An Approach for Explaining Technological and Functional Variation Between Four Montane Lithic Assemblages Near Mount Rainier, Washington

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Abstract *In the past few decades, archaeologists have begun to recognize the importance of Pacific Northwest montane environments in the subsistence and settlement strategies of pre-contact people. Little is understood about stone tool technological and/or functional variation between montane sites in comparable environmental settings. Four lithic assemblages (45PI406, 45PI408, 45PI429, and 45PI438) were compared across the upper maritime forest and subalpine environmental zones on the slopes of Mount Rainier. An evolutionary archaeology approach was applied to define and measure variables relevant to stone tool manufacture and use. Statistically significant non-random associations were contextualized within the known environmental constraints and regional land use models for upland subsistence and settlement strategies in the southern Washington Cascades. Lithic assemblage samples were dominated by debitage and consistent with those produced as a result of tool manufacture at limited activity sites. However, the assemblages differ synchronically in the frequency and type of use wear, as well as reduction trajectories for tool manufacture, indicating that localized climate regimes and microenvironments may have influenced stone tool manufacture and use across space.*

Keywords
Stone tool manufacture and use, late Holocene climate variability, selective conditions, human adaptation.

Introduction

Increased research in recent decades has enabled archaeological surveys that have recorded hundreds of upland pre-contact archaeological sites in the southern Washington Cascades (e.g., Meirendorf 1986; Lewarch and Benson 1991; Burtchard 1998; Dampf 2002; Andrews 2008; Mack et al. 2010; Vaughn 2010; Mierendorf and Baldwin 2015). Efforts to understand prehistoric subsistence and settlement patterns have generated significant research questions about past land use in and around Mount Rainier National Park. As of the 2023 field season, fieldwork efforts have resulted in the documentation of 87 pre-contact archaeological sites (Diaz, pers. comm., 2023) within Mount Rainier National Park. Many of these sites are lithic scatters remaining from stone tool manufacture and use, potentially serving as sources of important information on past land use patterns. However, despite their occurrence, the amount of functional and technological data available for addressing research questions remains low (particularly for inter-site comparisons) in comparison to the large amount of recorded pre-contact archaeological sites in the southern Washington Cascades (Andrews 2008; Vaughn 2010; Ferry 2015; Lewis 2015; Andrews et al. 2016).

With the purpose of designing a model that will contribute to our understanding of upland land use subsistence and settlement patterns in the Pacific Northwest, this research adds to the growing body of data on excavated upland archaeological sites in the Washington Cascades. Our general strategy is to ascertain how people used upland landscapes, whether those efforts contained a mountain lithic tool kit (i.e., stone tool assemblages that are similar across upland archaeological contexts [Ferry 2015:6]), and whether this type of material culture varies by microenvironment.

The question guiding this research is: what were the selective conditions of the variable microenvironments on Mount Rainier under which stone tools were made and used? By selective conditions we are referring to the past environmental constraints (e.g., tool stone raw material availability or resource diversity) that influenced stone tool manufacture and use at each site (Kassa and McCutcheon 2016; Parfitt and McCutcheon 2017). It is possible that mountain environments limited selective conditions affecting subsistence and settlement patterns due to the character of their extreme conditions relative to lowland habitats (e.g., high annual snow fall and seasonal temperature variations in microclimates around the mountain) (Burtchard 1998, 2003, 2007). Identifying the selective conditions under which people made and used stone tools provides an empirically based and theoretically informed understanding of how past people organized their stone tool technology (McCutcheon 1997; Kassa and McCutcheon 2016; Parfitt and McCutcheon 2017).

The research question is addressed by testing a series of hypotheses with data from four lithic assemblages from upland environments near Mount Rainier. Significant inter-variable relationships between stone tool cost and performance variables indicated through non-random associations are explained within the historic context of implied environmental conditions inferred from paleoclimate data and hypotheses derived from existing pre-contact subsistence and settlement models. We believe that this work contributes to an empirically-based understanding of past human interactions within the selective conditions of the environment in an upland context. Furthermore, this database provides an opportunity to investigate past human land use. For instance, by comparing assemblages from different locations, we can describe whether past people were doing the same or different activities, and if there is evidence of cultural transmission across those spaces based on trade and exchange of tool stone materials like obsidian (e.g., Parfitt and McCutcheon 2017).

The Assemblages

Previous studies of pre-contact sites in the southern Washington Cascades provide a regional basis against which to compare the results of this research (Dampf 2002; Burtchard 2003, 2007; Andrews 2008; Vaughn 2010; Schurke 2011; Andrews et al. 2016). Following the approaches applied in previous research by McCutcheon (1997), Dampf (2002), and Vaughn (2010), the following makes a synchronic comparison of pre-contact lithic assemblages from the 45PI429, 45PI438 (Schurke 2011), 45PI408 (artifacts recovered prior to 2011 fieldwork), and 45PI406 sites on or near the slopes of Mount Rainier (Figure 1). All assemblages are from sites that have undergone well-documented, subsurface excavations. Assemblages excavated from intact stratigraphic context were separated into defined temporal components using the dated Mount St. Helens Yn (MSH-Yn) tephra layer as a stratigraphic marker bed observed during each site's excavation.

Three of the assemblage datasets (45PI429, 45PI408, and 45PI406) were generated by using

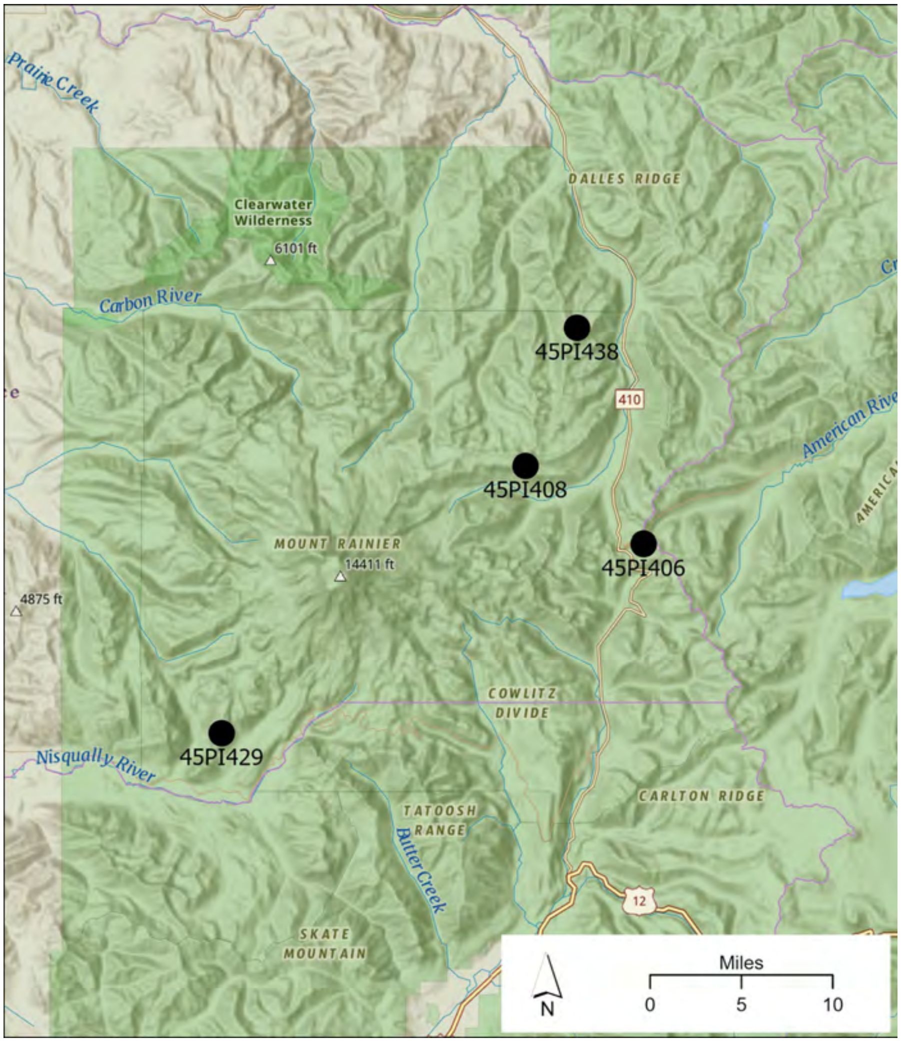

Figure 1. Location of the sites being compared in this research.

lithic paradigmatic classifications (Kassa and McCutcheon 2016; Parfitt and McCutcheon 2017). This approach is explained in more detail below. The 45PI438 assemblage was analyzed using a free-standing typology, based on Andrefsky (2005:129), and influenced by Sullivan and Rozen (1985) and Flenniken and Raymond (1986). Sullivan and Rozen's (1985) research is important as it calls for comparability in debitage analysis and provides an interpretation-free approach to achieve that end. Their application of that approach is then used to identify patterns in lithic technology based on lithic type frequencies (relative proportions of debitage, lithic tools, cores, etc.). Comparisons to the 45PI438 assemblage using the paradigmatic classifications were accomplished using an analytical key (Vaughn 2010) explained below.

45PI429

The 45PI429 site is situated on the southwestern slope of Mount Rainier in the upper Nisqually River Valley, at about 4,300 ft. elevation in the Pacific Silver Fir and Mountain Hemlock zones of the upper Northwestern maritime forest (Biek 2000). It should be noted that the southern and western slopes of Mount Rainier are the primary locations of resource rich, lush, herbaceous meadows (Burtchard 2003). The lithic assemblage from 45PI429 considered here is 1,057 chipped stone artifacts consisting mostly of debitage, which includes a complete stone point (Columbia corner notched A [Lohse and Schou 2008]). The stratigraphic context of the assemblage ranges from 7627 cal. yr. B.P. to present based on published radiocarbon dates (Table 1) (Mullineaux 1974, 1996). Excavated contexts at this site yielded an additional date of 7880–8020 cal. yr. B.P., measured from charcoal samples recovered from a pre-Mazama O paleosol (cf. Burtchard 2011).

45PI438

The 45PI438 site is situated on a mountain bench landform on the northeastern slopes of Mount Rainier in the Mountain Hemlock and Subalpine Parkland Meadow zones of the upper maritime forest (near the subalpine zone) at 5,400 ft. elevation (Biek 2000; Schurke 2011). This site is located in an open habitat adjacent to a small lake. The portion of the assemblage compared here is 2,354 pieces of chipped stone artifacts consisting mostly of debitage from the pre-MSH Yn and post-MSH Yn components. These were analyzed in previous research effort (Schurke 2011). Schurke (2011) selected a sub-sample of the 45PI438 assemblage, which is used for statistical comparisons in this study. The assemblage was excavated from the pre-MSH Yn and post-MSH Yn tephra components and is a sub-sample from a single 1 m^2 excavation unit (Schurke 2011).

45PI408

Lithic assemblages of two other high elevation sites on Mount Rainier, the 45PI406 and 45PI408 sites, were studied using identical analytical protocols as the ones applied to the 45PI429 assemblage (Vaughn 2010). The 45PI408 site is located on the eastern slope of Mount Rainier, in the White River drainage at 4,884 ft. elevation in the Mountain Hemlock zone of the upper Northwest Maritime forest (Biek 2000; Vaughn 2010). The 45PI408 site is a pre-contact site with an assemblage size considered here of 4,408 chipped stone artifacts consisting mostly of debitage. The site was tested from 1997 to 2001 by Central Washington University field school students under the direction of the lead author. Lithic remains were analyzed and reported by Lewis et al. (2011; also see Vaughn 2010). As of 2011, only a negligible number of artifacts were identified below the MSH Yn tephra layer (ca. 4200 cal. yr. B.P.) in the 45PI408 assemblage. However, there was a pronounced Mount Rainier C (MR C) tephra layer (ca. 2470 cal. yr. B.P.) above it. That tephra marker bed separated two

Table 1. Division of Temporal Components According to Tephra Layer Dates (Mullineaux 1974:25) and Artifact Sample Sizes for Statistical Comparisons.

Cultural Component	Calibrated Years B.P.[a]	Sites		
		45PI429	45PI438	45PI408
Post-MSH Yn (tephra layers X through P[b])	3370–Present	179	2075	944
MSH Yn tephra set (lower tephra bed, tephra layer MSH Yn, and upper tephra beds)	4400–3370	860	-	3297
Pre-MSH Yn (tephra layers B through R)	4400–7627	44	281	-

[a] Radiocarbon dates published in Mullineaux (1974) were calibrated using Calib 5.0.1. (Stuiver and Reimer 1993). Where more than one date was presented for above and below tephra layers, the maximum dates for each range was averaged.
[b] These layers can include MR C and MSH W layers.

substantial parts of the lithic assemblage and was used in past studies to demarcate separate archaeological components (Lewis et al. 2011). As such, the components within the 45PI408 assemblage are labeled above MR C (present–2805 cal. yr. B.P.), or below MR C (2805–4200 cal. yr. B.P.) (Mullineaux 1974). Despite the lack of delineation between the MSH Yn tephra layer, the below MR C component of the 45PI408 includes the MSH Yn tephra set, where the preponderance of artifacts were observed. The tephra layers above MSH Yn, like MSH P, were void of artifacts. Artifact occurrence increased again above MR C, which is above MSH P. Thus, the artifacts recovered on top of MSH Yn are from layers with radiocarbon date ranges that are comparable to those of the MSH Yn component in the 45PI429 assemblage.

45PI406

The 45PI406 site is located in the Mountain Hemlock and subalpine meadow zones at about 5,440 ft. elevation near crest of the Cascades within park boundaries immediately east of Mount Rainier. The 45PI406 assemblage analyzed here is 759 pieces of chipped stone artifacts consisting mostly of debitage from a probable multi-component site with mixed stratigraphic integrity. Excavators noted the presence of historic artifacts in some excavation units, as well as mixed tephra layers due to bioturbation and freeze/thaw (Vaughn 2010). As a result, the site assemblage was not segregated into distinct components, but instead was limited to a whole-site comparison with the other study sites.

All of the study sites are situated in the subalpine ecotone or just below it in the upper maritime forest ecozone (Biek 2000). Three of the sites (45PI429, 45PI438, and 45PI408) are located on the slopes of Mount Rainier, while 45PI406 is located below the crest of the Cascades due east of Mount Rainier. While the former three sites are in microclimates that tend to be drier due to the rainshadow effects of the mountain, 45PI429 is located where effective precipitation is more persistent. In all, the site locations make it possible to investigate how small but significant differences in microclimates may generate selective differences for making and using stone tools.

Temporal Components

Three temporal components are defined based on the artifact yielding deposits above, within, and below MSH Yn tephra marker beds observed at most of the sites (Table 1). Comparisons of the post-MSH Yn component at three sites (45PI429, 45PI438, and 45PI408) attempts to contrast artifacts that were deposited after MSH Yn. Artifacts recorded as excavated within the MSH Y tephra set of layers have been separated as a distinct component for synchronic statistical comparisons for only two of the sites (45PI429 and 45PI408). MSH Y tephra set of layers were deposited over a range of years that are well known (Mullineaux 1974), and those layers were identified at two of the sites. The layers below MSH Yn were lumped together for a comparison between just two of the sites: 45PI429 and 45PI438 as shown on Table 1.

Lipo and Eerkens (2008) created a formula to determine how significant the effects of formation processes are on measures of similarity between assemblages. The formula, Similarity = *f*(Preservation, Turbation, Field Methods), uses the three primary formation processes (Lipo and Eerkens 2008). The formula is a rubric for ensuring that assemblages come from comparable archaeological contexts and were generated with similar recovery strategies. For instance, if soil chemistry affects artifact survival or tree root disturbance is present at some sites and not others, this could cause biases that are not the result of past human activity. We use this formula here to determine the degree to which the statistically significant associations may have been influenced by these formation processes.

At all sites, the pre-contact artifacts were well preserved, as the assemblages consist of chipped stone debitage and tools. Furthermore, the sites were not heavily disturbed, with the exception of mixed component site 45PI406 (Vaughn 2010). Field observations and assessments of stratigraphic integrity at the 45PI408, 45PI429, and 45PI438 sites contained artifacts that were intercalated between distinct tephra layers. At each of these sites there was evidence of some post-depositional alteration, but not to the extent where large scale mixing would have resulted. To account for the post-depositional alterations at 45PI406, this assemblage is used only in whole-site comparisons. Finally, comparative variation in the data sets is minimal as all assemblages were recovered from sediments sieved through an 1/8-inch mesh screen and, with one exception (45PI406), from natural stratigraphic layers.

While some primary formation processes may have impacted our measures of similarity, the biases imposed on the data is minimized by the large sample sizes and aggregation of artifacts using stratigraphically distinct layers. Also, we performed a resampling analysis that allowed us to select only those classification dimensions (e.g., fragment type, cortex type, etc.) that had representative artifact type frequencies; that is, where the the frequencies of artifact types reach redundancy and additional sampling provides no new information (Mooney and Duval 1993). Thus, we conclude that statistically significant associations are the result of sorting in the archaeological record resulting from natural selective conditions affecting human populations using the mountain at different times and/or places.

Theory, Method, and Technique

The investigation of the lithic assemblages was guided by an evolutionary approach, where a historical sequence of artifact variations from stratigraphically defined archaeological components are compared across space and through time (O'Brien and Lyman 2000; Prentiss 2019). The method was adapted to lithic studies at Mount Rainier as a means of determining if different environmental pressures (selective conditions) affected lithic artifact variation as assumed by past researchers (Dampf 2002; Burtchard 2007; Vaughn 2010). Elsewhere researchers have found that the structure of the environment affects the nature of the lithic assemblage, which result from human land use (Campbell 1981; Teltser 1991; Ingbar 1994). For example, material scarcity will have implications for the range of forms found and, in this case, could result in lithic assemblages with more evidence of highly curated stone tools (Andrefsky 1994a, 1994b).

The artifact classes from our method were designed to measure the results of people interacting with the environment (O'Brien and Lyman 2000). This approach allowed the assessment of whether lithic artifact classes occur independent of environmental factors, or, alternatively, if they exhibit non-random associations with geographically variable environmental factors (Endler 1986; O'Brien and Lyman 2000). The long-term study of variation (in the frequency distribution of artifact traits) through an evolutionary method is an effective means to detect the selective conditions under which stone tools are manufactured and used (Kassa and McCutcheon 2016; Parfitt and McCutcheon 2017).

This method describes lithic manufacture and use with lithic technological and functional variables as they are patterned by interaction with or demands of the environment (natural selection) (Dunnell 1978a, 1978b; Lyman 2008). The inter-variable relationships between technological and functional variables (and their sub-variables) are used to identify what might be found (archaeological expectations) given different variable states (McCutcheon 1997; Kassa and McCutcheon 2016; Parfitt and McCutcheon 2017).

To ensure comparability across assemblages, our analytical approach used a lithic classification system that was previously applied to pre-contact assemblages from Mount Rainier National Park (Dampf 2002; Vaughn 2010) and elsewhere (Campbell 1981; Kassa and McCutcheon 2016; Parfitt and McCutcheon 2017). These studies employ sets of mutually exclusive lithic technological and functional dimensions (e.g., raw material type, completeness, thermal alteration, reduction class, platform type, and use wear) to classify each artifact. By identifying common frequencies of artifact types across sites and site components, occurrence (or sorting) of chipped stone artifacts in the archaeological record was tested for non-random associations across technological and functional dimensions.

Relative frequencies of artifact types were used to assign each assemblage or component to one of the four technological groups (Sullivan and Rozen 1985): un-intensive core reduction (UCR), tool manufacture (TM), intensive core reduction (ICR), and core reduction and tool manufacture (CR/TM). The artifact type proportions used to identify technological groups in Table 2 are based on the relative abundances of debitage, cores, and retouched artifact pieces (Sullivan and Rozen 1985). Applying Sullivan and Rozen (1985) types to the assemblages/components allowed us to use the relative artifact frequencies to make interpretations for the type and intensity of tool manufacture that was occurring in each component of the assemblages being studied here. Prentiss (1998) used experimental data to identify problems of validity especially in experimental conditions with highly vitreous materials like obsidian. Although most of our materials are not obsidian, we believe this approach is still valid in that it provides a starting place for stone tool analysis and a means by which to make coarse-grained comparisons. In general, we agree with Prentiss (1998) that such approaches can suppress the variation we are trying to explain and should be used cautiously.

Before making those interpretations, we used bootstrapping statistics to describe the representativeness of each assemblage/component (Mohr et al. n.d.; Mooney and Duvall 1993; Cochrane 2002; Lipo and Eerkens 2008; Vaughn 2010). Resampling is one approach to bootstrapping statistical analysis. Resampling is a non-parametric approach used to identify where samples are redundant and can be assumed to characterize the population of artifacts from which they were recovered (Mooney and Duval 1993). Restricting statistical testing to representative samples only, allows confidence in the statistical analysis results (Cochrane 2002). Where representative artifact trait frequencies were determined by resampling, they were used in a comparison of each assemblage's pre-MSH Yn, MSH Y set, and post-MSH Yn components between the 45PI429, 45PI438, and 45PI408 assemblages (Ferry 2015). The lithic frequencies analyzed from site 45PI406 were restricted to whole-site comparisons only.

Table 2. Artifact Category Percentages Used to Assign Assemblages/Components Technological Groups (after Sullivan and Rozen 1985).

Artifact Category	Technological Group			
	UCR	CR/TM	ICR	TM
Complete Flakes	53.4	32.9	30.2	21.0
Broken Flakes	6.7	13.4	8.1	16.8
Flake Fragments	16.0	35.3	34.7	51.3
Debris	6.1	7.9	23.0	7.3
Cores	14.7	2.8	2.0	0.6
Retouched Pieces	3.1	7.5	2.0	3.1

UCR: Un-intensive core reduction; CR/TM: core reduction and tool manufacture; ICR: intensive core reduction; TM: tool manufacture.

The goal of our statistical analysis was to identify non-random associations between the modes or attributes of dimensions through chi-squared testing, or log-likelihood testing when sample sizes were insufficient for chi-squared testing (Zar 1974; VanPoole and Leonard 2011). When non-random associations were identified, nonparametric test (χ^2 or g values) values were used to assign Cramér's V values (Cramér 1946). These values (0.0 to 1.0) along with the degrees of freedom and sample size were used to measure the effect size (Cohen 1988). The effect size was a means to know the strength of any particular non-random association revealed by the test statistic. Cramer's V and effect size allowed for an additional evaluation of the statistical result and thus augment the interpretation of chi-square/log likelihood statistical comparisons. When a statistically significant result was observed using chi-square tests, we used an analysis of the residuals to demonstrate which of the contingency table cell values were contributing most to the rejection of the null hypothesis. A rejection of the null hypothesis (that the data is non-randomly associated) means that there are statistically significant patterns in our data and differences across assemblages are tied to stone tool technology or function.

Results

Sullivan and Rozen (1985) Technological Groups

Each lithic assemblage component was assigned to one of Sullivan and Rozen's (1985) technological groups in order to identify any broad scale patterns through time, and/or differences between assemblages, in their technological organization. As shown in Table 3, the most common technological group was TM (tool manufacture), followed by ICR (intensive core reduction). The technological group CR/TM is a mix of core reduction and tool manufacture (Table 3).

Technological organization of the assemblages varies among sites. For instance, the pre-MSH Yn component of the 45PI429 assemblage is a mixed tool manufacture and core reduction technological group, whereas the same component of the 45PI438 lithic assemblage is indicative of intensive core reduction.

The post-MSH Yn component of the 45PI438 assemblage also contains a large frequency of debitage, indicative of intensive core reduction. This pattern differs from the technological organization of the 45PI429 and 45PI408 assemblages, both of which resemble tool manufacture technological groups.

The pre-MSH Yn component of the 45PI429 assemblage differs from the later components in

Table 3. Technological Groups (Sullivan and Rozen 1985) of the Assemblages Using Data from Table 4.

Component	Assemblage			
	45PI429	45PI438	45PI408	45PI406
Whole site	TM	ICR	TM	TM
Post-MSH Yn	TM	ICR	TM	-
MSH Yn	TM	-	TM	-
Pre-MSH Yn	CR/TM	ICR	-	-

CR/TM: core reduction and tool manufacture; ICR: intensive core reduction; TM: tool manufacture.

that the proportions of attributes of completeness closely resembled those of a mixed core reduction and tool manufacture technology, with many small thin, non-cortical flakes. Uniquely, the entire 45PI438 assemblage sample is assigned to intensive core reduction, as debris makes up a significant proportion of lithic debitage in the sample and across all of its components.

These results show that there is a good deal of similarity in the assemblages/components when using a coarse-grained measure like the Sullivan and Rozen (1985) technological groups, which is not surprising given the large amount of overlap in lithic categories with experimentally replicated assemblages (Prentiss 1998). However, whether or not these similarities are present when comparing more of the lithic technological and functional variation needs to be determined to explain how subtle differences (e.g., the use of stone tool heat treatment) in microenvironments might influence lithic manufacture and use (McCutcheon 1997).

Statistical Comparison Results

As discussed above, a broad scale analysis using Sullivan and Rozen (1985) types suggests the following: 1) the type and intensity of tool manufacture differed between the 45PI438 assemblage and the other assemblages; 2) the type of tool manufacture appeared to be stable through time in the 45PI438 and 45PI408 assemblages; and 3) a potential shift in technology between the earliest, pre-MSH Yn component, and the MSH Yn component of the 45PI429 assemblage.

Additional variability in the lithic technological organization can be explored further using the individual dimensions employed in our analysis, revealing subtle differences in comparisons between assemblages and through time that may not be seen using the Sullivan and Rozen (1985) technological types alone. Statistical comparisons among the filled class attribute frequencies, as seen in Table 4, show the counts by each dimension's attributes for each assemblage. While Table 4 shows counts for assemblages (coarse-grained), these frequencies were also used for comparisons between sites within the post-MSH Yn, MSH Yn, and pre-MSH Yn temporal components.

The null hypothesis for all comparisons was that differences between assemblages recovered from variable environmental zones are random. Non-random differences or associations potentially reveal the effects of sorting in the archaeological record as patterns in the distribution of the attributes of each dimension. Our argument is that sorting was caused by selective conditions (e.g., environmental constraints like tool stone availability) that influenced the choices and success of stone tool makes and users at the sites (e.g., Kassa and McCutcheon 2016; Parfitt and McCutcheon 2017).

Sample size differences from Table 4 limited the number of statiscal comparisons to eight, one of which (fragment type) did not reject the null hypothesis meaning that variation in fragment type across assemblages and their components is random. Table 5 summarizes the results of seven coarse-grained (whole site) comparisons using the chi-square/log-likelihood test statistics that rejected the null hypothesis. Table 5 reveals that of these seven comparisons, four of them were strong non-random associations. Each of these results are significant and reveal inter-site patterns. Rejection of the null hypothesis by the majority of coarse-grained, whole site comparisons indicates that there is strong evidence for sorting in the attribute frequencies across filled stone tool manufacture and use classes. Resampling results demonstrates that some level of representativeness was present in all comparisons, and lacking site formation or recovery technique biases discussed above, these initial whole-site comparisons show that lithic assemblages vary significantly across variable types of space or microenvironments. Thus, evidence is lacking for uniformity in stone tool technology across the landscapes of Mount Rainier, which is a result not surprising given the current spatial variability in geology and climate, and associated plant and animal communities.

For the synchronic comparisons between components both within and between site

Table 4. Counts of Modes (Attributes) Compared for Whole Assemblages.

Dimension	Mode (Attribute)	Sites			
		45PI406	45PI408	45PI429	45PI438
Raw Material	Chert	682	4,168	1,037	2,279
	Obsidian	36	40	3	-
	Igneous	41	200	17	75
Completeness	Whole Flake	7	67	74	227
	Broken Flake	148	1,310	528	129
	Flake Fragment	592	2,797	413	1,249
	Debris	15	71	58	749
Thermal Alteration[a]	Lustrous/ Non-Lustrous	12	229	272	281
	Lustrous Only	690	3,075	647	661
	High Temperature	48	365	50	52
Reduction Class	Initial	2	11	10	57
	Intermediate	90	32	261	335
	Terminal	-	1,089	282	-
	Bifacial Thinning	20	61	-	-
	Bifacial Resharpening	33	94	24	-
Platform Type	Cortical	21	-	1	5
	Simple	92	14	255	303
	Faceted	447	71	94	46
	Bifacial	117	53	12	-
	Fragmentary	2,146	584	354	-
	Pressure	360	19	112	-
	Technologically Absent	25	1	20	-

[a] Thermal alteration dimension measures the occurrence of different states of alteration as defined in McCutcheon (1997) where Lustrous/Non-Lustrous flakes scars and Lustrous flakes scars are defined as indicators of stone tool heat treatment and the High Temperature attribute is an indication of thermal alteration that does not facilitate flint knapping and the production of stone tools.

Table 5. Statistically Significant, Non-Random Coarse-Grained Associations.

Dimension	Assemblages	Cramér's V ($\chi 2$)	*df*	Strength of Association
Thermal Alteration	45PI406 45PI408 45PI429	0.2	2	Small
Use Wear	45PI406 45PI429 45PI408	0.13	1	Small
Completeness	45PI406 45PI408 45PI429 45PI438	0.31	3	Large
Platform Type	45PI406 45PI408 45PI429	0.36	9	Large
Reduction Class	45PI406 45PI408 45PI429 45PI438	0.52	4	Large
Complexity of Dorsal Surface	45PI438 45PI406	0.76	1	Large
Raw Material	45PI406 45PI408 45PI429 45PI438	0.1	3	Small

assemblages, sample sizes frequently were insufficient for chi-squared testing, in which case log-likelihood test (G) results were substituted (Table 6). Out of a total of 31 coarse-grained and synchronic statistical comparisons, just over half, or 17, of the statistical comparisons resulted in a rejection of the null hypothesis. In those comparisons where the null hypothesis was rejected, a minimum of one half to a maximum of 100% of cell values contributed to the rejection of the null hypothesis, based on an analysis of the residuals (VanPoole and Leonard 2011). This suggests that the variability observed in stone tool manufacture and use frequencies are both similar and different depending on what dimension is being compared. Unfortunately, only raw material attributes could be compared across each component and were found significantly different for each time period. Raw material abundance is a function of what is available locally and what materials are being imported, both of which will have implications for other parts of stone tool manufacturing (Andrefsky 1994a, 1994b).

Use Wear

Use wear comparisons excluded the 45PI438 assemblage as it was not analyzed in a comparable manner (Schurke 2011). In a comparison of the presence/absence of use wear between sites, the 45PI429 assemblage had fewer occurrences or artifacts with use wear present than the 45PI406 and 45PI408 assemblages. Use wear can occur multiple times on a single artifact,

Table 6. Statistically Significant, Non-Random Synchronic Associations.

Component	Dimension	Assemblages	Statistically Significant Association	χ^2 or *G* Value > p	Cramér's V (χ^2 or *G*)	*df*	Strength of Association
Pre-MSH Y	Raw Material	45PI429 45PI438	*G*	31.10	0.31	2	Medium
	Completeness	45PI429 45PI438	*G*	33.44	0.36	3	Medium
MSH Y	Reduction Class	45PI429 45PI408	*G*	132.10	0.35	4	Medium
	Thermal Alteration	45PI429 45PI408	χ^2	53.35	0.13	2	Small
	Completeness	45PI429 45PI408	*G*	120.40	0.19	3	Small
Post-MSH Y	Thermal Alteration	45PI429 45PI408	χ^2	32.22	0.18	2	Small
	Use Wear	45PI429 45PI408	χ^2	38.31	0.18	1	Small
	Raw Material	45PI429 45PI408 45PI438	*G*	85.38	0.11	2	Small
	Reduction Class	45PI429 45PI408	χ^2	66.15	0.41	4	Medium
	Completeness	45PI429 45PI408 45PI438	χ^2	657.67	0.32	3	Medium

which accounts for the apparent increase in artifact counts in Table 7. Even though, those differences do not account for a difference of five times in the amount of use wear seen on the larger assemblages (Table 7). Analysis of residuals shows that the non-random associations between assemblages for use wear was driven by both the presence and absence of use wear in all assemblages. Analysis of the residuals shows that there was a higher incidence of use wear for artifacts in the 45PI408 assemblage than expected, and less use wear than expected in the 45PI429 assemblage. In the post-MSH Yn components, the proportion of use wear was significantly higher in the 45PI408 assemblage than in the 45PI429 assemblage (Table 7). In summary, the absence of use wear at 45PI429 is driving much of the rejection of the null hypothesis when comparing sites and their components.

When comparing frequencies of functional wear types (e.g., chipping, crushing, abrasion, and polish) in all components of the 45PI406, 45PI408, and 45PI429 assemblages, the most common functional wear type was unifacial chipping, with limited crushing. The assemblages do not display diverse wear types overall. Alternatively, the shape of wear was highly variable in all assemblages, with convex, concave, and straight all on angular edges present (in high to low relative order of occurrence). Shape of wear is influenced by the size of object the tool form is used on; larger sized worked materials result in convex shaped wear, whereas concaved shaped wear occurs from working materials that are smaller than the worked edge (Dancey 1973; Dunnell and Lewarch 1974; Dunnell 1978a; Campbell 1981). This tells us that variably sized materials were being worked by these stone tool assemblages.

Raw Material

The frequencies of raw material types present (chert, obsidian, igneous, and other) were compared between components within assemblages, and between assemblages. Comparisons revealed that chert tool stone raw material was present in significantly higher frequencies than all other raw material types combined for all assemblages (Table 8). In the 45PI408, 45PI438, and 45PI429 assemblages, statistical analysis revealed a non-random association between temporal components of the assemblages for raw material type. Analysis of the residuals showed that the non-random associations were driven by higher and lower than expected frequencies for all types of raw material in all assemblages, indicating statistically significant, non-random sorting for and against certain raw material types over others. The exception was the absence of obsidian from the analyzed 45PI438 assemblage sample. This association can be explained in that the dominant available raw material numerically swamps the variation of the assemblages when sorted by material types.

When comparing the 45PI408, 45PI429, and 45PI438 assemblages from the post-MSH Yn component, the 45PI408 assemblage has a 6% lower proportion of chert than the other assemblages as this component's tool stone raw materials contain most of the site's obsidian lithic artifacts. Non-random association was driven by higher frequencies of all raw material types than expected in the 45PI408 assemblage, and lower frequencies of all raw material types than expected in the 45PI438 assemblage sample.

In the MSH Yn component of the 45PI429 and 45PI408 assemblages, comparisons show no significant variation in the distribution of raw material types in both assemblages. Analysis of residuals shows that the non-random association between the 45PI429 and 45PI408 assemblages was driven by higher and lower than expected frequencies of different raw material types.

In a comparison of the 45PI429 and 45PI438 assemblages in the pre-MSH Yn component, the 45PI438 assemblage has a significantly higher proportion of chert (21%) than the 45PI429 assemblage. All cell values significantly contributed to the rejection of the null hypothesis, meaning that they were greater (> 1.96) or less (< -1.96) than what would be expected through random selection. This indicates that these values drove the non-random statistically significant associations, as a result of non-random selection for (> 1.96) and against (< -1.96) certain raw material types (Table 9).

Of note due to the distance from the source (Obsidian Cliffs in Oregon), obsidian appears to have been initially present in small amounts in the excavated portion of the 45PI429 assemblage. Obsidian was present in the highest frequency in the pre-MSH Yn component, in a lower frequency in the MSH Yn component, and completely absent from the post-MSH Yn component. This was in contrast to the presence of obsidian in the 45PI408 assemblage, where almost all obsidian occured in the MSH Yn component. Unfortunately, 45PI406 could not be considered here as it lacked stratigraphic integrity.

When non-random, statistically significant associations were identified, analysis of residuals was applied in order to detect which attributes of the dimensions were driving the association, and whether they were being selected for or against. Table 9 lists the components of the assemblages that were found to have non-random associations, and which attributes of the dimensions were driving the associations, and whether the selection was for or against each attribute. Analysis of the residuals reveals that the attributes of the dimensions being selected for and against in each component of each assemblage sample compared were variable both

Table 7. Presence and Absence of Artifacts with Use Wear Counts (Proportions).

		Sites			
Dimension	Mode	**45PI406**	**45PI408**	**45PI429**	**45PI438**
Use Wear	Present	135(15.6)	619(13.9)	32(3.0)	-
	Absent	732(84.4)	3833(86.1)	1025(97.0)	-

Table 8. Coarse-Grained Raw Material Distribution for All Sites.

Raw Material Type	45PI408	45PI438	45PI406	45PI429
Chert	94%	97%	89%	98%
Obsidian	1%	-	5%	<1%
Igneous	4%	3%	5%	<2%
Other	1%	-	1%	-
Total	100%	100%	100%	100%

between assemblages and through time. Table 9 reveals how often the assemblages considered here are non-randomly different from each other and those particular attributes that contribute to the differences. For instance, all three sites have lithic frequencies that fall short of or exceed what would be expected based on an analysis of the residuals (VanPool and Leonard 2011). Table 9 shows that 45PI429 lithic frequency cell values are most often the cause for rejection of the null hypothesis, followed by 45PI408 and then much less so for 45PI438. This pattern is the case in both where there are higher (>1.96) or lesser (<-1.96) lithic frequencies than expected.

Artifact frequencies are variable across contemporaneous (synchronic) assemblage components. Differences between the assemblages (see Tables 6 and 9) within similarly aged components indicate variation in the selective conditions of the environment at each of the sites. Within single assemblages, artifact frequencies are variable across temporal components as well. Most importantly, this diachronic variation indicates changes in the technological and functional solutions to particular selective conditions.

Discussion

The following discussion first considers the lithic variation across space and through time set in the changing environmental contexts. Secondly, we consider the variation in lithic raw materials used across space and through time to further resolve the impacts of different selective conditions between and across the four lithic assemblages.

Lithic Variation Set in Environmental Contexts

Table 10 summarizes environmental, technological, and temporal data for the four Mount Rainier study sites. Variation between the assemblages, such as differences in the selective conditions for raw material types and the intensity of tool manufacture, can be tied to the variable environments present. These differences, in turn, reveal the impact of differing selective conditions of those environments on the resultant stone tool assemblages. As the overall environment became more variable due to major pyroclastic and fire events (Mullineaux 1974; Tweiten 2007; Sisson and Vallance 2009; Walsh et al. 2017), similarities emerged between

Table 9. Residuals for Synchronic Comparisons.*

Component	Dimension	Modes	Residuals > 1.96	Residuals < -1.96
Pre-MSH Yn	Raw Material	Chert	45PI438	45PI429
		Obsidian	45PI429	45PI438
	Completeness	Broken flakes	45PI429	45PI438
		Debris	45PI438	45PI429
MSH Y	Reduction Class	Initial	45PI429	45PI408
		Intermediate	45PI429	45PI408
		Terminal	45PI408	45PI429
		Bifacial Resharpening	45PI408	45PI429
		Bifacial Thinning/ Reduction	45PI408	45PI429
	Thermal Alteration	Lustrous/ Non-lustrous	45PI429	45PI408
		Lustrous Only	45PI408	45PI429
	Completeness	Whole flake	45PI429	45PI408
		Broken flake	45PI429	45PI408
		Flake fragment	45PI408	45PI429
		Debris	45PI429	45PI408
Post-MSH Yn	Thermal Alteration	Lustrous/ Non-lustrous	45PI429	45PI408
		Lustrous Only	45PI408	45PI429
	Use Wear	Absent	45PI429	45PI408
		Present	45PI408	45PI429
	Raw Material Type	Chert	45PI438	45PI408
		Obsidian	45PI408	45PI438
		Igneous	45PI408	45PI438

*Sites listed in each residuals column either had a greater (> 1.96) or lesser (< -1.96) amount than expected through random chance.

Table 10. Summary of Variation Between Assemblages and Environment Through Time.

				45PI406	45PI438	45PI408	45PI429
				(W) 5,440 ft.	(NE) 5,400 ft.	(W) 4,884 ft.	(SW) 4,300 ft.
				Subalpine meadow	Subalpine meadow	Upper Northwestern maritime forest	Upper Northwestern maritime forest
Component	**Age**		**Environment**	Mountain Hemlock	Subalpine Fir	Mountain Hemlock	Pacific Silver Fir
Post-MSH Yn: MSH P to Surface	3370 cal. yr. B.P.** to present[4]	Late Holocene: 4000 yr cal B.P. to present	Little Ice Age: 550–100 cal. yr. B.P.[1,6] Medieval Climate Anomaly: 1100–700 cal. yr. B.P.[1,6] Neoglacial Period: 3400–2200 cal. yr. B.P.[6] Coolest, wettest period, and greatest variability in the Holocene Epoch[6]	Tool manufacture; Most use wear; Lowest diversity in types of wear; Highest proportion of obsidian	Intensive core reduction; Dominated by flake fragments; Decrease in intermediate reduction; Obsidian absent	Pronounced tool use; Slight increase in tool manufacture; Directional selection for heat treatment in late reduction stage	Increase in tool use; Increase in tool manufacture; Directional selection for heat treatment in early and late reduction stages
MSH Yn: Yn tephra set (deposition of MSH Yn tephra ca. 3650 cal. yr. B.P.[2*])	4400–3600 cal. yr. B.P.[4]				-	Greatest technological and functional diversity	Tool manufacture only; Dramatic increase in heat treatment
Pre-MSH Yn: MR B to O tephra (Mazama)	>7627–4400 cal. yr. B.P.[5]	Early to Middle Holocene: 8000–4000 cal. yr. B.P.	Warmer and drier period initially,[3] shifting to cooler, wetter conditions after 6600 cal. yr. B.P.[6]		Intensive core reduction; Highest proportion of igneous; Obsidian absent	-	Intermediate core reduction and tool manufacture; 15% obsidian present

[1]Goosse et al. 2012:1; [2]Mullineaux 1996:8; [3]Whitlock 1992; *Or 3690–3890 cal. yr. B.P. (Mullineaux 1996:8); **2990–3370 cal. yr. B.P. (Mullineaux 1996:8); [4]Sisson and Valance 2009:6; [5]Zdanowicz 1999, [6]Walsh et al. 2017.

the assemblages in the frequency and types of thermal alteration. This could indicate where natural selection fixed part of the organization of technology strategy in favor of stone tool heat treatment. While the initial cost of heat treatment in time and energy is greater, it reduces time spent procuring higher quality workable tool stone and increased wastage by enhancing the predictability of fracture and utility (sharper edges and tool symmetry) of the stone tools (McCutcheon 1997; Domanski and Webb 2007). An in-depth discussion of the variation and similarities follows.

Around 4400 cal. yr. B.P. the frequency of heat treatment (lustrous only and lustrous/non-lustrous flake scars) in the 45PI429 assemblage increased significantly, indicating strong directional selection (Endler 1986) for the application of stone tool heat treatment on early and late reduction trajectory flakes. Strong directional selection for heat treatment was also present in terminal reduction flakes in the 45PI408 assemblage from around 3000 cal. yr. B.P. to present. Directional selection for heat treatment in the assemblages could be based on decreasing the cost of stone tool manufacture, given that heat treatment decreases the fracture toughness and increases predictability of fracture for some types of chert (McCutcheon 1997; Domanski and Webb 2007). The environmental effect of the local abundance of, and proximity to, tool stone chert sources was likely a contributing factor in the selection of using a material that requires heat treatment (Vaughn 2010). In addition, increased performance offsets the cost of stone tool heat treatment through greater degrees of symmetry via more predictable fracture and sharper edges because of increased intra-granular fracture in heat-treated materials (McCutcheon 1997; Domanski and Webb 2007).

The absence of obsidian from the analyzed 45PI438 lithic sample, and the disappearance of obsidian from the 45PI429 assemblage sample after its initial appearance in the early pre-MSH Yn component, and the absence of obsidian in layers dated after 3000 cal. yr. B.P. at 45PI408 suggests a directional shift away from non-local tool stone, which were expensive to transport such long distances like central eastern Oregon (Parfitt and McCutcheon 2017). The significant decrease in igneous rock at 45PI429 and 45PI438 after 4400 cal. yr. B.P. could be related to the increase occurrence in the heat treatment of locally available chert. Because the 45PI438 and 45PI406 assemblages are primarily composed of chert, and heat-treated artifacts dominate the 45PI406 assemblage, this relationship suggests that similar environmental conditions of raw material type and availability may have contributed to the fixing of heat treatment in stone tool manufacture and perhaps outcompeted the need for nonlocal materials (e.g., obsidian), regardless of their greater predictability in manufacture and performance in use.

The shift in the organization of technology in the 45PI429 assemblage from intermediate core reduction and tool manufacture to a primarily tool manufacture focus also occurred around 4400 cal. yr. B.P. The abrupt change in technological organization and the increase in heat treatment were generally concurrent with regional shifts in climate beginning around 6600 cal. yr. B.P., from the xeric conditions of the middle Holocene to the more mesic climate of the late middle and late Holocene (Walsh et al. 2015, 2017). The shift in technological organization could have been an adaptation to the effects of a cooler moister climate, and the subsequent expansion of the subalpine zone or increased forest cover (Walsh et al. 2017). Decreased erosion caused by greater vegetation cover or higher annual snowfall totals and shorter summer snow-free periods, may have in turn decreased the exposure of tool stone sources. This could have created conditions that favored finished stone tools, rather than transporting raw material or unfinished tools to another location for resource exploitation. In addition, during this period of time, the series of pyroclastic events that resulted in the deposition of the MSH Yn tephra layers from ca. 4400–3000 cal. yr. B.P. significantly altered the regional environment

(Dunwiddie 1986), if only for a short duration of a few decades (Zobel and Antos 1997). Changes in the selective conditions during and after the deposition of the MSH Yn tephra set, such as ecosystem composition and structure, could have influenced stone tool technology and function as people exploiting resources on the mountain adjusted to rapid environmental shifts. Additionally, frequent eruptions and higher fire activity during the late Holocene, presumably caused by greater interannual climate variability than compared to earlier and/or the resetting of the seral continuum to low seral conditions where abundant vegetation biomass contexts good for game appear (cf. Burtchard 2007; Walsh et al. 2015, 2017). One means of adapting to greater climate variability is to apply technologies like stone tool heat treatment that can decrease cost of manufacturing stone tools and increase performance as discussed above.

Unlike that of the 45PI429 assemblage, the organization of technology in the 45PI408 and 45PI438 assemblages was stable through time. Differences between the 45PI408 and 45PI438 assemblages are present at other scales of our analysis as well. The former was assigned to the tool manufacture technological type, while the latter assemblage was typical of an intensive core reduction technological type. This supports the idea that the local selective conditions that influenced stone tool manufacture at the 45PI408 and 45PI438 sites differed from each other and from those at the 45PI429 site. Long-term differences in the local abundance and types of natural resources available at each site, such as herbaceous vegetation as compared to forest, or the presence or absence of game animals, could have driven the stabilizing selection in reduction trajectory class similarities.

From ca. 3000 cal. yr. B.P. to present, the frequency of traits associated with tool manufacture in the 45PI429 and 45PI408 assemblages increased, with a decrease in initial and terminal reduction flakes, and directional selection for intermediate reduction flakes. This indicates that either initial reduction was occurring elsewhere, there was a raw material characteristic that accounted for the lack of cortex, or a combination of both.

In the 45PI438 assemblage, the proportion of faceted platforms increased in frequency between ca. 4400 and 3000 cal. yr. B.P. to present, while simple platforms (8%) and intermediate reduction flakes decreased (7%). While closed array effects could account for some of the changes (whereas one attribute frequency decreases the others must increase numerically when using proportions), it could also indicate a directional selection against simple platform types and intermediate reduction flakes. This result could be surprising given what appears to be a continuation in the technological organization of the assemblage toward intensive core reduction and expedient tool production; however, any strong conclusions should not be drawn based on concerns of applying the Sullivan and Rozen (1985) types uncritically (Prentiss 1998) as discussed above.

The increasingly divergent technological organization of the assemblages indicates that the different local selective conditions at the sites became more pronounced over time, and/or the lithic assemblages became more specialized as the people creating the tools in each location adapted to the selective conditions of the environment in different manners. These conditions do not appear to have favored a singular mountain stone tool kit but instead more of a reliance on technologies like heat treatment that create flexibility and resilience in the organization of technology (Table 10).

The incidence of use wear in both the 45PI429 and 45PI408 assemblages increased around 3000 cal. yr. B.P., suggestive of changing selective conditions where an increase in use of objectives is indicated by a greater occurance of wear on chipped stone artifacts. Following a significant period of fire activity, the post-3000 cal. yr. B.P. environment may have increased in resource abundance and diversity (Walsh et al. 2017), creating not only more opportunities for tasks that incur wear on stone tools but also a more diverse set of tasks.

Lithic Raw Material Variation

The distribution of raw materials was similar within all assemblages in both the whole site comparisons and in the synchronic comparisons between similar-aged components. This result suggests that environmental constraints affecting tool stone procurement cost may have influenced the diversity of raw materials used in tool manufacture. The dominance of chert in all components of all sites indicates that the selection for chert over other raw materials may be based on lower costs of procurement and manufacture. Chert tool stone quarry sites near to the sites being studied are likely to have been readily available, but have not yet been identified near these sites (cf. Burtchard 1998). Based on the regional geology it is likely that tool stone sources are readily available on the slopes of Mount Rainier (Fiske et al. 1963), or in the river valley and creek bed gravel bars leading up to and on the mountain slopes. The use of stone tool heat treatment at all sites suggests that technological procedure was well known and would provide greater access to fracture properties not available in unaltered tool stone raw materials.

The low frequency of fine-grained volcanic tool stone materials (e.g., andesite) in all of the assemblages can be attributed to higher procurement cost, higher cost of manufacture, lower fracture predictability, and limited performance (McCutcheon 1997; Vaughn 2010). Without larger sample sizes of these types of artifacts, it is difficult to determine the range of stone tool manufacture and uses for fine-grained volcanic rocks.

Obsidian artifacts from the 45PI406, 45PI408, and 45PI429 assemblages were analyzed using x-ray fluorescence (XRF) by Northwest Obsidian Research Laboratory. The XRF analysis revealed that a number of non-local source locations were well represented on the slopes of Mount Rainier (Parfitt and McCutcheon 2017). A total of nine distinct sources were identified, one of which is an unknown source (Table 11). Obsidian occurrence may not always be tied to cost and performance as has been shown elsewhere (Parfitt and McCutcheon 2017), and could instead be linked to cultural transmission mechanisms where upland landscapes provide the opportunity for the interaction of people from diverse communities on either sides of the Cascade Crest.

An obsidian flake from the pre-MSH Yn component of the 45PI429 assemblage was also sent for XRF analysis, which revealed Obsidian Cliffs in Oregon as the likely source. The obsidian debitage in the 45PI429 assemblage is very small (≤ 0.11 g), consistent for distant tool stone source materials (Parry and Kelly 1987). Proximity to sources of raw material for stone tool manufacture would have been an environmental constraint, assuming that transporting tool stone through the rugged terrain was difficult (Burtchard 2003).

The high cost of procurement for obsidian could be offset by obsidian's fracture predictability (decreased cost) and edge sharpness (increased performance) (Kassa and McCutcheon 2016). Obsidian was only present in the earliest components of the 45PI408 and 45PI429 assemblages and was absent from the analyzed 45PI438 lithic assemblage. The stratigraphic pattern in the distribution of obsidian artifacts could indicate variation in travel routes between early and late Holocene peoples, and/or a relationship between stone tool heat treatment and the use of obsidian (Hansen and McCutcheon 2013). The use of obsidian is thought to have changed during the Holocene in the Cowlitz River Valley, with evidence of the use of Elk Pass obsidian (a local source) as early as 8,200 years ago (Mack et al. 2010). Conversely, the small amount of obsidian present and the isolation of the obsidian to the pre-MSH Yn component of the 45PI429 assemblage could indicate that the procurement and use of obsidian at the 45PI429 site was an idiosyncratic event, unrelated to overall stone tool manufacture and use strategies present later in time.

Table 11. Obsidian Counts and Sources for the 45PI406 and 45PI408 Assemblages (Vaughn 2010).

Source	Assemblage	
	45PI406	45PI408
Brown's Bench/Bickleton Ridge	2	1
Elk Pass	3	-
Indian Creek	-	1
Glass Buttes I	-	1
Newberry Volcano	14	6
Obsidian Cliffs	8	17
Quartz Mountain	-	14
Unknown	-	3
Whitewater Ridge	6	-
Total	33	43

Conclusions

Many of the changes in technological and functional organization of the assemblages, and the level of diversity between assemblages, can be causally related to selective conditions of the environment in which stone tools were manufactured and used. Based on what is known from paleoclimate studies and the recorded tephra layers, we have identified several selective conditions under which pre-contact peoples' material culture phenotype was influenced on the slopes of Mount Rainier. Those selective conditions are presented here as equally contributing factors.

1. Previous research has acknowledged that the deposition of the MSH Yn tephra layers could have disrupted prehistoric use of the mountain through changing the availability and abundance of resources (Dunwiddie 1986; Lewarch and Benson 1991; McClure 1992; Tweiten 2007), if only for a short time of a few decades to a century or two (Zobel and Antos 1997). Based on the increase in technological and functional diversity in all assemblages after ca. 4400 cal. yr. B.P., it is likely that the combined series of pyroclastic events, like what produced the MSH Y tephra set, had a more significant impact on human adaptations to the montane environment of Mount Rainier than previously understood. In addition, greater climate variability and higher fire severity and frequency during the late Holocene (Walsh et al. 2017) could have contributed to a less predictable environment and selected for greater reliance on resilient behaviors like the use of stone tool heat treatment and the anthropogenic use of fire.
2. Some changes in the composition and abundance of resources on Mount Rainier after 3400 cal. yr. B.P. can be linked to neoglacial cooling (Walsh et al. 2017). The shift to a mesic climate could have

necessitated a change in lithic reduction strategies, adapting to the resources that would have become less abundant in the cooler moister climate, like decreased tool stone raw material availability through decreased erosion, and/or the employment of other land modification techniques (e.g., anthropogenic burning [Tweiten 2007; Walsh et al. 2017]) to maintain diverse environments. Increased population pressures from lowland settings could have equally stressed use of these upland landscapes (Burtchard 2007).

3. Microenvironments, created by variations in average annual precipitation (the southern and western slopes are wetter and more resource rich), and the kinds and amounts of stone available, have uniquely influenced the manufacture and use of stone tools at each site. Large variations between the assemblages indicate that the selective conditions of local microenvironments on the mountain, such as variations in the abundance of natural resources, and the availability of different types of raw materials, significantly influenced stone tool manufacture and use taking place at the sites, a finding similar to other researchers (Andrews et al. 2016). Sample size was a limiting factor in cross-microenvironment comparisons. For instance, the lithics from the 45PI438 assemblage were sampled from a single 1x1 meter test unit. The sample size for 45PI438 could be increased by analysis of the larger sample using materials recovered from continued excavation that took place following Schurke's (2011) analysis. In addition, the sample size from 45PI429 could be increased with further excavation at the site.

The pre-contact regional land use and settlement model for the Southern Cascades overall is supported by the technological and functional organization of the assemblages (Lewarch and Benson 1991; Burtchard 1998). The evidence from the sites studied in this research largely support Burtchard's (2007) prehistoric regional high-elevation, land use model, where shifts in stone tool manufacture and use result from human adaptation to variable montane environmental patterns and changing population dynamics played out over a long stretch of time ranging from the early Holocene to the present.

Results were limited by small sample sizes, illustrating the need for further research of assemblages from high elevation archaeological assemblages in the southern Washington Cascades. Diachronic conclusions are suggestive largely because of the limitations on the data. The size of the assemblages was insufficient to make statistical comparisons between components within sites, particularly for the 45PI429 assemblage of which the pre-MSH Yn component consisted of only 44 pieces of debitage. Further excavation at the 45PI429 site would increase sample sizes, allowing for a comprehensive investigation of change over time. More robust sample sizes will be necessary to formulate more detailed explanations of why these sites differed in technological and functional organization over time and between environments. Additionally, application of the research strategy first developed by McCutcheon (1997) and later modified in these upland contexts will benefit future studies of upland montane lithic assemblages through providing a comparable analysis of lithic variation across variable environments (cf. Vaughn 2010; Lewis 2015).

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