsidian artifacts than sites in the upper Columbia River (Galm 1994a). Despite the absence of associated source data, obsidian has been mainly attributed to nonlocal sources in southern Washington, Oregon, Idaho, and British Columbia (Chatters 1986; Galm 1994a; Schalk and Mierendorf 1983). Where source data are available, occurrence follows expected patterns of decreased weight as the distance from source-to-site increases (Galm 1994a).

Previous research in the Mid-Columbia River Valley identified the archaeological occurrence Chelan Butte obsidian, a low-quality obsidian or vitrophyre from a presumably unknown, local source (Chatters 1986; Draper 1968; Galm 1994a; Galm and Masten 1985; Grabert 1968; Gunkel 1961; Mierendorf and Bobalik 1983). Prior to my thesis research, artifacts from Chelan Butte have been geochemically characterized at only three sites, 45CH216, 45CH782, and 45OK419 (Craig Skinner, personal communication July 17, 2012; Skinner and Thatcher 2010). In previous analyses, vitrophyre was categorized as local or regional occurrences (Chatters 1986; Galm 1994a) and the parent source likely small due to the material's highly localized distribution in the archaeological record (Galm 1994a; Grabert 1968; Gunkel 1961).

Though obsidian has been a component of regional lithic studies for decades, research in the Columbia Plateau has yet to establish a general pattern of obsidian occurrence over time (Galm 1994a). Work in the Wells Reservoir of the upper Mid-

Columbia River (Chatters 1986; Grabert 1968) indicated that local and regional materials varied in frequencies in early and late sites, but were present throughout. Limited evidence also suggests that slight increases of obsidian over time are seen in the southern Plateau, but remain unobserved in the north (Galm 1994a). In late period assemblages, obsidian bifaces, interpreted as evidence of obsidian trade appeared in higher frequencies; however, debitage continued to be the most common artifact type recovered (Ames et al. 1998; Galm 1994a). During this time, Schalk and Mierendorf (1983) also observed higher proportions of glass or obsidian (up to 5 percent) compared to glass with phenocrysts or vitrophyre (less than 5 percent). While early and middle period assemblages contained higher proportions of glass with phenocrysts (5-40 percent) compared to glass (<5 percent). This research confirmed that obsidian is present in early, middle, and late periods; however, it is apparent that additional research is needed to establish if obsidian source frequency and tool types vary over time.

Recent Pacific Northwest Obsidian Studies

Recent regional obsidian research has relied heavily on XRF sourcing techniques to provide geochemical characterizations that generate source-to-site data. Many studies focused on the archaeological distribution of sources through inter- and intra-site comparisons, while others focused on the distribution of a single source. These studies employed obsidian sourcing to understand change over time in trade and exchange, social interaction spheres, variation in distance decay, and representation of object types from different sources.

Carlson (1994) provides a regional perspective of obsidian trade and exchange networks by comparing the geographic distributions over time. In this research, he examined 1,302 pieces of obsidian from 180 sites in British Columbia and adjacent areas. All specimens were geochemically characterized to sources on the Canadian west coast in addition to eight Oregon sources. Source occurrence was analyzed by 1,000-year increments to demonstrate changes in obsidian procurement areas and artifact distributions over time. Results established that regional obsidian trade gradually increased between 9500-6000 B.P., and between 6,000-4,000 B.P. obsidian was found ubiquitously along the west coast. However, after 1,500 B.P. fewer obsidian artifacts and sites containing obsidian artifacts were observed; correspondingly, a decline in chipped stone tool use during this time was observed along the coast, which included obsidian and local lithic raw materials.

In addition to analyzing obsidian in regional trade and exchange systems, researchers have sought to understand changes in local procurement ranges over time. Cadena (2012) employed obsidian hydration, in addition to XRF sourcing, to study this problem. In his analysis, 88 near complete, diagnostic obsidian projectile points were identified to 18 sources in Oregon. Hydration dating and projectile point typologies were used as chronological markers. Results indicated a decrease in source-to-site distances and source diversity from the Early to Late Holocene with only two sources utilized during every period.

Mack et al. (2010) discussed a similar trend in the decrease of obsidian source-to-site distances based on evidence from the Beech Creek Site (45LE415). This site located

in southwest Washington was occupied between 3440±40 – 1650 ± 40 B.P. Of the total artifact assemblage, 13 percent of the obsidian was sourced. Diversity consisted of five sources in descending abundance: Elks Pass, Whitewater Ridge, Tule Springs, and Wolf Creek, and decreased over time to the following sources in declining abundance: Elks Pass, Newberry, and Whitewater Ridge. The authors suggested that social interactions spheres became more localized over time to the Cascade region. They also noted that obsidian debitage represented late stage reduction as well as tool maintenance with little difference in size between the local Elks Pass source and those from Oregon. These findings are in contrast to distance to source patterns suggested by Eerkens et al. (2007).

Recent research in Washington also demonstrated that other generally accepted patterns, e.g., distance decay (Renfrew 1977), did not account for the variation observed in obsidian assemblages (Parfitt 2013; Vaughn 2010). Vaughn (2010) employed McCutcheon's (1997) cost and performance model to generate lithic technological and functional data from five archaeological sites (45LE415, 45LE285, 45PI408, 45KI435, and 45PI406) containing 2,010 obsidian artifacts in the southern Washington Cascades. Object types occurred in descending abundance as flakes, bifaces, and cores. Obsidian flakes occurred mainly as intermediate and bifacial reduction indicative of biface manufacture and retouch. Of the total, 144 (7 percent) were sourced to six Oregon and three Washington sources. Source frequency resulted in the identification of three to seven sources per site. Obsidian Cliffs and Newberry Volcano in Oregon had the highest frequencies while the nearest source, Elks Pass, was only the third most frequently represented source. Results indicated no observable relationship between source-to-site

distance and the amount of material found; accordingly, cost in terms of source-to-site distance did not appear to influence obsidian source occurrence. Rather it was suggested that rock physical properties, which may aid or hinder material reduction, influenced material selection.

Parfitt (2013) also employed McCutcheon's model to understand obsidian occurrence at the Grissom Site (45KT301), dating to 2500 B.P. in the northern Kittitas Valley, Washington. Research questions centered on source diversity and if concentrations of obsidian existed within site. Of the 165 obsidian artifacts, 49 artifacts were identified to six Oregon (20, 41 percent) and three Washington sources (29, 59 percent). Stray Gulch from Washington represented the highest frequency of artifacts followed by Indian Creek in Oregon. Source frequency appeared to remain relatively consistent throughout time; however, results did not indicate a correlation between source frequency and source-to-site distance. Moreover, obsidian did not appear to be concentrated in any area of the site. Object types were found in descending abundance flakes, chunks, cores, and bifaces, and source variation across object type demonstrated that bifaces and flakes had the highest source diversity; furthermore, most flakes exhibited characteristics of initial reduction. Of the eleven cores, ten were from Stray Gulch and one was from Bickleton Ridge, both Washington sources.

Parfitt (2013) compared the Grissom assemblage with the Sunrise Ridge Borrow Pit and Tipsoo Lake site assemblages, located on Mount Rainier, and the Beech Creek Site, located in southwest Washington (Mack et al. 2010; Vaughn 2010). At these sites, flakes were the most common object type followed by bifaces. Cores were only present at

the Grissom Site, which may be attributed to source proximity; however, results also indicated that source-to-site distance did not necessarily affect the amount of obsidian present at the Grissom Site. Of the four sites, Grissom and Beech Creek were the only where the closest obsidian source had the highest representation.

In contrast to the studies discussed above, McClure's (2014) research focused on the archaeological distribution of a single source, Elks Pass. This source occurs as low-quality nodules in the high Cascades of southwestern Washington. Debitage, indicative of core and biface reduction is the most common artifact type found at the source. Elks Pass has been documented in 17 precontact archaeological sites within a 52-kilometer radius of the source in the Upper Cowlitz River watershed containing a total of 160 obsidian artifacts from a number of sources. Elks Pass comprised 61 percent of the total sourced artifacts, with higher frequencies at sites nearer to the source, and occurred over early, middle, and late periods. Results concluded that Elks Pass is a low-quality, local source occurring in a restricted mountainous area that did not appear in regional exchange. Rather the distribution of Elks Pass aligns with the historic territory of Taytnapam bands. Based on this evidence, it was likely acquired through direct, embedded procurement.

Mierendorf and Baldwin (2014) noted a similar pattern in source occurrence during investigations of the geographically isolated Copper Ridge vitrophyre source in the North Cascades. Copper Ridge, similar to Chelan Butte, commonly exhibits large, abundant phenocrysts embed in a glassy groundmass; whereas, toolstone quality material has few phenocrysts and conchoidal fracture characteristics similar to quality obsidian. However, quality material it is uncommon. Copper Ridge was identified through analysis

of 154 artifacts from 20 sites and 67 samples from source outcrops. Of the total, 87 were submitted for XRF analysis revealing nine known, geochemically distinct sources. Sources differed in color, quality, and intra-source geochemical variation. High intra-source variation was attributed to high densities of phenocrysts and hackly surfaces, which may inhibit precise source characterization.

Use of Copper Ridge vitrophyre over time was based on ten associated radiocarbon dates, establishing that Copper Ridge was used from the middle Holocene into late precontact periods. Exploitation of this material was limited by the availability of quality toolstone; consequently, it appeared primarily as small flake cores and utilized flakes. Analogous to Elks Pass, Copper Ridge occurred in high frequencies at sites near the quarries and rapidly decreased as the distance from quarry increased; however, it was also documented at two sites far from the quarry. According to the authors, the distribution patterns of this material were influenced by physical properties, abundance, and access to the raw material.

Cost and Performance Variables

The models discussed above (Andrefsky 1994; Eerkens et al. 2007; McCutcheon 1997; Renfrew 1977) define variables used to measure stone tool occurrence in the archaeological record. Researchers in the Pacific Northwest have used elements of these to identify attributes related to the presence and distribution of obsidian, which has resulted in some general patterns of obsidian occurrence in Washington.

Whereas obsidian sources from Oregon tend to be widely distributed in the archaeological record, Washington sources are generally found at sites in close proximity

to the source (McClure 2014; Mierendorf and Baldwin 2014). Many Washington studies note obsidian commonly occurring as bifaces and resharpening flakes (Chatters 1986; Galm 1994a; Mack et al. 2010; Parfitt 2013; Vaughn 2010). Some researchers observed a decrease in source-to-site distances over time (Cadena 2012; Mack et al. 2010), while others observed relatively no change (McClure 2014; Mierendorf and Baldwin 2014; Parfitt 2013). Other studies demonstrated the inapplicability of Renfrew's (1977) distance decay model (Parfitt 2013; Vaughn 2010); however, low-quality obsidian generally adheres to expected patterns of distance decay (McClure 2014; Mierendorf and Baldwin 2014). In many of these studies, raw material quality is asserted to be a central variable influencing the inclusion and distribution of sources into the archaeological record (Andrefsky 1994; Eerkens et al. 2007; McClure 2014; McCutcheon 1997; Mierendorf and Baldwin 2014; Vaughn 2010).

In order to understand if obsidian artifacts in the Mid-Columbia River Valley follow patterns seen elsewhere, I first sought to empirically determine the range of variation present across obsidian sources. To achieve this, I adapted relevant models and variables to classify artifact material, technological, and functional attributes to measure difference and change over time and space. Stone tool analytical models and regional research discuss variables related to cost and performance. Cost is defined as the amount of energy needed to construct a given object, and performance is the work that is done by an object in its interactive environment (McCutcheon 1997). These variables are further explored in order to identify sub-variables and to contextualize the relationship of cost and performance in stone tool industries.

Cost

In relation to lithic technology, cost refers to energy expenditure associated with raw material procurement, material preparation, manufacture, and tool durability (McCutcheon 1997). When performance variables are held constant, the lower relative costs associated with an activity will lead toward a selective advantage. Conversely, increased costs may be offset by increased performance.

Material Acquisition. As the distance from source-to-site increases, distance decay of raw materials is observed depending on the quantity, distance, and mode (e.g., direct procurement, or trade and exchange) by which raw material was acquired (Jeske 1989; Mitchell and Shackley 1995; Renfrew 1977). Costs associated with procuring material are dependent on proximity to a site and abundance (Andrefsky 1994), as well as the form (e.g., a primary or secondary source) in which a material occurs (McCutcheon 1997; Shackley 2005). Abundance can be quantified by number of pieces, weight, and distance from source; however, weight is generally the most useful consideration as cost is a reflection of the heaviness of the transported material (Wright 1970; Wright and Grodus 1969). Conversely, counts of formal artifacts may be more useful for examining items that were products of trade (Ericson 1977).

Archaeologists also recognize variation in the quantity and type of object depending upon the distance between source and site (Beck et al. 2002; Eerkens et al. 2007). At sites further from sources, more reduction takes place at the source, presumably to lower the costs of transport, and fewer and smaller debitage is present at the site (Beck 2008). Sites closer to sources contain relatively larger debitage and cortical material,

indicating early stages of reduction (Beck et al. 2002). Teltser (1992) notes that cortex is often a useful indicator to describe variability in reduction trajectories. Her research demonstrated that flakes with cortical platforms are on average larger than flakes with simple or faceted platforms, and flakes exhibiting dorsal surface cortex and a single flake scar are also larger than the average flake with no dorsal surface cortex. Increased costs associated with using nonlocal sources generally outweigh any benefits; accordingly, local sources that are less costly to procure are used instead (Andrefsky 1994; Beck et al. 2002; Cheshier and Kelly 2006).

The natural form of stone tool raw material may influence the cost of procurement (McCutcheon 1997). Primary sources, such as domes and dikes, must be quarried, requiring energy and tools (Crabtree 1972; McCutcheon 1997). Secondary sources are nodules that have eroded from a primary source and may be easily picked out of gravel bars or outwash (McCutcheon and Dunnell 1998). Additionally, raw material preparation involves extra steps, which may increase failure rates; however, preparation may enhance performance (McCutcheon 1997).

Material. Rock fracture mechanics are affected by the structure of lithic materials, which determine 1) fracture toughness or the ability to withstand crack initiation and propagation, and 2) predictability of fracture (McCutcheon 1997). Fracture toughness is dependent on groundmass and the presence or absence of inclusions (McCutcheon and Dunnell 1998), which control the ease and predictability of fracture (Crabtree 1972). Structure, grain size, and/or presence and distribution of solid or void inclusions can increase the energy necessary to fracture a given material, as a crack must propagate

around or through such obstacles (McCutcheon 1997; McCutcheon and Dunnell 1998). These variables increase failure rates above those normally incurred, and the ability to predict those rates prior to reduction. The results of which affect the form and performance of a tool (Andrefsky 1994; Crabtree 1972).

Manufacture. Stone tool manufacture is a reductive process, described as the fracture and removal of stone to create a desired form (Andrefsky 2005; Crabtree 1972). Manufacture can be described by 1) rock physical properties, 2) stone tool requirements, and 3) technology (McCutcheon 1997). Rock physical properties are described as the type of groundmass and presence or absence of inclusions in a raw material (McCutcheon and Dunnell 1998), which may structure tool form and use (Andrefsky 1994; Crabtree 1972). These properties dictate quality, or the ease and predictably of fracture of a stone during reduction (Andrefsky 1994). Obsidian is considered highly desirable for chipped stone tool technologies as it flakes easily and predictably producing very sharp edges (Shackley 2005).

The requirements of stone tools vary based on the desired function and the limitations of the material. Technology refers to whether the tools are manufactured into curated (formal) or expedient (informal) tools. Curated tools are more costly to make as they are designed for multiple uses and easy transport, while expedient tools are created for immediacy and a specific task (Bamforth 1986). Thus, curated tools have higher manufacture costs than expedient tools due to increased steps and functions (McCutcheon 1997).

Tool Durability. Raw material durability affects stone tool technology (shape, size, and use) and dimension (length, width, and thickness) (Cheshier and Kelly 2006). Archaeologists maintain that certain raw material qualities are desirable for specific uses; high-quality material such as obsidian is easy to work, but less durable. Thus, obsidian may only be manufactured into certain artifacts and may be highly retouched due to easy breakage. Stone tool durability connects physical properties with technology and tool requirements (McCutcheon 1997).

Performance

Performance is affected by 1) physical properties, 2) requirements of the tool, and 3) technology (McCutcheon 1997). Physical properties of lithics can either enhance (e.g. homogenous material) or hinder (e.g. heterogeneous material) the technological and functional characteristics of a tool. Archaeologists have suggested that raw material quality is a factor that affected source inclusion and abundance in the archaeological record (Carlson 1994; McCutcheon and Dunnell 1998; McClure 2014; Mierendorf and Baldwin 2014). McCutcheon and Dunnell (1998) demonstrated that precontact people in the central Mississippi River Valley selected stone tool material based on groundmass, presence of voids, and distribution of inclusions; however, no selective preference was observed regarding solid inclusions. The authors also established that fracture toughness was dependent on groundmass and the presence or absence of inclusions. Carlson (1994) and McClure (2014) noted that local low-quality obsidian sources occurred less frequently in the archaeological record than nonlocal high-quality sources, and low-quality material did not appear valuable in trade and exchange (Carlson 1994; McClure

2014; Mierendorf and Baldwin 2014). Accordingly, cost related to increased source-to-site distances may be offset by the performance of high-quality materials (McCutcheon 1997).

As discussed above, increased performance characteristics of lithic materials may outweigh associated costs of manufacture. Obsidian performs exceedingly well for tools that require sharp edges; however, it is not very durable and may only be used for certain tools or tasks. Furthermore, the same qualities of raw materials that aid in facilitating the reduction process may also be detrimental to performance through higher rates of breakage or wear (Cheshier and Kelly 2006).

Measuring Diversity in Stone Tool Assemblages

Once lithic variables are identified, the next step to effectively document diversity in stone tool assemblages would be to assess the representativeness of measured artifact dimensions (Kintigh 1984). Ordinal measurements of diversity can be accomplished with a simple method of resampling that uses the bootstrapping technique (Mooney and Duval 1993). Bootstrapping is applied to understand the representativeness of the observed populations prior to statistical analysis (Mooney and Duval 1993). The basic premise is to evaluate diversity as a measure of artifact frequency variation within a set of classes (Jones and Leonard 1989; Kintigh 1984). This is described through the number of categories within the chosen population (richness) and the distribution of the population across those categories (evenness). This technique has been employed in numerous stone tool analyses (Eerkens et al. 2007; Lipo 2000; McCutcheon 1997; McCutcheon et al. 2008; Vaughn 2010). Despite implications by some researchers that this technique has an

intrinsic degree of subjectivity (Cochrane 2002), bootstrapping has been validated by others as a useful nonparametric technique that does not rely on assumptions about the sample population (Lipo 2000; McCutcheon 1997).

Chi-square analysis has been the statistical method of choice in many Pacific Northwest lithic studies (Eerkens et al. 2007; Evans 2009; Kelly 1988; Mack et al. 2010; Vaughn 2010). Chi-square analysis (χ^2) is a statistical hypothesis test introduced into archaeology by Spaulding (1953) as a way to understand a non-random co-occurrence between attributes empirically represented in artifacts. However, in many cases sample sizes are too small or expected values are too low for a chi-square analysis and instead an alternative test, such as Fisher's exact, may be employed.

Such statistical techniques help delineate the attributes of obsidian that were selected and incorporated into lithic industries. Once cost and performance variables are documented, the intersections of those variables can be statistically analyzed to determine if non-random relationships exist between representative data. This allows hypotheses regarding obsidian occurrence in the Mid-Columbia River Valley to be tested and results to be compared with other Pacific Northwest studies. Previous approaches noted patterns and variables that affect obsidian occurrence, yet few of these studies have gone beyond documentation and employed statistical techniques. An approach combining stone tool and statistical analysis would assist in identifying non-random associations between attributes which can elucidate patterns in obsidian occurrence.

CHAPTER IV

THEORY, METHOD, AND TECHNIQUE

Theory

The purpose of this section was to address Objective 1: to adapt an evolutionary archaeology approach to explain the occurrence of obsidian in the Mid-Columbia River Valley. Evolutionary archaeological theory has been applied to a variety of lithic analyses (McCutcheon 1997; Parfitt 2013; Shott 2008; Vaughn 2010), as an explicit way to understand difference and change over time in archaeological assemblages. One causal mechanism this framework employs is natural selection, which refers to an increase of certain forms in a population (e.g. lithic assemblages) because they are better adept to function under a given set of environmental conditions (O'Brien and Lyman 2000). Consequently, the physical environment is the selective agent structuring assemblages.

In the Pacific Northwest, an evolutionary archaeology framework has only been recently employed to understand obsidian occurrence over time (Parfitt 2013; Vaughn 2010). These studies revealed that generally accepted models (e.g., Renfrew 1977) do not account for the selective conditions under which obsidian is incorporated into stone tool manufacture and use. In order to explicitly understand the selective conditions influencing obsidian occurrence in the Mid-Columbia River Valley, an evolutionary archaeology approach was applied that documents stone tool technological, functional, and physical property variables of cost and performance present in obsidian artifacts (Andrefsky 1994; Eerkens et al. 2007; Ericson 1977; McCutcheon 1997; McCutcheon and Dunnell 1998). Utilizing this approach can help record occurrence and compare

results to patterns noted elsewhere (Cadena 2012; Mack et al. 2010; McClure 2014; Mierendorf and Baldwin 2014; Parfitt 2013; Vaughn 2010). If obsidian occurrence was not associated with cost and performance elements of stone tool manufacture and use, then the causal mechanism is not natural selection. Rather, consumption patterns may be a result of cultural transmission where the exchange information (e.g. style) is neutral to selective pressures. Consequently, culture was the selective agent that produces similarities in behavior and artifacts (Dunnell 1978a; Eerkens and Lipo 2007; O'Brien and Lyman 2000).

Evolutionary archaeology provided a framework for guiding the proposed research objectives outlined in Chapter I. The next step was to adapt a model that provided the procedures for classifying artifacts. The method, in turn, guided the techniques by which artifacts were measured.

Method

Methods often encompass models that contain variables (and sub-variables) to define classifications by which a set of data can be measured and described. Objective 2 sought to adapt a model of cost and performance to capture data on variables of stone tool industries that were influenced by the selective conditions of a given environment. Once defined the following hypothesis could be tested: *Obsidian source occurrence is random across stone tool manufacture and use*. If obsidian did not occur randomly, then I could explore why different sources of obsidian were chosen and utilized in central Washington.

Numerous models have provided procedures for measuring and describing variability in lithic assemblages (Andrefsky 1994; Beck et al. 2002; Brantingham 2003; Eerkens et al. 2007; Jeske 1989; McCutcheon 1997; Odell 2004; Renfrew 1977; Wilson 2007; Wood and Wood 2005). After a review of pertinent literature, I chose a model of cost and performance developed by McCutcheon (1997), as it provided an evolutionary approach for capturing variation of manufacture and use across lithic assemblages.

Explaining obsidian occurrence in the Mid-Columbia River Valley is complex, as local sources appear variable in composition and numerous in occurrences. Source diversity in the study area is high; however, it is unknown if sources are tied to particular artifact types. It was first necessary to design a means to measure variability. The selected model provided a basis for the techniques of classification, collection, and manipulation of occurrence data.

Cost and performance is based on three paradigmatic classifications: rock physical properties, technology, and function (McCutcheon 1997). These paradigms are the intersection of dimensional attributes, which in turn are composed of mutually exclusive, equivalent modes (Dunnell 1971). Thus, each paradigm provides the means to record specific elements of stone tool industries. These classifications, when coupled with spatial and temporal data, provide a valuable tool for assessing how cost and performance variables structure obsidian consumption on a landscape scale.

Technique

This section focused on Objective 3, defining artifact classifications and representativeness, and Objective 4, outlining a stepwise statistical approach. Technique is defined as the collection and manipulation of data (Dunnell 1971). It provides the means of applying the classifications (e.g. rock provenance, rock physical properties, technological, and use-wear) to the empirical record (e.g. lithic assemblage). Classifying artifacts organizes data into manageable units from which patterns can be identified, compared, and communicated (Andrefsky 2005).

Data was generated by analyzing 656 obsidian artifacts from the 18 archaeological site collections (Table 3). Site assemblage information was acquired from

Table 3. Archaeological Site and Artifact Count.

Archaeological Site	Artifact Count	Archaeological Site	Artifact Count
45CH57	12	45OK382	7
45CH58	29	45OK383	20
45CH61	284	45OK419	9
45DO372	1	45OK422	143
45DO387	38	45OK424	47
45DO409	43	45OK426	2
45DO417	5	45OK69	6
45DO59	7	45OK92	1
45OK113	1	45OK94	1

associated site forms and reports (Chatters 1986; Galm 1994a; Grabert 1968; Gunkel 1961; Schalk and Mierendorf 1983) available through the Washington Information System for Architectural and Archaeological Records Data (WISAARD) and from the

Colville Tribal Repository. Laboratory analysis consisted of collecting empirical data on obsidian abundance, and classification of material, technological, and functional variables (McCutcheon 1997). A representative sample of artifact variation across material, technological, and functional data was submitted for XRF analysis to help determine the selective mechanism sorting assemblages. The intersection of these documented classes were then statistically tested to determine if obsidian source occurred randomly across stone tool manufacture and use.

Rock Physical Property Classification

Consistent description of stone tool physical properties is essential as many physical characteristics control the ease and predictability by which material fractures (Crabtree 1972). Structure, grain size, and/or presence and distribution of solid or void inclusions variables affect the form and performance of a tool (Crabtree 1972). Other physical properties, such as color or light transmittance, are related to visual differences and do not necessarily interact with fracture mechanics. However, these variables may help identify selective conditions regarding cultural preferences if technological or functional classifications fail to explain obsidian source exploitation (Luedtke 1992; Taliaferro et al. 2010).

I used a paradigmatic classification described by McCutcheon (1997) and recently used by Parfitt (2013) and Vaughn (2010), and obsidian descriptive terminology defined by Northwest Research Obsidian Studies Laboratory (NROSL) (2013) to describe macroscopic and microscopic obsidian physical properties. Eleven dimensions were used to record groundmass and six dimensions were used to describe cortex. The *Geologic*

Rock-Color Chart produced by Munsell Color (2009) was used to record color. These dimensions were described through the following modes (see Table 4).

Table 4. Rock Physical Properties Classification: Dimensions and Modes.

Dimensions	Modes
Cortex-Grain Size	Crypto-crystalline, Aphanitic, Fine-Grained, Coarse-Grained, No Cortex Present
Cortex-Solid Inclusions	Present, Absent, No Cortex Present
Cortex- Void Inclusions	Present, Absent, No Cortex Present
Cortex-Distribution of Solid Inclusions	Random, Uniform, Structured, None, No Cortex Present
Cortex- Distribution of Void Inclusions	Random, Uniform, Structured, None, No Cortex Present
Cortex- Color	See Munsell
Groundmass	Uniform, Bedding Planes, Concentric Banding, Mottled
Groundmass -Solid Inclusions	Present, Absent, Cortex Present
Groundmass - Void Inclusions	Present, Absent, Cortex Present
Groundmass -Distribution of Solid Inclusions	Random, Uniform, Structured, None, Cortex Present
Groundmass - Distribution of Void Inclusions	Random, Uniform, Structured, None, Cortex Present
Groundmass- Surface Texture	Smooth, Flawed, Matte, Grainy, Hackly, Not Applicable
Groundmass- Surface Luster	Chatoyant, Earthy, Resinous, Vitreous, Not Applicable
Groundmass- Light Transmittance	Opaque, Translucent, Transparent, Not Applicable
Groundmass- Patina	Entire Artifact, Entire Dorsal, Partial Dorsal, Entire Ventral, Partial Ventral, Portions of Dorsal and Ventral, None, Platform Only
Groundmass- Color	See Munsell Color (2009)

Groundmass. The groundmass of a rock is defined as the fine-grained matrix in which larger inclusions may be present (McGraw-Hill 2003). The patterning of the groundmass color and texture are described as: Uniform (an even and unchanging in both color and structure), Bedding planes (parallel linear striations), Concentric Banding (concentric layering), and Mottled (uneven and abrupt variation) (McCutcheon 1997).

Grain size. The grain size of raw materials interacts with fracture mechanics (Crabtree 1972) and ranges from cryptocrystalline to coarse grained (McCutcheon 1997). Obsidian is characterized by a glassy groundmass (Shackley 2005). Therefore, grain size was recorded only for the dimension of cortex. Cryptocrystalline is characterized by individual grains that are not visible under magnification. Aphanitic is described as grains that are not visible to the unaided eye. Fine-grained refers to small, evenly distributed individual grains visible to the unaided eye. While coarse-grained refers to large interlocking grains visible to the unaided eye.

Inclusions. Obsidian artifacts were classified based on the presence and the distribution of solid and/or void inclusions, visible to the unaided eye and up to 40X magnification. Inclusions are inhomogenatities that occur at a higher scale within a rock's groundmass and are visually distinguishable (McCutcheon 1997). Solid and void inclusions interact with crack propagation in different ways (McCutcheon and Dunnell 1998). Void inclusions consistently hinder crack propagation; where as solid inclusions unpredictably disrupt propagation. If present, the distributions of these inclusions were described as: Random (irregular and unpatterned), Uniform (evenly distributed), or Structured (patterned or isolated). The presence and distribution of inclusions affects

fracture toughness and predictability in two ways: 1) random distributions decrease predictability, and 2) uniform and structured distributions increase predictability (McCutcheon 1997).

Surface Texture. This dimension refers to the textural appearance of a broken surface of obsidian (NROSL 2014). It can be described as a visual extension of how the presence and distribution of solid and/or void inclusions affects the way obsidian fractures. The modes of this dimension are: Smooth (unflawed, like freshly broken glass), Flawed (small blemishes, but otherwise smooth), Matte (surface is dull), Grainy (surface appears granulated, but individual grains cannot be seen), Hackly (highly irregular surface due to inclusions), or Not Applicable (presence of cortex or patina prevents determination) (Adams 1980; Skinner 1987).

Surface Luster. This dimension refers to the light reflected from a broken surface (Dana 1959; NROSL 2014). Surface luster is dependent upon the degree of crystallinity of the glass and is described in the following modes: Chatoyant (pearl-like sheen or iridescence), Earthy (lack of luster due to grainy texture), Resinous (appearance of resin), Vitreous (freshly broken glass), or Not Applicable (presence of cortex or patina prevents determination).

Light Transmittance. This dimension describes the amount of light that passes through a fragment of obsidian (NROSL 2014). Light transmittance modes are: Opaque (little to none), Translucent (light passes through, but text cannot be read), Transparent (light passes through and text can easily be read), and Not Applicable (cortex or patina prevents determination).

Patina. Patination or cortification is the dulling of a broken rock surface through corrosive activity or weathering where the exterior rind is slowly being reconstructed from a fresh break (Edmonds 1997). Like cortex, the presence of a patina can inhibit the characterization of the groundmass (NROSL 2014). Eight modes were recorded in relation to the location the patina: Entire Artifact, Entire Dorsal, Partial Dorsal, Entire Ventral, Partial Ventral, Portions of Dorsal and Ventral, None, or Platform Only.

Color. Rock color was recorded using the Munsell *Geological Society of America Rock-Color Chart*, the standard by which obsidian is described (NROSL 2014). Color was recorded for both the groundmass and the cortex by color values for hue, value, and chroma (Munsell Color 2009). The three dominate colors, in order of abundance, were listed for each artifact. Obsidian color is related to the degree of crystallinity of the natural glass and mineral phase of the crystalline components (NROSL 2014). It is important to note that obsidian chemical composition of is not affected by color, thus reinforcing the importance of trace element provenance studies.

Technological Classification

Stone tool manufacture is explained through physical properties, requirements of a tool, and available technology (McCutcheon 1997). Documenting technology aids in distinguishing between curated and expedient technologies, which are based on the amount of production effort (Andrefsky 1994, 2005; Nelson 1991). Byproducts of the reduction process are cores and waste flakes. Classification is intended to identify characteristic elements of the reduction trajectory so that object types can be isolated and

compared across source diversity. The dimensions and modes used to describe technology attributes are provided in Table 5.

Table 5. Technological Classification: Dimensions and Modes.

Dimension	Modes
Object Type	Biface, Small Flake/Flake Fragment, Large Flake/Flake Fragment Chunk, Cobble, Core
Amount of Cortex	Primary, Secondary, Tertiary, None
Presence of Wear	Present, Absent
Other Modification	None, Flaking, Grinding, Pecking, Incising, Other
Platform Type	Cortex, Simple, Faceted, Bifacial Unfinished, Bifacial Unfinished, Wear Present, Bifacial Finished, Bifacial Finished Wear Present, Potlids, Fragmentary, Not Applicable, Pressure Flakes, Technologically Absent
Completeness	Whole, Broken, Flake Fragment, Debris, Other
Reduction Class	Initial Reduction, Intermediate Reduction, Terminal Reduction, Bifacial Reduction/Thinning, Bifacial Resharpener, Not Applicable

Object Type. Object Type refers to the technological form in which an artifact occurs and can represent stages of the manufacture sequence (McCutcheon 1997).

Conchoidal fracture is the primary manner by which stone tools are manufactured (Crabtree 1972; Cottrell and Kamminga 1987). It is important to distinguish between lithic object types that exhibit characteristics of conchoidal fracture (e.g. bifaces, flakes, or cores) from those that do not (e.g. chunks, spalls, or cobbles) (McCutcheon 1997).

McCutcheon (1997) lists five modes for this dimension:

- A Flake is a rock fragment exhibiting attributes of conchoidal fracture, principally in the form of positive flake scars, a bulb of percussion, eorillure scars, and an intact point of impact.

- A Biface is characterized by only negative flake scars initiated from both sides of the rock edge.
- A Core is rock exhibiting non-cortical surfaces, but exhibits negative flake scars from conchoidal fracture due to the removal of a flake.
- A Chunk is characterized by non-cortical surfaces with no evidence of conchoidal fracture.
- A Cobble exhibits cortical surfaces with no evidence of fracture.

Amount of Cortex. Cortex indicates the presence of the outer rind of a rock formed from weathering processes. This dimension, in part, aids in defining the reduction trajectory class (Sullivan and Rosen 1985). Four modes were recorded for this dimension (McCutcheon 1997): Primary (cortex covering the dorsal surface of an artifact), Secondary (mixed cortical and non-cortical surfaces), Tertiary (presence of cortex only on the point of impact), and None. It is important to note that the amount of cortex present is not explicitly related to technology and is also influenced by other factors such as: raw material type, nodule size, reduction intensity, etc. (Sullivan and Rosen 1985).

Presence of Wear and Other Modification. Alterations to the Object Type through technological modification or use are documented by the presence or absence of Wear and Other Modification, respectively (McCutcheon 1997). Presence of Wear denotes the presence or absence of reduction from physical interactions with the environment (Dancey 1973). If present, the associated mode is recorded and further described by the Use-Wear paradigmatic classification (see below). The presence or absence of Other

Modification refers to additional technological or non-wear alterations to an Object Type: Flaking, Grinding, Pecking, Incising, or Other.

Platform Type. Platform Type describes the point of impact of flakes and flake fragments. Recording platform type reveals information about the object from which flakes were detached and when used in conjunction with other technological dimensions can describe reduction trajectories (McCutcheon 1997). Twelve modes were recorded for this dimension. Cortex indicates the presence of cortical material on the point of impact. Simple is the presence of a single flake scar. Faceted is characterized by more than one flake scar. Bifacial unfinished platforms are bifacially flaked with a single stratum of flake scars, whereas bifacial unfinished wear present are bifacially flaked platforms with use-wear present over a single stratum of flake scars. Bifacial finished is a bifacially flaked platform exhibiting several strata of flake scars. Bifacial finished wear present is a bifacially flaked platform exhibiting use-wear over several strata of flake scars. Potlids are generally smaller flakes produced from heating with a point of force located at the apex of the convex side of the flake. Fragmentary platforms are either missing the entire platform or point of force. Pressure Flakes are generally small flakes with very thin platforms with an intact, yet diffuse, bulb of percussion. Technologically Absent platforms occur due to indirect percussion that results in additional flake removal from the bulb of percussion on the ventral side. Not Applicable refers to bifaces, cores, chunks and cobbles.

Completeness. Completeness assists determining the frequency of debitage categories and provides information on the technology from which flakes were produced

(Sullivan and Rosen 1985). Completeness consists of five modes (McCutcheon 1997). Whole defines complete flakes that have a discernable interior surface, point of force, intact margins, and no broken edges (i.e., step-fractured margins). Broken refers to flakes that have a discernable interior surface, and point of force with fragmented margins exhibiting step fractures. Flake Fragment denotes flakes that have a discernable interior surface with no clear point of applied force. Debris refers to objects that have no discernable interior surface. Other describes Object Types that are not applicable to this dimension: flake fragments, bifaces, cores, chunks and cobbles.

Reduction Class. This dimension is based on a hierarchical key that denotes the presence or absence of variability exhibited by complete and broken flakes (Table 6) (McCutcheon 1997; Sullivan and Rosen 1985). As the reduction class moves from

Table 6. Reduction Classes and Attributes (Adapted From Sullivan and Rozen 1985:759).

Reduction Class	Cortex and Platform Attributes
Initial reduction	Dorsal cortex present
Intermediate Reduction	No cortex present and simple dorsal surface
Terminal Reduction	No cortex, complex dorsal surface, and lipped platform
Bifacial Reduction/Thinning	No cortex, complex dorsal surface, lipped and unworn platform
Bifacial Resharpener	No cortex, complex dorsal surface, lipped and worn platform

initial to bifacial resharpener, flakes exhibit increasingly complex proximal ends and dorsal surfaces. The mode Not Applicable was added to account for all flake fragments and non-flake artifacts (e.g., cores). The accuracy of this technique was demonstrated by

McCutcheon (1997) who observed that the average flake weight is greatest for those assigned to the initial reduction and decreases with following modes.

Use-Wear Classification

Use-wear describes the functional variability related to tool manufacture, material properties, and material provenance (McCutcheon 1997). Use-wear is dulling from damage that occurs on the surface or edges of an object through its articulation with the environment (Dancey 1973). This is differentiated from technological and curation damage, which produces different reduction patterns. Use-wear dimensions follow a macroscopic functional use-wear classification based on Dunnell and Lewarch (1974) and are outlined in Table 7.

Table 7. Use-Wear Classification: Dimensions and Modes.

Dimensions	Mode
Kind of Wear	Chipping, Abrasion, Crushing, Polishing, None
Location of Wear	Angular Point, Angular, Edge, Angular Plane, Curvilinear Point, Curvilinear Edge, Curvilinear Plane, None
Shape or Plan of Worn Area	Concave, Convex, Straight, Point, Oblique Notch, Acute Notch, None
Orientation of Wear	Perpendicular to Y-Plane, Oblique to Y-Plane, Variable to Y-Plane, Parallel to the Y-Plane, No Orientation, None

Use-wear was recorded for the entirety of an artifact; therefore, a specimen can exhibit multiple sets of wear data. Patterns of use-wear may indicate tool function (Odell 2004); however, it is difficult to attribute use-wear to a specific task. Thus, evidence of use-wear is defined by general wear patterns (Odell 2004), which are analyzed through both macroscopic and microscopic (40X) visual examination.

Kind of Wear. Kind of Wear describes the types of wear present and is described by four modes resulting from different uses. Chipping is the patterning of flake scars and recorded for five or more overlapping flake scars. Abrasion is characterized by striations along an artifact edge and/or surface. Crushing is the removal of irregular fragments in an un-patterned manner. Polish is characterized by a glossing of the surface where the artifact has been used in comparison to unused areas (Witthoft 1967).

Location of Wear and Shape or Plan of Worn Area. The remaining modes are useful for describing the particulars of present use-wear. These dimensions are likely too high resolution for describing broad patterns in obsidian occurrence, and are therefore discussed briefly. Location of Wear describes the location(s) of use on an artifact and is described by eight modes: Angular Point (the intersection of three planes), Angular Edge (the intersection of two planes), Angular Plane (a singular planar surface), Curvilinear Point (three dimensional parabola), Curvilinear Edge (two dimensional parabola), Curvilinear Plane (a curved planar surface), or Non-localized (no specific location). Shape or Plan of Worn Area describes differently formed areas on artifacts that exhibit wear. Seven modes are used to record this dimension: Concave, Convex, Straight, Point, Oblique Notch or Angle, and Acute Notch or angle.

Orientation of Wear. The Orientation of Wear differentiates between edge on, unifacial, bifacial or multidirectional, and/or encompassing the entire artifact. It is described relative to the Y-Plane of an artifact, which is the plane perpendicular to the X-Plane on which the wear is found. For example, if a flake is resting on a surface, ventral side down, the Y-Plane is parallel to the surface with edge wear along the X-Plane. Edge-

on wear is described as perpendicular to the Y-Plane (e.g. crushing or pitting). Unifacial or single directional wear is described as oblique to the Y-Plane (e.g. unifacial chipping). Bifacial or multidirectional wear is described as Variable to the Y-Plane and Parallel to the Y-Plane (e.g. bifacial chipping). Wear encompassing the entire artifact is described as No Orientation.

Provenance Classification

The most common method used for obsidian source identification is non-destructive XRF, which characterizes the presence of diagnostic trace elements (e.g., strontium (Sr) and zirconium (Zr)) and their concentrations. Trace element concentrations vary in each geologic source creating a unique signature for each obsidian flow (Shackley 2005). Once analyzed, a sample can be correlated to a characterized obsidian source or a geochemical source group if the trace elemental signatures fall within two standard deviations of either the upper or lower limit of the chemical variability cluster (Northwest Obsidian Research Studies 2014).

Selection of Sourcing Samples

Of the total 656 obsidian artifacts, 97 (15 percent) were selected based on material, technological, and functional classifications to identify obsidian source variability. Initial observations based on artifact classifications demonstrated the majority of artifacts were a highly distinctive greenish/blue gray material exhibiting abundant phenocrysts, likely from the presumed Chelan Butte source. In order to determine if this material was indeed the same source, artifacts were chosen across observed macroscopic variation, then across technological and functional variation. Of the total, 44 were not

visually analogous to Chelan Butte and were submitted for XRF analysis. Artifacts were selected in this manner to accurately identify all present sources.

In addition, sample selection was structured in the following way. Artifacts were chosen from all 18 archaeological sites in proportion to the number of artifacts present in the collection. All artifacts from sites containing two or fewer artifacts were submitted. Object types chosen included 7 bifaces, 13 cores, and 76 flakes based on recorded variation, and object types identified as cobbles and chunks were not selected because these forms lacked technological and functional information.

A representative sample of 62 artifacts was submitted for XRF analysis to NROSL and an additional 35 artifacts were submitted to the Archaeometry Laboratory at the University of Missouri Research Reactor (MURR). NROSL (2013) required samples to be at least one centimeter in diameter and one millimeter in thickness. MURR did not require a minimum size, which can bias source representation (Eerkens et al. 2007). Two artifacts could not be securely characterized to a source; consequently, these artifacts were excluded from source analysis in this thesis. The selection and results of artifact count and source frequency are summarized in Table 8.

Archaeological Site Chronology Classification

An occupation is an assemblage of artifacts deposited by a group of people during a single period of residence at an archaeological site over a period of time (Dunnell 1971). Occupation periods are used to organize data into cultural phases to facilitate comparisons over time; however, it is important to remember that variation also occurs within phases. Analyzing artifact change over time followed cultural phases for the

Table 8. Artifact Sourcing Selection and Results.

Site	Number of Artifacts	Number Sourced	Percentage Sourced (%)	Source Diversity
45CH057	12	3	25	1
45CH058	29	3	10	1
45CH061	284	7	2	1
45DO059	7	4	57	2
45DO372	1	1	100	1
45DO387	38	6	16	4
45DO409	43	10	23	3
45DO417	5	2	40	1
45OK069	6	6	100	2
45OK092	1	1	100	1
45OK094	1	1	100	1
45OK113	1	1	100	1
45OK382	7	7	100	3
45OK383	20	19	95	4
45OK419	9	4	44	1
45OK422	143	14	10	1
45OK424	47	4	9	1
45OK426	2	2	100	1
Total	656	95	15	10

Okanogan highlands as defined by excavations in the Wells Reservoir (Chatters 1986; Grabert 1968).

Chronological assignment of sites was accomplished by comparing artifact provenience information to the associated excavation report (Chatters 1986; Gunkel 1961; Schalk and Mierendorf 1983). Since debitage comprised the majority of the collection, little detailed provenience information was available. Thus, much of the debitage could only be assigned to the age range of an archaeological site.

In the presence of potential biases, chronometric hygiene was employed to establish a more accurate chronology by removing or acknowledging inaccurate data. Following this approach, artifact chronological data was ranked on a scale of high to low according to the level of confidence associated with the compiled dates. Dates associated with absolute dating methods (e.g. radiocarbon) were ranked as a high level of confidence. A moderate level of confidence was associated with relative dating methods (e.g. projectile point typologies). A low level of confidence was associated with artifacts from sites that had been significantly disturbed, precluding chronological control.

Testing Representativeness and Statistical Analysis

Objective 4 was accomplished by assessing data for representativeness through resampling prior to statistical comparison and interpretation. Before broader research questions could be statistically investigated, it was important to determine if assemblage data was representative of the archaeological record (McCutcheon et al. 2008). Analyzing artifact class representativeness helped to determine if sample sizes were sufficient to statistically investigate broader questions regarding the organization of stone tool manufacture and use along the Mid-Columbia River.

Testing Representativeness

A resampling curve was computed for each dimension. Resampling was performed in the R programming language using the bootstrapping technique. Bootstrapping was employed to derive an estimate of the mean number of classes for a number of intermediate subsamples to assess the representativeness of the original sample. These curves plot the number of classes represented (richness) as a function of

the subsample size (evenness) (Kintigh 1984; McCutcheon 1997). Resampled curves were assigned to one of three categories based on the asymptotic characteristics of the generated curve: rich with even class distributions (Rank 1); rich with uneven distributions (Rank 2); and very uneven distributions regardless of richness (Rank 3), see Figures 4 and 5 (McCutcheon 1997; Lipo 2000).

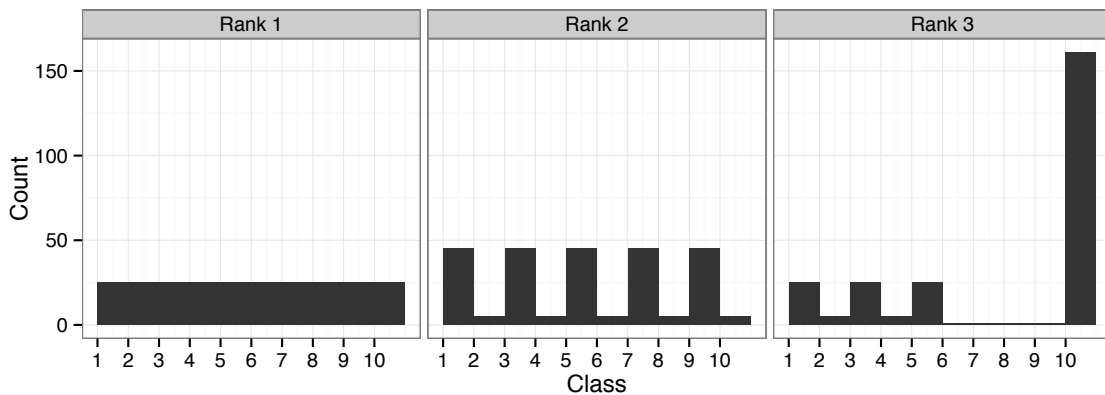


Figure 4. Hypothetical Distributions Representing Rank 1, 2, and 3 Resampling Curves.

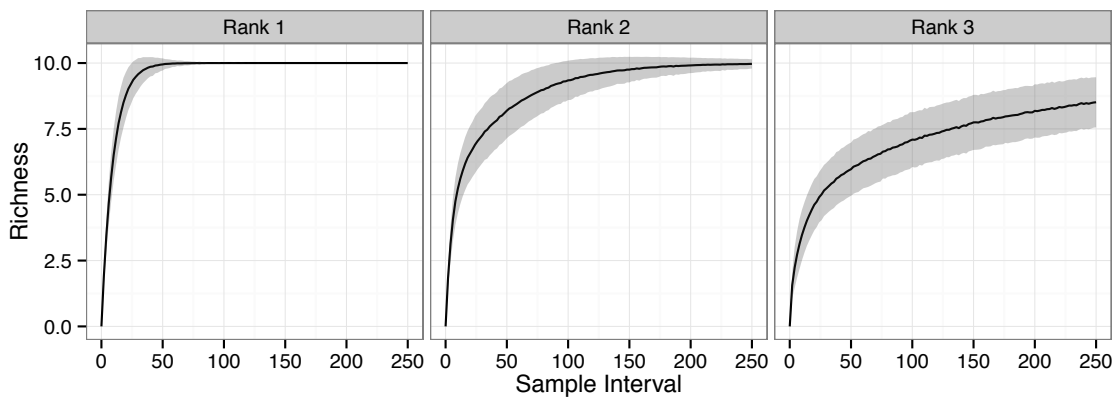


Figure 5. A Representation of Hypothetical Rank 1, 2, and 3 Resampling Curves.

Rank 1 curves have evenly distributed frequencies across represented classes.

These curves reach the asymptote before the maximum sample size is reached (Mooney

and Duvall 1993). Samples that generate curves of this shape have even richness and are presumed to be representative and sufficient for making accurate inter-assemblage comparisons (McCutcheon 1997; Lipo 2000).

Rank 2 curves are characteristic of samples with a high degree of richness, but an uneven distribution. Like Rank 1, these curves are asymptotic; however they reach the asymptote shortly before the maximum sample size is reached. Vaughn (2010) defined Rank 2 as curves that reach the asymptote by 75 percent of the sample size. This cut-off was also employed in this thesis research to define Rank 2 curves.

Rank 3 curves are defined as curves that fail to reach the asymptote. These curves were considered unrepresentative as the standard deviation of the number of classes fails to reach zero. Dimensions assigned to this rank were insufficient due to the unevenness of the data represented across the number of classes (McCutcheon 1997; Lipo 2000).

Statistical Analysis

Once the level of representativeness of each dimension was determined, statistical analyses were employed to explore if non-random associations existed between only the representative dimensions to test the hypothesis: *Obsidian source occurrence is random across stone tool manufacture and use*. A stepwise analytical strategy was used to identify non-random associations, assess the strength of those associations, and identify which modal intersections of dimensions were contributing those associations. Non-random associations were further sub-divided and compared to determine if the organization of obsidian occurrence was consistent with observed regional data.

First, measured artifact dimensions were cross tabulated using two statistical techniques, chi-square test (χ^2) or a Fisher's exact test to evaluate if the dimensions were either randomly or non-randomly associated (Sokal and Rohlf 1969; Zar 1974). Both tests required a null and alternative hypothesis. Simply put, the null hypothesis states that cross tabulated dimensions occur independently or randomly and the alternative hypothesis states that dimensions do not occur independently or non-randomly of each other; accordingly, the dimensions are associated (Sokal and Rohlf 1969; Zar 1974). Chi-square analysis was employed if one-fifth of the expected frequencies in a contingency table were at least five. Chi-square values were calculated for all modes of the intersected dimensions to reflect the difference between observed and expected values (Shennan 1988). The significance value (α) for these tests was .05, which was cross-referenced with the degrees of freedom to calculate the critical value (p) to determine if the null hypothesis was either rejected or not rejected. If data did not meet criteria necessary for chi-square, then a Fisher's exact test was employed so that the exact p -value could be calculated rather than relying on the chi-square approximation (Tamhane and Dunlop 2000).

If the chi-square test resulted in a non-random relationship, investigation continued using Cramer's V (V) to measure the strength of the non-random association between two dimensions (Cramér 1946; Privitera 2012). Cramer's V was only appropriate to calculate when the chi-square test was suitable. This test produced a value between 0 (no relationship) and 1 (perfect relationship) (Shennan 1988). Spearman's Rho (ρ) rank-order correlation was employed as a separate statistical technique to measure

inter-dependence between two ranked variables (Tamhane and Dunlop 2000). The equations, variables, and assessments of these tests are outlined in Table 9.

Table 9. Statistical Tests.

Statistical Test	Equation	Variables	Assessment
Chi-square (χ^2)	$\chi^2 = \frac{\sum(F_o - F_e)^2}{F_e}$	Σ - Sum F_o - Frequency Observed F_e - Frequency Expected	Significance of relationship between two variables if sample size is sufficient
Fisher's Exact	(see Fisher 1970)	(see Fisher 1970)	Significance of relationship between two variables if sample size or expected values were insufficient for Chi-square
Cramer's V	$V = \sqrt{\frac{\chi^2}{n(k-1)}}$	χ^2 - Chi-Square n - Grand Total k - the total number of rows or the total number of columns (whichever is less)	Strength of relationship between two variables if sample size is sufficient
Adjusted Residuals	$R = \frac{(F_o - F_e)}{\sqrt{F_e \cdot (1 - RP) \cdot (1 - CP)}}$	RP - Row Proportion CP - Column Proportion	Identification of cells contributing to the significance of the relationship
Spearman's Rho	$\rho = 1 - \frac{6\sum d_i^2}{n(n^2 - 1)}$	n - Sample size d - Difference between ranks i - Iteration 6 - Constant	Measure of statistical dependence between two variables

Next, an analysis of adjusted residuals was calculated for both chi-square and log likelihood tests in order to determine which cross tabulated modes of the non-randomly occurring dimensions were significantly contributing to the rejection of the null hypothesis. Adjusted residuals took into account sample size, and provided a measurement of the difference between the observed and expected values for the intersected modes of dimensions (SUNYG n.d.). If the null hypothesis was not rejected then an analysis of residuals was not employed (VanPool and Leonard 2011).

Paradigmatic classifications of stone tool manufacture and use, when coupled with statistical techniques, provide an effective mechanism for assessing if obsidian sources occur randomly across stone tool manufacture and use. By recording dimensions of material, technological, and functional classifications, and obsidian provenance, I could document cost and performance variables and use the outlined stepwise statistical analysis to identify associations between recorded cost and performance variables. Doing so also elucidated the organization of technology for my sample of obsidian from the Mid-Columbia River. From this approach, I could form arguments for why particular partitions of observed data are representative and statistically significant, and compare significant data to regional patterns of obsidian occurrence.

CHAPTER V
THE ARCHAEOLOGY OF OBSIDIAN OCCURRENCE IN STONE TOOL
MANUFACTURE AND USE ALONG THE MID-COLUMBIA RIVER,
WASHINGTON

The student coauthors this manuscript with the committee chair and it will be submitted to the *Journal of Northwest Anthropology*. The manuscript begins on the next page and will be the version submitted; the final manuscript (if accepted) may result in differences based the results of editorial and blind peer reviews.

**The Archaeology of Obsidian Occurrence in Stone Tool Manufacture and Use
Along the Mid-Columbia River, Washington**

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Abstract

An evolutionary archaeology model containing stone tool cost and performance variables and a stepwise statistical analysis was employed to describe and explain the selective conditions structuring obsidian occurrence in the Mid-Columbia River Valley, Washington. Our sample consisted of 656 local, low-quality and nonlocal, high-quality artifacts from 18 archaeological sites. Hypotheses were tested to elucidate occurrence in our study area. Results revealed that spatial distributions of source diversity and reduction trajectories varied between the northern and southern reaches; changes over time were contrary to those documented elsewhere; and source diversity increased through time, while frequencies of local sources decreased.

Introduction

The occurrence of hundreds of obsidian artifacts in lithic assemblages from the Mid-Columbia River Valley is fairly unique for Washington State, where obsidian typically occurs in low frequencies making up less than one percent of lithic assemblages (Galm 1994). In these assemblages, obsidian artifacts are crafted from local, low-quality obsidian sources as well as nonlocal, high-quality sources. While it is known that Columbia River people used local and nonlocal obsidian sources (Galm 1994), the quantity and degree to which certain sources occur across stone tool manufacture and use remains unknown.

Obsidian provenance studies in the Pacific Northwest Region have identified inconsistencies in the archaeological occurrence of obsidian. In the Mid-Columbia and adjacent areas, some studies (McClure 2014; Mierendorf and Baldwin 2014) observed that obsidian source frequencies consistently followed patterns predicted by monotonic decay (Renfrew 1977), while others found that frequencies did not follow these patterns (Parfitt 2013; Vaughn 2010). In studies regarding obsidian source occurrence over time, source-to-site distances and source variability-decreased, becoming localized (Cadena 2012; Mack et al. 2010). A study near our research area reported that obsidian source frequency remained relatively consistent throughout time (Parfitt 2013). These incompatible results demonstrate that explaining obsidian occurrence is complex and requires identifying the selective conditions under which obsidian was incorporated into lithic industries. For example, variables such as the material properties or quality of a

source would have likely influenced not just obsidian source occurrence, but also the physical forms of those sources found in the archaeological record (Andrefsky 1994).

In order to explain the occurrence of obsidian stone tool variation present in Mid-Columbia River assemblages, we employed an evolutionary archaeology model based on cost and performance variables (McCutcheon 1997). This model articulates these variables so that classifications could be defined to measure differences in obsidian provenance, material, technological, and functional properties. Once documented, a resampling technique and a stepwise statistical analysis were used to make arguments for why particular partitions of the data were representative and non-randomly associated. Consequently, the selective conditions structuring obsidian occurrence in the Mid-Columbia River Valley were documented and compared to regional patterns.

Mid-Columbia River Valley Study Area

A review of literature in the study area (Chatters 1986; Daugherty 1956; Galm 1994; Galm and Masten 1985; Grabert 1968; Gunkel 1961; Schalk and Mierendorf 1983) identified 18 archaeological sites containing a total of 656 obsidian artifacts (Fig 1). The majority of obsidian appeared attributable to a presumed local source, Chelan Butte; however, the exact provenance is currently unknown. Artifacts exhibiting these visual characteristics have been of interest to archaeologists studying the Mid-Columbia Region since the 1960s (Galm 1994; Galm and Masten 1985; Grabert 1968; Gunkel 1961; Schalk and Mierendorf 1983). As yet, there has been no comprehensive analysis of these artifacts; thus, an examination of these and other obsidian artifacts is necessary to understand obsidian selection and incorporation into stone tool manufacture and use.

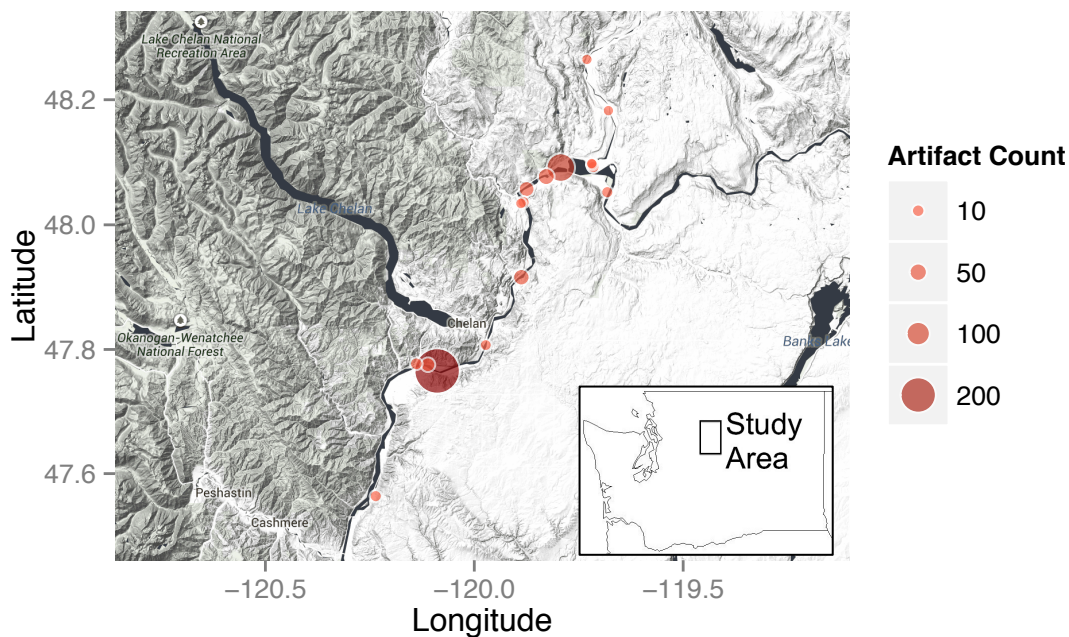


Fig 1. Archaeological Sites and Associated Artifact Frequencies (Base Map Provided by Google Maps 2014). Dashed Line Represents The Boundary Between The Northern And Southern Reaches.

For the purposes of this research, the Mid-Columbia River Valley is defined as the land adjacent to the banks of the Columbia River from the town of Entiat north to Bridgeport, Washington. The northern and southern reaches of the study area vary in topography and in resource availability, which in turn affected human utilization of the landscape. The northern reach is generally steep, with the exception of low-lying river terraces and floodplains; here the Methow and Okanogan rivers converge with the Columbia. This reach has a diverse environment with accessible resources, and is favorable for human habitation (Chatters 1986). The southern reach is characterized as a steep-sided river valley interspersed by low relief terraces and channel bars (Mierendorf 1983); here the deeply incised Chelan River connects Lake Chelan and the Columbia

River. The steep relief of this reach likely restricted human habitation and resource procurement, and constrained the movement of peoples throughout this area (Schalk and Mierendorf 1983). As such, site types identified within this reach demonstrate an orientation towards hunting/processing activities, unlike the more diverse set of land use patterns observed upstream or downstream of this reach.

Research Method/Model

Evolutionary archaeological theory is useful for guiding stone tool manufacture and use studies (McCutcheon 1997; Shott 2008; Wilhelmsen 2001), providing an explicit way to explain structure and variation in artifact assemblages over time and space (Dunnell 1978a, 1978b). Under this theory, cultural transmission and natural selection are two causal mechanisms that sort variation in human phenotype populations (e.g., lithic assemblages) of stone tool producers and users (Leonard and Jones 1987). While formation processes need to be assessed for how they affect the structure of the archaeological record (O'Brien and Lyman 2000; Schiffer 1996; Waters 1997), differences in relative attribute frequencies of stone tool manufacture and use are affected principally by two variables: style and technology/function (Dunnell 1978a; Shott 2008). Cultural transmission filters for selectively neutral or stylistic traits, such as lithic raw material color. Representations of these traits in artifacts are a product of replication of the phenotype on the social scale and innovation on an individual scale (Eerkens and Lipo 2007). Under natural selection certain phenotypic forms within a population become increasingly abundant because they have adapted to function under a given set of environmental conditions (Dunnell 1978b, 1980; O'Brien and Lyman 2000).

Accordingly, the physical environment or natural selection is the mechanism producing differential sorting. These mechanisms produce distinct patterns that structure lithic organization, the remains of which manufacture, use, maintenance, and discard form the material archaeological record (Eerkens and Lipo 2007) and are used to assess lithic raw material occurrence (McCutcheon 1997).

Additionally, it may be that sorting is a function of fieldwork, mitigation, and time limiting our scale of measurement to nominal and ordinal levels (Lipo and Eerkens 2008). All of the artifacts used in this analysis were collected during hydroelectric mitigation projects for the Columbia River dams. Accordingly, the different fieldwork crews, conditions (e.g., trenches vs. controlled excavation, surface collections vs. buried materials), and time constraints as well as archaeological mitigation requirements structured the quantity and type of archaeological data collected over two and a half decades. As such, these variables may have resulted in sorting that has led to an unrepresentative sample rather than a random one.

Archaeologists define stone tool analytical models which include variables (and sub-variables) that identify what needs to be known to measure and describe meaningful variability in lithic assemblages (Andrefsky 1994; Beck et al. 2002; Eerkens et al. 2007; Jeske 1989; McCutcheon 1997; McCutcheon and Dunnell 1998; Renfrew 1977; Wilson 2007; Wood and Wood 2005). McCutcheon's (1997) evolutionary archaeology approach employed a method that contained a model of stone tool cost and performance (Fig 2),

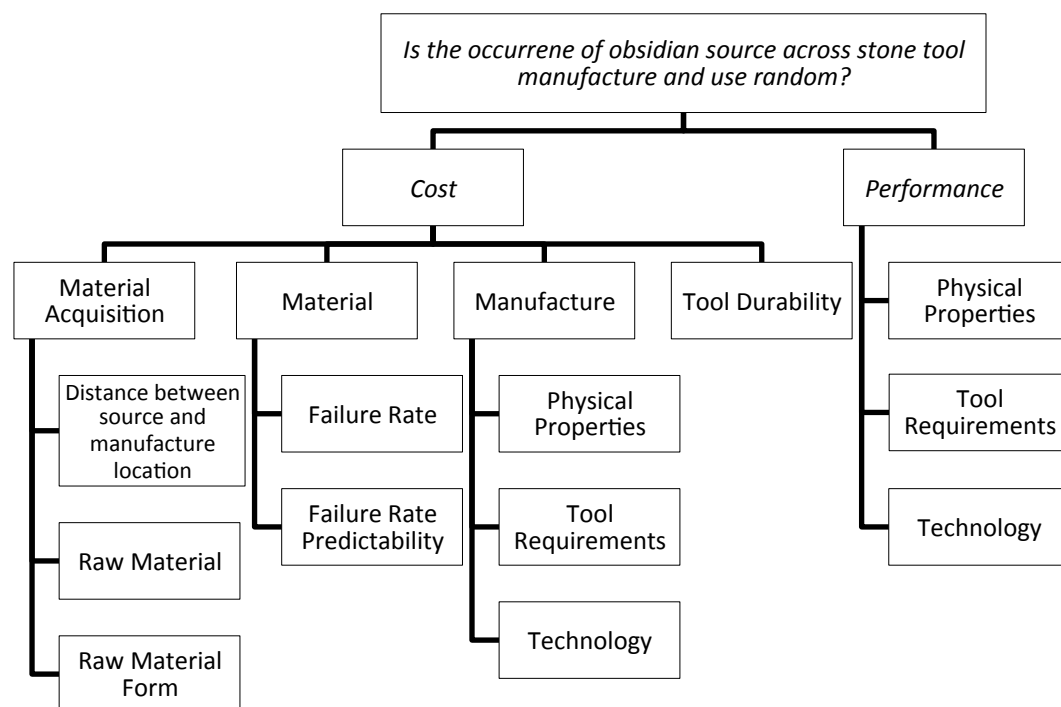


Fig 2. Adapted from McCutcheon's Model: Cost and Performance (1997: Figure 60).

and a technique comprised of three paradigmatic classifications derived explicitly from his method's variables. These classifications, composed of dimensions of stone tool material, technological and functional properties, affect stone tool cost and performance (e.g., Kornbacher 2001; Pfeffer 2001; Pierce 2005; Wilhelmsen 2001). In turn, each dimension is composed of mutually exclusive, equivalent modes or attributes (Dunnell 1971). Thus, each paradigm provides the means to record specific elements of stone tool industries. When coupled with spatial-temporal data, these paradigms provide a valuable tool for assessing the interrelationship between cost and performance and for defining the selective conditions of obsidian occurrence. These paradigms have been employed in the

Pacific Northwest Region for over the past 40 years (e.g., Dancey 1973, Dunnell and Lewarch 1974; Campbell 1981; Dampf 2002; Vaughn 2010; Parfitt 2013).

Cost

In relation to lithic technology, cost may refer to energy expenditure associated with raw material acquisition, material properties, manufacture, and tool durability (McCutcheon 1997). Performance being equal, lower relative costs will lead toward a selective advantage. However, increased costs may be offset by increased performance.

Material Acquisition. As the distance from source-to-site increases, distance decay of raw materials are observed depending on the quantity, distance, and mode (e.g., direct procurement, or trade and exchange) by which raw material was acquired (Jeske 1989; Mitchell and Shackley 1995; Renfrew 1977). Costs associated with procuring materials are dependent on proximity to a site and abundance (Andrefsky 1994), as well as the form (e.g., a primary or secondary source) in which the material occurs (McCutcheon 1997; Shackley 2005). Increased costs associated with using nonlocal sources generally outweigh any benefits; accordingly, local sources that were less costly were used instead (Andrefsky 1994; Beck et al. 2002; Cheshier and Kelly 2006).

Material Properties. Rock fracture mechanics are affected by the structure of lithic materials, which determine 1) fracture toughness or the ability to withstand crack initiation and propagation, and 2) predictability of fracture (McCutcheon 1997). Fracture toughness is dependent on groundmass and the presence or absence of inclusions (McCutcheon and Dunnell 1998), which control the ease and predictability of fracture (Crabtree 1972). Rock physical properties, defined as structure, grain size, and/or

presence and distribution of solid or void inclusions, can increase the energy necessary to fracture a given raw material, as a crack must propagate around or through such obstacles (McCutcheon 1997; McCutcheon and Dunnell 1998). These variables can increase failure rates above those normally incurred and decrease the ability to predict those rates prior to reduction. Thus fracture mechanics affects the form and performance of a tool (Crabtree 1972).

Manufacture. Stone tool manufacture is a reductive process, which is controlled by rock physical properties, tool requirements, and technology (Andrefsky 2005, 2009; Crabtree 1972; McCutcheon 1997). Rock physical properties interact with tool form and use (Andrefsky 1994; McCutcheon and Dunnell 1998). Tool requirements vary based on the desired form and are limited by the rock physical properties. Technology refers to the object types crafted; which is influenced by the physical properties and tool requirements.

Tool Durability. Raw material durability is associated with stone tool technology (required shape, size, and use) and technological dimensions (length, width, and thickness) (Cheshier and Kelly 2006). Archaeologists maintain that stone tool raw materials exhibiting certain qualities are desirable for specific uses and high-quality material like obsidian is easy to work, but less durable. Stone tool durability links the physical properties to stone tool manufacture or technology and stone tool requirements (McCutcheon 1997).

Performance

The selective conditions of the physical environment also affect stone tool performance (Dunnell 1978b; McCutcheon 1997). Rock physical properties can either

enhance (e.g. homogenous material) or hinder (e.g. heterogeneous material) the technological and functional characteristics of a tool. Tool stone raw material quality is an important variable that affects source frequency and inclusion in the archaeological record; low-quality sources occur less frequently and do not appear to be valuable in trade and exchange (Carlson 1994; McCutcheon and Dunnell 1998; McClure 2014; Mierendorf and Baldwin 2014). Increased performance characteristics of materials, such as quality, may outweigh associated costs of manufacture and offset costs related to increased source-to-site distances (McCutcheon 1997).

Technique: Measuring the Variation

Our technique applied McCutcheon's (1997) paradigmatic classifications to analyze rock physical properties, technological, and functional attributes of artifacts, and non-destructive x-ray fluorescence spectrometry (XRF) to document rock provenance of the 18 lithic assemblages. Filled class frequencies were assessed for representativeness and analyzed for non-random associations using a stepwise statistical analysis. If observed, non-random associations between cost and performance variables may have identified selective conditions and allowed us to then construct explanations of obsidian occurrence in stone tool industries.

Obsidian is highly desirable for chipped stone tool technologies as it flakes easily and predictably producing very sharp edges (Shackley 2005). However, obsidian, like other lithic materials varies in quality from source to source (Shackley 1988). Therefore, it is essential to document stone tool physical property dimensions and modes (Table 1).

TABLE 1. ROCK PHYSICAL PROPERTIES CLASSIFICATION: DIMENSIONS AND MODES.

Dimensions	Modes
Groundmass -Solid Inclusions	Present, Absent, Cortex Present
Groundmass - Void Inclusions	Present, Absent, Cortex Present
Groundmass -Distribution of Solid Inclusions	Random, Uniform, Structured, None, Cortex Present
Groundmass - Distribution of Void Inclusions	Random, Uniform, Structured, None, Cortex Present

Stone tool manufacture or technology is a function of material properties, tool requirements, and available technology (Campbell 1981; McCutcheon 1997). This classification is intended to identify characteristic attributes of the reduction trajectory so that artifact types can be isolated and compared across source diversity. Use-wear is dulling from damage that occurs to the surface or edges of an artifact through articulation with the environment (Dancey 1973; Dunnell 1978b). This is differentiated from technological (e.g. other modification) and curation damage, which produce patterns of attrition that are not palpably dull (e.g., platform preparation). These technological dimensions and modes are outlined in Table 2.

Resampling, performed using the R programming language (Venables et al. 2014), employed the bootstrapping technique to assess the representativeness of each filled artifact dimension. Though some researchers have indicated this technique has an intrinsic degree of subjectivity (Cochrane 2002), others have validated that bootstrapping is a useful nonparametric technique that does not rely on assumptions about the sample population (Eerkens et al. 2007; Lipo 2000; McCutcheon 1997; Vaughn 2010). Results,

TABLE 2. TECHNOLOGICAL CLASSIFICATION: DIMENSIONS AND MODES.

Dimensions	Modes
Object Type	Biface, Large Flake/Flake Fragment (greater than 10mm), Small Flake/Flake Fragment (less than 10mm), Chunk, Cobble, Core
Amount of Cortex	Primary, Secondary, Tertiary, None
Presence of Wear	Present, Absent
Other Modification	None, Flaking, Grinding, Pecking, Incising, Other
Platform Type	Cortex, Simple, Faceted, Bifacial unfinished, Bifacial, unfinished, wear present, Bifacial, finished, Bifacial finished wear present, Potlids, Fragmentary, Not Applicable, Pressure Flakes, Technologically Absent
Completeness	Whole, Broken, Flake Fragment, Debris, Other
Reduction Class	Initial Reduction, Intermediate Reduction, Terminal Reduction, Bifacial Reduction/Thinning, Bifacial Resharpener, Not applicable

plotted as resampled curves, were assigned to one of three categories based on the asymptotic characteristics of a curve: rich with even class distributions (Rank 1); rich with uneven modal distributions (Rank 2); and very uneven distributions regardless of richness (Rank 3) (McCutcheon 1997; Lipo 2000). Dimensions were considered either representative (Ranks 1 and 2) or unrepresentative (Rank 3) of the archaeological record.

Once dimensional representativeness was assessed, a step-wise statistical strategy was employed to systematically identify the non-random associations between only the representative filled artifact dimensions, assess the strength of those associations, and identify which modal intersections of dimensions significantly contributed to the non-random association. The analysis sought to test the null hypothesis (H_0): *Obsidian source occurrence is random across stone tool manufacture and use*. Associations between dimensions were calculated using a chi-square test (χ^2) or, if the calculated expected

values or observed sample sizes were too small for the chi-square test, Fisher's exact test was used as an alternative (Tamhane and Dunlop 2000). An alpha level of .05 was used for all statistical tests.

If H_0 was rejected because obsidian did not occur randomly, then observed data was used to assess the alternative hypothesis (H_a): *Obsidian source occurrence is not random across stone tool manufacture and use*. Next, the strength of the non-random association was assessed using Cramer's V (Cramér 1946; Privitera 2012); however, this test was only appropriate to use for chi-square analyses. An analysis of adjusted residuals was then calculated to identify which intersecting modes of dimensions significantly contributed to the rejection of H_0 (Van Pool and Leonard 2011), potentially identifying selective conditions of obsidian consumption. Spearman's Rho (ρ) rank-order correlation was employed as a separate statistical technique to measure inter-dependence between two ranked variables (Tamhane and Dunlop 2000).

Hypotheses for Obsidian Occurrence

Our objective for hypotheses testing was to determine what empirical evidence existed in our collection for statistically significant non-random sorting. If evidence of inter-variable relationships did exist, we could use it to identify the selective conditions. From these conditions, we could place our results into a historical context for precontact obsidian occurrence.

We anticipated that obsidian occurrence in the Mid-Columbia River Valley would be patterned as follows. First, we expected that raw material quality was an essential variable for structuring stone tool assemblages (Andrefsky 1994; Eerkens et al. 2007;

McClure 2014; McCutcheon 1997; Mierendorf and Baldwin 2014; Vaughn 2010). Based on this premise, we predicted that local obsidian rock physical properties would be biased in their occurrences of inclusions present and heterogeneous inclusion distribution modes. We made this assumption because obsidian sources in Washington State are generally recorded as low-quality with minimal dispersion from the source (McClure 2014; Mierendorf and Baldwin 2014). Accordingly, we expected that local, low-quality material would be used across all object types (cores, small flakes, large flakes and bifaces) as local obsidian is readily available, while nonlocal material would be higher quality and occur as small flakes and bifaces (Andrefsky 1994; Eerkens et al. 2007). We also anticipated patterns in distance decay to some extent, where further away sources would have lower representation (Renfrew 1977). We expected little change over time in relation to source-to-site distances as obsidian was readily available from local sources, and that procurement did not become localized over time (Cadena 2012; Mack et al. 2010). Finally, we anticipated higher source diversity at sites in the northern reach. In this area, the landscape is more suitable for habitation with numerous winter villages site types located at the confluences of Methow and Okanogan Rivers with the Columbia River (Chatters 1986). As certain trade routes are believed to have followed rivers (Chatters 1986), more evidence of regional trade may be seen in the northern reach near river confluences in the form of higher source diversity relative to the southern reach.

If patterns are random, mechanisms other than natural selection could be explored. For instance, cultural transmission mechanisms may play a role in structuring the archaeological record in other ways than those (cost and performance) directly

impacted by natural selection. If this were the case, observed patterns might be consistent with stylistic variables that have little to do with the fitness of an artifact's physical interaction with the environment.

Results

Geochemical Analysis

A representative sample of 97 artifacts was submitted to Craig Skinner at Northwest Research Obsidian Studies Laboratory (NROSL) and, as NROSL was closed for a period of time, additional samples were sent to Jeffery Ferguson at the Archaeometry Laboratory at the University of Missouri Research Reactor (MURR). In a collaborative effort, MURR reanalyzed all artifacts sent to NROSL to accurately identify sources present in the study area and to create an analogous data set for the authors. Initial artifact classifications demonstrated that the majority of the collection (612, 92 percent) was a highly distinctive greenish/blue, gray material exhibiting abundant phenocrysts in a glassy groundmass, matching the description of the local Chelan Butte obsidian source (Skinner and Thatcher 2010). To determine if this material was indeed Chelan Butte, a representative sample of artifacts were selected based first on variation across rock physical property classes, and second across technological and functional classes. The remaining 44 artifacts not visually analogous to Chelan Butte were submitted for analysis. XRF analysis securely assigned 95 of the 97 artifacts to ten sources: four in Washington, five in Oregon, and one in Idaho (Fig 3). The two unassigned artifacts, due to size or irregular surfaces, were excluded from source analysis.

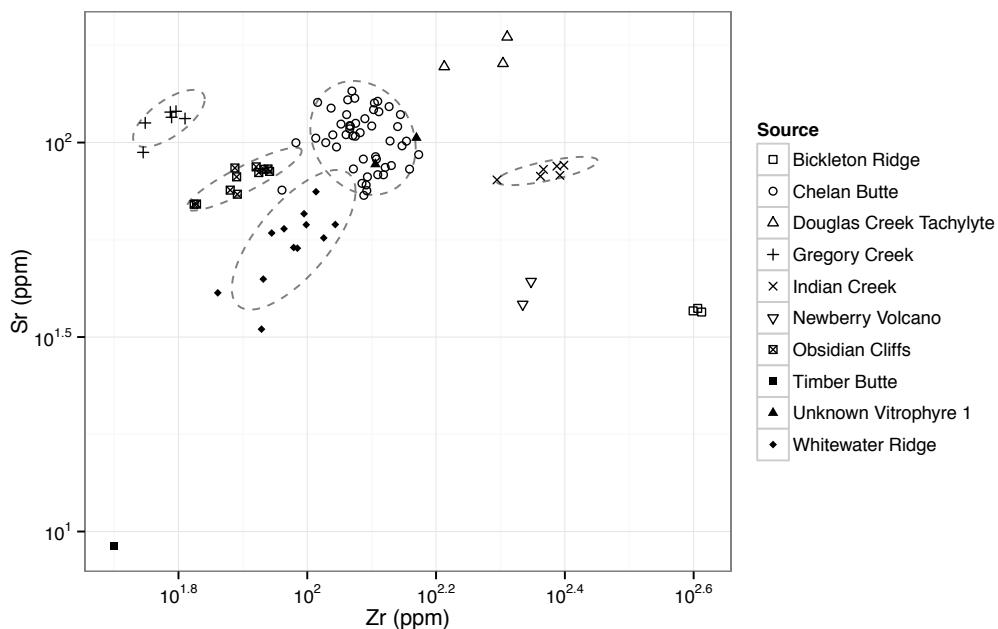


Fig 3. XRF Sourcing Data Adapted From MURR (2014). Ellipses Represent 90% Confidence Intervals Assuming a t-distribution (MURR 2014). Scales Are Log Transformed.

Chelan Butte and Unknown Vitrophyre 1 identified during sourcing were combined into a single source for this analysis (CB/UV1). This was done because during MURR's reanalysis the two Unknown Vitrophyre 1 artifacts fell within the 90% confidence interval of Chelan Butte indicating the same source; the sources were visually analogous; both sources have only been characterized archaeologically; and nearby vitrophyre sources are known to exhibit high intra-source variability (Mierendorf and Baldwin 2014). As the Chelan Butte source has a highly localized archaeological distribution (Chatters 1986; Galm and Masten 1985; Grabert 1968; Gunkel 1961; Mierendorf and Bobalik 1983) and is macroscopically highly distinctive, it was considered reasonable to visually characterize the remaining artifacts in this sample

exhibiting the documented variation (Fig 4) as Chelan Butte (Craig Skinner personal communication February 3, 2014).

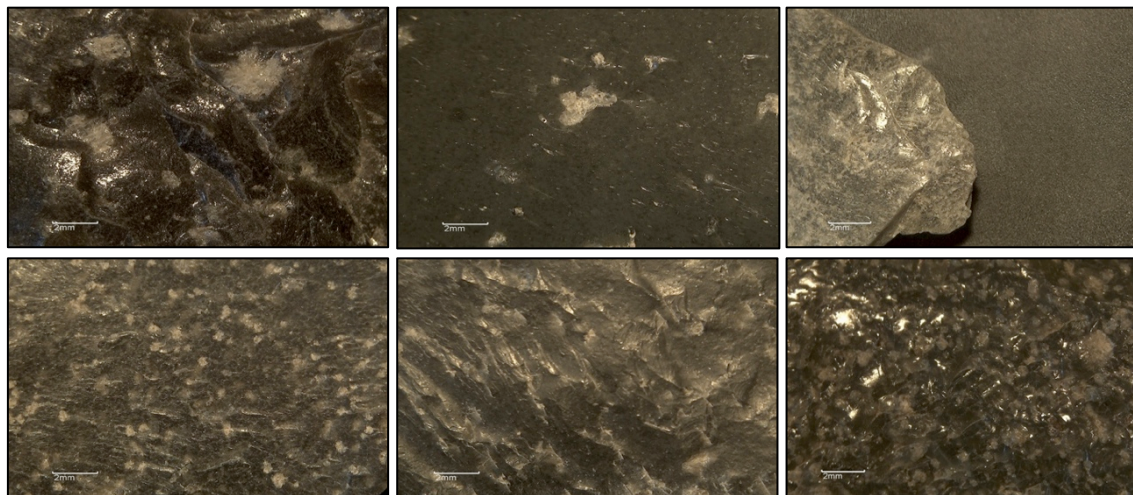


Fig 4. Microscopic (10X) Groundmass Variation of the Chelan Butte/Unknown Vitrophyre 1 Source(s). A 2 mm Scale Bar Located in the Bottom Left Hand Corner of Photographs.

Analysis Across Obsidian Source

Prior to statistical analysis, dimensions were analyzed for representativeness. The dimensions Platform Type and Amount of Cortex were unrepresentative when resampled and were not included in our investigation of obsidian occurrence. For the dimension Object Type, the modes chunk and cobble were observed in very low counts in our sample and identified as Chelan Butte obsidian, but were not included in analysis as these objects contain little technological or functional data. Analysis across obsidian source was achieved in two ways. For measures of association, obsidian sources were aggregated into local and nonlocal sources (Table 3). For Spearman's Rho analyses, unaggregated obsidian sources were employed.

TABLE 3. LOCAL AND NONLOCAL OBSIDIAN SOURCE DESIGNATIONS AND COUNTS.

Local/Nonlocal Source	Obsidian Source	Count
Local	CB/UV1	606
	Douglas Creek	6
Nonlocal	Bickleton Ridge	3
	Indian Creek	6
	Whitewater Ridge	12
	Obsidian Cliffs	11
	Newberry Volcano	2
	Gregory Creek	6
	Timber Butte	1

To identify non-random patterns of obsidian occurrence, we analyzed data from rock physical property, technological, and functional classifications across obsidian source. In total, nine sources were represented; however, source frequency across site was unevenly distributed with no more than four sources observed per site, and many sites had only a single source represented. A Spearman's Rho analysis resulted in a test statistic of $p = .14$, which indicated a very weak correlation between source diversity and sample size as illustrated in Fig 5.

To test our premise that raw material quality played an important role in local and nonlocal source occurrence in stone tool industries, we analyzed the rock physical property class frequencies recorded for local and nonlocal obsidian sources. The cross tabulation of the dimension Distribution of Void Inclusions did not reject H_0 , establishing that this dimension occurred randomly across local and nonlocal sources. However, cross tabulations of Solid Inclusions ($p < .001$; two-tailed Fisher's exact), Distribution of Solid

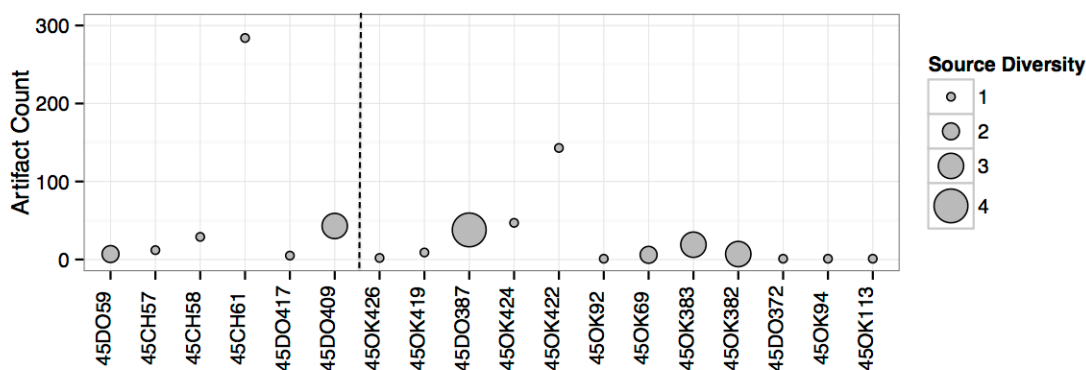


Fig 5. Relationship Between the Number of Artifacts Observed and Sources at a Site, from South (Left) to North (Right). The Dashed Line Represents the Transition Between the Southern and Northern Reaches.

Inclusions ($p < .001$; two-tailed Fisher's exact), and Void Inclusions ($\chi^2 = 177.29$; $df = 1$; $p < .001$) rejected H_0 demonstrating non-random associations across sources. Based on a Cramer's V calculation, Void Inclusions resulted in a moderate association ($V = .52$), demonstrating that we can be only relatively confident in predicting that a local or nonlocal artifact will exhibit a presence or absence of void inclusions. These non-random associations help identify the attributes structuring local and nonlocal obsidian physical property source selection.

Once the rock physical property attributes of local and nonlocal sources were analyzed, we examined how obsidian quality influenced the occurrence of technological and functional dimensions across these sources. Analysis demonstrated that five dimensions exhibited significant non-random associations, Object Type ($p = .003$; two-tailed Fisher's exact), Flake Completeness ($p = .001$; two-tailed Fisher's exact), Other Modification ($\chi^2 = 9.60$; $df = 1$; $p = .002$), Flake Reduction Class ($p < .001$; two-tailed

Fisher's exact), and Presence of Wear ($p < .001$; two-tailed Fisher's exact) demonstrating the distribution of technological and functional attributes across local and nonlocal sources. A Cramer's V calculation for Other Modification resulted in a weak non-random association ($V = .12$), demonstrating that we can only be minimally confident in predicting that a local or nonlocal artifact will exhibit other modification or not. Table 4 contains the frequency counts of artifacts from the material, technological, and functional non-random associations across local and nonlocal obsidian sources identified above. For chi-square tests only the statistically significant counts based on the analysis of adjusted residuals are reported. For Fisher's exact tests all counts are reported.

TABLE 4. COUNTS OF STATISTICALLY SIGNIFICANT CROSS TABULATIONS OF DIMENSIONS AND MODES ACROSS OBSIDIAN SOURCE.

Obsidian Source	Local	Nonlocal
Solid Inclusions		
Present	605	8
Absent	6	33
Distribution of Solid Inclusions		
Random	480	2
Uniform	125	6
Void Inclusions		
Present	538	3
Absent	73	38
Object Type		
Biface	5	1
Core	37	0
Large Flake	529	32
Small Flake	34	8
Flake Completeness		
Whole Flake	43	10
Broken Flake	242	10
Flake Fragment	278	20

TABLE 4. (CONTINUED).

Obsidian Source	Local	Nonlocal
Flake Reduction Class		
Initial	71	3
Intermediate	175	6
Terminal	24	6
Bifacial	15	5
Other Modification		
Present	116	16
Absent	496	25
Presence of Wear		
Present	58	15
Absent	554	26

A Spearman's Rho test was calculated to analyze if a correlation existed between obsidian source, and count and weight as discussed by previous researchers (Beck et al. 2002; Renfrew 1977) and based on the assumption that increased transport costs are incurred as the distance from source to a site increases. The count and aggregated weight of each source organized by distance from the study area is summarized in Table 5.

TABLE 5. RANK ORDER OF OBSIDIAN SOURCE: COUNT AND AGGREGATED WEIGHT.

Rank	Obsidian Source	Count	Aggregated Weight (g)
1	CB/UV 1	606	586.58
2	Douglas Creek	6	10.52
3	Bickleton Ridge	3	1.09
4	Indian Creek	6	0.42
5	Whitewater Ridge	12	2.18
6	Obsidian Cliffs	11	1.76
7	Newberry Volcano	2	0.07
8	Gregory Creek	6	3.00
9	Timber Butte	1	0.45

A test of the correlation between obsidian source and count resulted in a value of $\rho = -.54$ demonstrating a moderate, negative correlation between the two variables (Fig 6). This corresponds to a variable trend between distance from source and count.

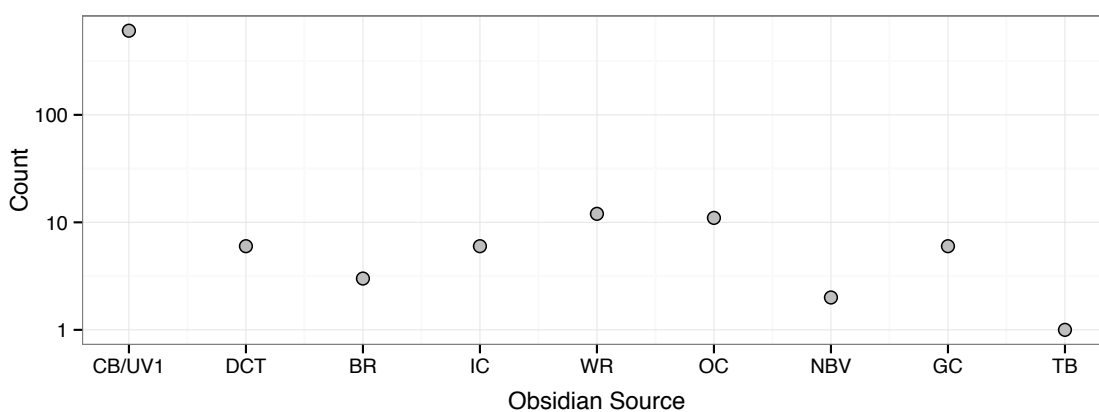


Fig 6. Scatter Plot of Obsidian Source Versus Log Transformed Count. Sources are Ordered by Distance to the Study Area from Left to Right. CBO/UV1= Chelan Butte/Unknown Vitrophyre 1(Precise geographic location of source in central Washington State is unknown), DCT=Douglas Creek Tachylyte, BR= Bickleton Ridge, IC=Indian Creek, WR=Whitewater Ridge, OC=Obsidian Cliffs, NBV= Newberry Volcano, GC=Gregory Creek, TB=Timer Butte.

A test of the correlation between obsidian source and aggregated weight resulted in a value of $\rho = -.50$ demonstrating a moderate, negative correlation between the two variables (Fig 7). This also corresponds to a variable trend between distance from source and weight.

Analysis Across Space

To determine if obsidian occurrence varied across space based on observed differences in landscape use (Chatters 1986; Schalk and Mierendorf 1983), occurrence was analyzed across the northern and southern reaches of the study area. The linear distance between the northernmost and southernmost sites is approximately 87

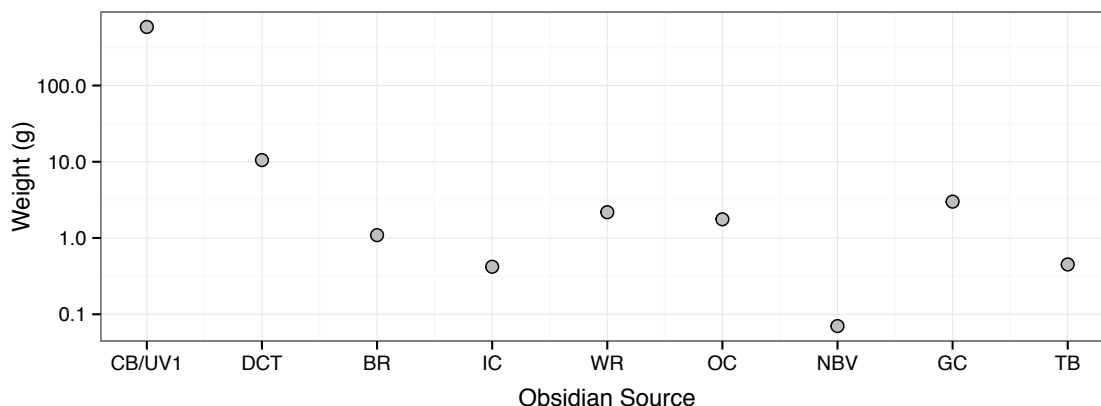


Fig 7. Scatter Plot of Obsidian Source Versus Log Transformed Weight. Sources are Ordered by Distance to the Study Area from Left to Right (see Fig 6 for abbreviation descriptions).

kilometers. The northern reach sample included 12 sites containing a total of 276

artifacts, while the southern reach sample included 6 sites containing 380 artifacts.

Source diversity was unevenly distributed between the northern and southern reaches:

with eight sources in the northern reach, twice the amount as the southern reach. Of the nine unique obsidian sources, only three were represented in both reaches: CB/UV1,

Gregory Creek, and Obsidian Cliffs. The spatial density of site, artifact, and source

diversity frequency within the study area are presented in Fig 8. These density

estimations reveal that site frequency is highest in the northern reach centering on the

confluences of the Methow and Okanogan Rivers with the Columbia River (Fig 8a);

artifact frequency is almost evenly distributed between the northern and southern reaches

(Fig 8b); and source diversity frequency is highest in the northern reach centering on the

confluences of the Methow and Okanogan Rivers with the Columbia River (Fig 8c).

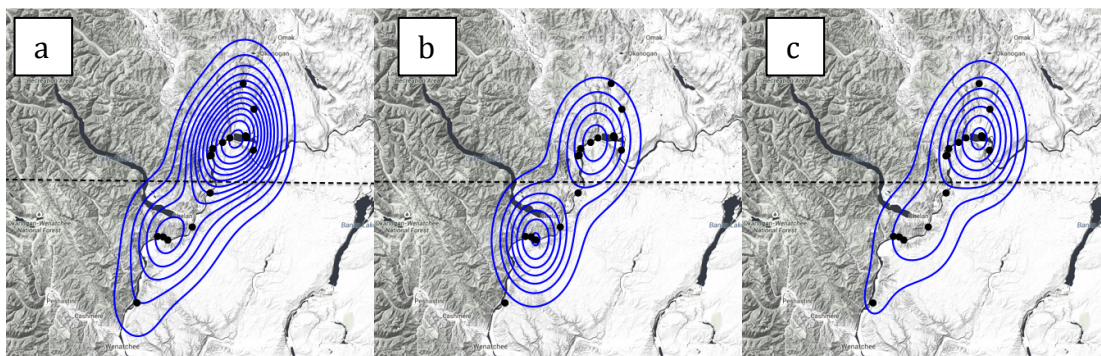


Fig 8. Spatial Frequency Distribution or Density Represented by 2-Dimensional Kernel Density Estimations of a) Site Frequency, b) Artifact Frequency at a Site, c) Source Diversity Frequency at a Site (Base Map Provided by Google Earth 2014). Black dots indicate the Location of Archaeological Sites and the Dashed Line Represents the Transition Between the Southern and Northern Reaches.

Pertinent stone tool dimensions were analyzed across space to determine if there were observable differences between the two reaches. The cross tabulation of Other Modification demonstrated a random occurrence across space. In contrast, Local/Nonlocal sources ($\chi^2 = 34.12$; $df = 1$; $p < .001$), Object Type ($p = .003$; two-tailed Fisher's exact), Flake Reduction Class ($\chi^2 = 27.34$; $df = 4$; $p < .001$), and Presence of Wear ($\chi^2 = 32.68$; $df = 1$; $p < .001$) rejected H_0 indicating non-random occurrences across the northern and southern reaches of the study area. Based on Cramer's V calculations, Local/Nonlocal sources ($V = .23$), Flake Reduction Class ($V = .30$), and Presence of Wear ($V = .22$) resulted in a weak non-random association. These test results demonstrate that it is difficult to confidently predict that if an artifact occur in a specific reach it will exhibit a particular reduction trajectory, presence/absence of wear, or a certain source locality. Table 6 contains the frequency counts of artifacts from the provenance, technological, and functional non-random associations across space identified above. For chi-square

tests only the statistically significant counts based on the analysis of adjusted residuals are reported. For Fisher's exact tests all counts are reported.

TABLE 6. COUNTS OF STATISTICALLY SIGNIFICANT CROSS TABULATIONS OF DIMENSIONS AND MODES ACROSS SPACE.

Space	Northern Reach	Southern Reach
Obsidian Source		
Local	238	374
Nonlocal	35	6
Object Type		
Biface	3	4
Core	20	17
Large Flake	223	338
Small Flake	29	15
Flake Reduction Class		
Intermediate	67	116
Terminal	23	7
Bifacial	16	4
Presence of Wear		
Present	54	20
Absent	222	360

Analysis Over Time

Analysis of occurrence over time was achieved by assigning artifacts to sub-regional cultural phases defined for the Okanogan Highlands (Chatters 1986; Grabert 1968). These phases consist of Okanogan (ca. 8000-6000 B.P.), Indian Dan (4400-3500 B.P.), Chiliwist (3300-2200 B.P.), and Cassimer Bar (1000 B.P.-historic). Only artifacts from proveniences that were securely assigned to these age ranges were used. The distribution of artifacts across cultural phases was Okanogan Phase (263 artifacts), Indian Dan Phase (53 artifacts), Chiliwist Phase (71 artifacts), and Cassimer Bar Phase (24

artifacts). Patterns in source selection over time were variable; source diversity was unevenly distributed in early periods, Okanogan Phase (3 sources) and Indian Dan Phase (8 sources), and evenly distributed in late periods, Chiliwist Phase (6 sources) and Cassimer Bar Phase (6 sources). Only CB/UV1 and Obsidian Cliffs were represented in all four periods and had uneven representation over time. Gregory Creek, Indian Creek, and Whitewater Ridge were present during the Indian Dan Phase into the Cassimer Bar Phase; however, the frequency of occurrence decreased over time. Douglas Creek was also present, but remained constant. Bickleton Ridge, Newberry Volcano, and Timber Butte were only present during a single time period.

When obsidian artifact occurrence was analyzed over time, the cross tabulation of Flake Reduction Class occurred randomly. In contrast, the dimensions Local/Nonlocal source ($p < .001$, two-tailed Fisher's exact), Object Type ($p = .005$; two-tailed Fisher's exact), Other Modification ($\chi^2 = 27.09$; $df = 3$; $p < .001$), Presence of Wear ($\chi^2 = 38.98$; $df = 3$; $p < .001$), and Space ($\chi^2 = 105.76$; $df = 3$; $p < .001$) rejected H_0 indicating non-random occurrences over time. The calculation of Cramer's V demonstrated that Other Modification ($V = .26$) and Presence of Wear ($V = .31$) had a weak non-random association over time, and Space ($V = .51$) had a moderate non-random association over time, indicating that in some cases it may be challenging to predict that during a certain time period these dimensions will be patterned as observed. Table 7 contains the frequency counts of artifacts from the provenance, technological, and functional non-random associations across time identified above. For chi-square tests, only the statistically significant counts based on the analysis of adjusted residuals are reported and

for Fisher's exact tests all counts are reported. All non-significant cells from the adjusted residuals for chi-square analyses are denoted by hyphens.

TABLE 7. COUNTS OF STATISTICALLY SIGNIFICANT CROSS TABULATIONS OF DIMENSIONS AND MODES ACROSS TIME.

Time	Okanogan Phase	Indian Dan Phase	Chiliwist Phase	Cassimer Bar Phase
Obsidian Source				
Local	259	22	54	16
Nonlocal	3	30	16	7
Object Type				
Biface	1	2	4	2
Core	23	5	3	3
Large Flake	211	38	55	13
Small Flake	28	8	7	6
Other Modification				
Absent	213	29	-	11
Present	50	24	-	13
Use-Wear				
Absent	227	29	-	12
Present	36	24	-	12
Space				
Northern Reach	229	-	21	-
Southern Reach	34	-	50	-

Discussion

This study sought to describe and explain the occurrence of obsidian sources in stone tool manufacture and use in the Mid-Columbia River Valley. The evolutionary archaeology model for stone tool cost and performance and the derived paradigmatic classifications were useful for identifying statistically significant non-random associations between dimensional attributes and identifying the specific modal intersections contributing to those associations. What remains is further consideration of

the historic context for these non-random associations so that the selective conditions can be explained.

Obsidian Source

The selective conditions structuring obsidian physical property occurrence were the presence and absence of solid inclusions and void inclusions, and the distribution of solid inclusions (random or uniform). Selection against these attributes appeared to occur only in nonlocal, high-quality sources of obsidian, whereas increased costs incurred by their presence was offset when they occurred in CB/UV1, a local, low-quality source abundant with phenocrysts (99 percent) and void inclusions (88 percent). Solid inclusions can have variable effects on crack propagation, while void inclusions add to the inhomogeneity of a rock, making crack propagation inconsistent or resulting in a longer crack path decreasing predictability (McCutcheon and Dunnell 1998). The distribution of solid inclusions also played a role in raw material quality. Local sources generally exhibited randomly distributed solid inclusions (79 percent), whereas nonlocal sources largely exhibited uniform solid inclusions (75 percent). Uniformly distributed inclusions increase the predictability of crack propagation by providing a guide for fracture; however, randomly distributed inclusions decrease predictability (McCutcheon and Dunnell 1998). Accordingly, CB/UV1 may not have performed equally to nonlocal sources because the high frequency of random inclusions increased cost in stone tool manufacture by causing increased wastage. CB/UV1 appears across all object types; as such, decreased costs likely due to local availability aided in offsetting tool performance. These results are consistent with expectations from our model as well as with research

regarding rock inclusions (McCutcheon 1997; McCutcheon and Dunnell 1998) and raw material quality (Andrefsky 1994).

The selective conditions structuring obsidian stone tool manufacture were the dimensions object type, other modification, flake completeness, and flake reduction class. Local sources occurred across all object types with flakes as the most frequent. All 37 cores were crafted from local sources, as were five of the six bifaces. Of the total flakes present, local sources represented 94 percent of the large flakes (2 sources) and 81 percent of the small flakes (1 source). Nonlocal sources represented 6 percent of the total large flakes (6 sources) and 19 percent of the total small flakes (5 sources). In comparison to patterns of source diversity and object type described by Eerkens et al. (2007), source diversity was actually higher for large flakes (8 sources), than for small flakes (6 sources) or bifaces (3 sources). Additionally, it was anticipated that nonlocal sources would generally occur as bifaces and small flakes; our sample produced opposite patterns with the majority of nonlocal sources occurring as large flakes. Other modification was present across both local and nonlocal obsidian sources as edge flaking or retouch. Other modification was more prominent on nonlocal sources (39 percent) than local sources (19 percent) perhaps due to the fact that nonlocal sources were higher quality and could be reduced in an easier and more predictable manner than low-quality local sources.

Both local and nonlocal sources were evenly split across flake completeness with 50 percent whole/broken flakes and 50 percent flake fragments. Nonlocal sources had equal frequencies of whole and broken flakes, and local sources had approximately five times more broken flakes than whole flakes. It was anticipated that local sources would

have higher frequencies of broken flakes or flake fragments because the abundance of solid and void inclusions would lead to more unpredictable fracture. Flake reduction class could only be discerned from whole and broken flakes. The reduction class frequencies observed for local and nonlocal sources were also generally consistent with expectations, with local and nonlocal occurring across all reduction classes. Of the total flakes present, reduction of local sources comprised the majority of the initial (96 percent), intermediate (97 percent), terminal (80 percent), and bifacial (75 percent) reduction. Accordingly, nonlocal flakes were most prominent in the total terminal and bifacial reduction classes. A pattern of distance decay was observed in flake reduction class and aggregated source weight. When considering the inter-variable relationships of stone tool cost and performance, it was expected that farther away sources would primarily be present as later reduction classes indicating that early reduction of nonlocal sources likely took place at quarry locations lowering the cost of transport (Beck 2008).

Our research also documented a selective condition against the presence of use-wear across local (9 percent) and to a lesser degree, nonlocal (37 percent) obsidian sources. As with observations across other modification, the presence of use-wear was higher on nonlocal sources presumably because the presence of other modification on the edges of obsidian tools provide a more robust and durable edge that lasts longer and can endure the accumulation of more use-wear. Overall, the entire obsidian collection was relatively unworn. This may be because on average obsidian is less durable than other lithic materials (Cheshier and Kelly 2006).

Space

The selective conditions sorting obsidian occurrence across the northern and southern reaches of the study area produced distinctive patterns. All object types were present in both reaches and were relatively equally distributed. The northern reach sample contained 3 bifaces, 20 cores, 223 large flakes, and 29 small flakes, and the southern reach sample contained 4 bifaces, 17 cores, 338 large flakes, and 15 small flakes.

The northern reach exhibited high source diversity (8 sources); however, the majority of the obsidian present was still local material (88 percent). The modes intermediate, terminal, and bifacial were the significant intersections for reduction class across space. While the northern and southern reaches had almost equal proportions of flakes (41 percent and 49 percent respectively), the northern reach contained 37 percent of the intermediate flakes, 76 percent of the terminal and 80 percent bifacial flakes present in the study area, indicating a bias toward later reduction trajectory. Source diversity was higher for terminal and bifacial flakes (4 sources) than intermediate flakes (3 sources) with only CB/UV1 and Whitewater Ridge occurring across all three significant reduction classes, consistent with Eerkens et al. (2007) findings referred to above. Large flakes and small flakes occurred across all reduction classes. Use-wear occurred on 20 percent of the artifacts from six sources, and was primarily observed on CB/UV1.

In the southern reach, selective patterns differed from those observed in the northern reach. Source diversity was lower (CB/UV1, Douglas Creek, Obsidian Cliffs,

and Gregory Creek) with an emphasis on local source exploitation (98 percent). Object type distribution was analogous to the northern reach, as discussed above. Artifacts (n = 6) from nonlocal sources occurred as a single broken biface and large flakes. CB/UV1 was present across intermediate, terminal, and bifacial flakes, Douglas Creek occurred as a single bifacial flake, and Obsidian Cliffs occurred as a single terminal flake. Source diversity was also higher for terminal and bifacial flakes (3 sources) than for intermediate flakes (1 source). Unlike the northern reach, large flakes and small flakes occurred as intermediate flakes, and only large flakes occurred as terminal and bifacial flakes, which included nonlocal sources. Like the northern reach, use-wear occurred primarily on CB/UV1; however, use-wear was minimally represented (5 percent) as the majority of artifacts present were unutilized flakes from local sources.

Time

The selective conditions observed over time can be summarized as follows: source diversity increased but local sources were present throughout; presence of other modification and use-wear increased; object type became more evenly distributed; and the spatial distribution of obsidian occurrence varied over time. In all phases with the exception of the Indian Dan (42 percent), local sources comprised the majority of the obsidian present. Source diversity was lowest in the Okanogan Phase (3 sources), with only 3 nonlocal artifacts (1 percent) present and highest in the Indian Dan Phase (8 sources). Source diversity generally increased over time, with CB/UV1 occurring less frequently and nonlocal sources occurring more frequently. Over all, artifact frequency

decreased over time and source diversity increased demonstrating that, for our samples, diversity is negatively correlated with sample size.

The selective conditions structuring the occurrence of stone tool manufacture and use over time were object type, other modification, and presence of wear. Object type frequencies became more evenly distributed over time. In all phases, object type frequencies adhered to the following pattern with increasing frequency: bifaces, cores, small flakes, and large flakes. In this sample of obsidian, the presence and absence of edge retouch/flaking was statistically significant in the Okanogan, Indian Dan, and Cassimer Bar Phases and became more evenly distributed over time. The presence and absence of use-wear was statistically significant in the Okanogan, Indian Dan, and Cassimer Bar Phases and increased over time from 14 percent in the Okanogan Phase to 50 percent present in the Cassimer Bar Phase.

Selection also acted on the spatial distribution of artifacts over time. Distributions of artifacts between the northern and southern reaches of the study area were statistically significant in the Okanogan and Chiliwist Phases. In the Okanogan Phase, there was nearly seven times the number of artifacts present in the northern reach than the southern reach. Whereas in the Chiliwist Phase, there were approximately twice as many artifacts in the southern reach as there were in the northern reach.

Conclusions

We predicted that the occurrence of obsidian sources in stone tool industries was non-random and followed a pattern of natural selection. The results of our research established that obsidian occurrence was influenced by natural selection where stone tool

attributes demonstrated a balance of cost and performance as established in our discussion. Above, we outlined a set of expectations based on natural selection as a causal mechanism for non-random occurrence for our sample of obsidian based on local and regional obsidian research; below, these expectations were revisited in light of our results.

First, we expected that raw material quality was an essential variable in structuring obsidian source occurrence. Based on related research (Andrefsky 1994; Eerkens et al. 2007; McClure 2014; Mierendorf and Baldwin 2014; Vaughn 2010), we anticipated that local obsidian material properties would exhibit higher frequencies of inclusions. Results confirmed that CB/UV1, a local source, exhibited a disproportionate presence of solid and void inclusions, decreasing the predictability of reduction and performance. Nonlocal sources exhibited little to no inclusions enhancing performance; accordingly they were likely valuable in long distance procurement and exchange (Galm 1994). Based on Endler's (1986) model of natural selection, our observations adhere to what is referred to as disruptive selection in which artifacts at either end of a distribution (low-quality, local to high-quality, nonlocal) are favored.

We also predicted that local, low-quality obsidian would be readily available and would to be used across all object types (e.g., small and large flakes, cores, and bifaces) (Andrefsky 1994; Eerkens et al. 2007), while nonlocal, high-quality material would occur mainly as small flakes and bifaces. Our results confirmed that local, low-quality sources occurred across all object types, and not just low energy and expedient tools (Andrefsky 1994). As expected, all cores were crafted from local sources. Contrary to expectations,

five of the six bifaces were crafted from local sources. Nonlocal sources occurred primarily as large flakes with small flakes as the next most frequently occurring object type. Observations across flake reduction class indicated that high-quality, nonlocal sources occurred in later reduction trajectories and low-quality, local sources occurred primarily across early reduction classes. These results align with research on reduction strategies and source to site distance. Sites further from sources generally exhibit less debitage because more reduction occurred at the source presumably to lower transport costs (Beck 2008). In turn, sites closer to sources are characterized by larger debitage exhibiting cortical material, indicating earlier stages of reduction (Beck et al. 2002; Teltser 1992).

Second, as observed by other local researchers (McClure 2014; Mierendorf and Baldwin 2014), we anticipated a pattern of monotonic decay as the distance from a source increases (Renfrew 1977). Unlike results seen in Vaughn (2010) and Parfitt (2013), a moderately strong, yet variable, negative correlation was observed between distance from source to study area, and count and aggregated weight for each obsidian source. As discussed above, flake reduction class also followed a pattern of distance decay, with nonlocal sources comprising higher percentages of later reduction classes and local sources comprising the majority of all reduction classes and almost the entirety of the initial and intermediate classes.

Third, we anticipated that source occurrence did not become localized over time (Cadena 2012; Mack et al. 2010). We observed that source diversity generally increased over time, with CB/UV1 occurring less frequently and nonlocal sources occurring more

frequently. Similar to Schalk and Mierendorf (1983), we observed high proportions of vitrophyre or CB/UV1 in early phases with high frequencies during these phases in the southern reach sample. The Indian Dan Phase exhibited a disproportionate percentage of nonlocal sources compared to other phases and had the highest source diversity, which was likely linked to the influx of trade and exchange during this phase as observed by Chatters (1986). Our study area is also located between two tertiary protohistoric Indian trade centers, which are described as “trade fairs or subsistence sites” (Swagerty 1988: Fig. 1). To the southwest is the Kittitas Fair in the Kittitas Valley and to the north is Okanogan Falls on the Okanogan River. Galm (1994) defined two main exchange systems conveying obsidian into the Columbia Plateau. The Great Basin network was the most prominent, transporting obsidian from central and southern Oregon north through trade centers along the Columbia River. The southern Idaho exchange network also facilitated obsidian trade into areas of eastern Washington after 6500-6000 B.P.

Fourth, differences in the spatial distribution of obsidian occurrence between the northern and southern reaches of the study met our expectations as we observed two distinct patterns. These results support the premise that based on variation in landscape suitability and resource availability there are observable differences in obsidian stone tool occurrence between the north and south reaches of the study area (Chatters 1986; Schalk and Mierendorf 1983). The northern reach exhibited higher source diversity; emphasis on later reduction classes, which had higher source diversity than intermediate reduction classes; higher frequencies of small flakes; and higher frequencies of use-wear. These patterns are consistent with Chatters (1986) research in this area. He concluded that over

time technology shifted from expedient manufacture to curated tool kits with an emphasis on “preparation over procurement” (Chatters 1986: 207). The southern reach exhibited patterns of low source diversity; emphasis on intermediate reduction; higher frequencies of large flakes from mainly local sources; and minimal use-wear. While lithic assemblages in this area exhibited an overall orientation towards mid- to late-reduction and manufacture, previous researchers noted that four of the six sites we studied were oriented toward initial stages of lithic processing (Schalk and Mierendorf 1983).

Based on our research efforts, we identified three areas to recommend for further study in the Mid-Columbia Region. First, the understanding of obsidian occurrence could be bolstered by the inclusion of additional obsidian assemblages from this area (e.g. 45OK74, 45CH216, 45CH782, 45DO68, 45CH62, 45CH254, and 45CH409); however, many of these sites were excavated during the same era as those we studied and therefore likely contain the same biases previously mentioned for our collection. Second, a systematic study of central Washington obsidian raw material source provenance and chemical signatures could help elucidate source inclusion and distribution in the archaeological record. For example, this study identified the occurrence of Unknown Vitrophyre 1. Since this source has only been characterized archaeologically, it is unknown if it is a new source or merely intra-source chemical variation of Chelan Butte obsidian. Third, this research focused on the selective conditions structuring obsidian occurrence in stone tool industries. It would be valuable to likewise demonstrate the selective conditions structuring the occurrence of other stone tool raw materials (e.g.,

chert) present, and compare those patterns to obsidian occurrence in Mid-Columbia River Valley.

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