FOOTPRINTS AND “FINGERPRINTS”:
A NORTHERN ARIZONA GEOCHEMICAL STUDY OF ARCHAIC PERIOD LITHIC PROCUREMENT AND MOBILITY

By Theodore M. Roberts

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Approved:

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Francis E. Smiley, Ph.D. Chair

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Christian E. Downum, Ph.D.

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Reed D. Riner, Ph.D.

ABSTRACT

FOOTPRINTS AND "FINGERPRINTS": A NORTHERN ARIZONA GEOCHEMICAL STUDY OF ARCHAIC PERIOD LITHIC PROCUREMENT AND MOBILITY

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This study examines igneous toolstone procurement and mobility strategies during the Archaic Period (9,000 B.P. – 2,400 B.P.) on the Coconino Plateau, Arizona. Relying on X-ray fluorescence analysis to determine the geologic source of 271 diagnostic projectile points, I investigate obsidian and fine-grained volcanic (FGV) source preferences and small-scale mobility patterns surrounding the San Francisco and Mt. Floyd Volcanic Fields. Included in the study is a sampling survey designed to provide a comparative geochemical source standard library (n = 355) for the region. The baseline survey served to ascertain the various performance characteristics of each raw material. These performance characteristics were then used as a foundation for a procurement model intended to explain the highly selective and patterned procurement behavior exhibited by the hunter-gatherers that occupied the area. I adapted the lithics-based model, termed the procurement preference model (PPM), from subsistence-based diet breadth models.

Archaic Period bands occupying the Coconino Plateau exploited only a handful of the lithic source options available in the research area. I assert that hunter-gatherers optimized procurement decisions and sought to maximize rate of energy return by choosing the highest quality lithic materials. I further argue hunter-gatherers practiced a disembedded procurement strategy once within the study area. Lastly, the specific igneous toolstone sources comprising the optimal set of lithic sources remained unchanged throughout the 6,600 years of the Archaic, although the overall percentage of the entire optimal set increased as observed in the projectile point sample. Thus, I conclude lithic source procurement became more specialized through time.

ACKNOWLEDGEMENTS

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The geochemical analysis essential in this study was provided generously by Craig Skinner of Northwest Research Obsidian Studies Laboratory. Mr. Skinner offered extensive advice, a great deal of personal time, and much assistance in bringing this thesis to fruition. Many thanks to Craig for guiding me through the complex world of obsidian.

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I’d like to thank Denny Carley for everything he taught me about local raw material sources and the northern Arizona natural environment. Mr. Carley’s thorough understanding of archaeology and passion for prehistory is inspiring. Thanks also for allowing me unrestricted access to his projectile point collection and for navigating our way out of the Black Tank conundrum…

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For Teagan, Elliott, and Nolan~
the next generation of archaeologists

Chapter One: An Introduction to an Archaic Period Lithic Study in the Arizona High Country

This study examines hunter-gatherer territorial ranges and procurement behavior in Northern Arizona during the Archaic Period in order to develop an understanding of regional prehistoric mobility strategies and band-level lithic raw material use. I draw inferences about band-level societies occupying the region during the Archaic Period through examination of diagnostic projectile points recovered from the area. The spatial distribution of lithic raw material relative to procurement locations can inform us on the organization of stone tool technology, mobility strategies, and settlement choices during the Archaic. My objective was to increase our understanding of the mobility patterns and obsidian procurement behaviors of Archaic groups occupying a stone-rich region in northern Arizona by doing an obsidian geochemical study of Archaic materials.

Obsidian figures prominently in the study because obsidian is the premier toolstone of the region yet occurs only at discrete locations in the northern Southwest. I examined the relative level of mobility exhibited throughout the Archaic Period as evidenced by the spatial distribution of diagnostic projectile points and by source procurement proportion trends. I attempted to answer questions about whether Archaic Period bands practiced high mobility based on subsistence constraints with toolstone selection simply integrated into their strategy or whether procurement of high quality raw material played such an essential role to primarily define mobility strategies. (Shackley, personal communication 2007).

The primary research objectives of my study include determining whether the majority of obsidian projectile points located across the Coconino Plateau consist of locally obtained obsidian and how individual obsidian sources were used through time. My study also examines:

1.) The role of obsidian procurement in driving residential and logistic mobility in band-level societies (Binford 1977).

2.) The extent to which the San Francisco Peaks region was used as a "retooling" center within larger Archaic Period mobility ranges.

3.) Whether raw material sources of equally high quality were available uniformly over the research area or whether people were making mobility decisions based upon raw material quality and availability situated differentially across the landscape?

4.) Whether obsidian sources located within the San Francisco and Mt. Floyd volcanic fields were used discriminately and if so, how do we explain the disproportionate exploitation of individual sources?

Obsidian

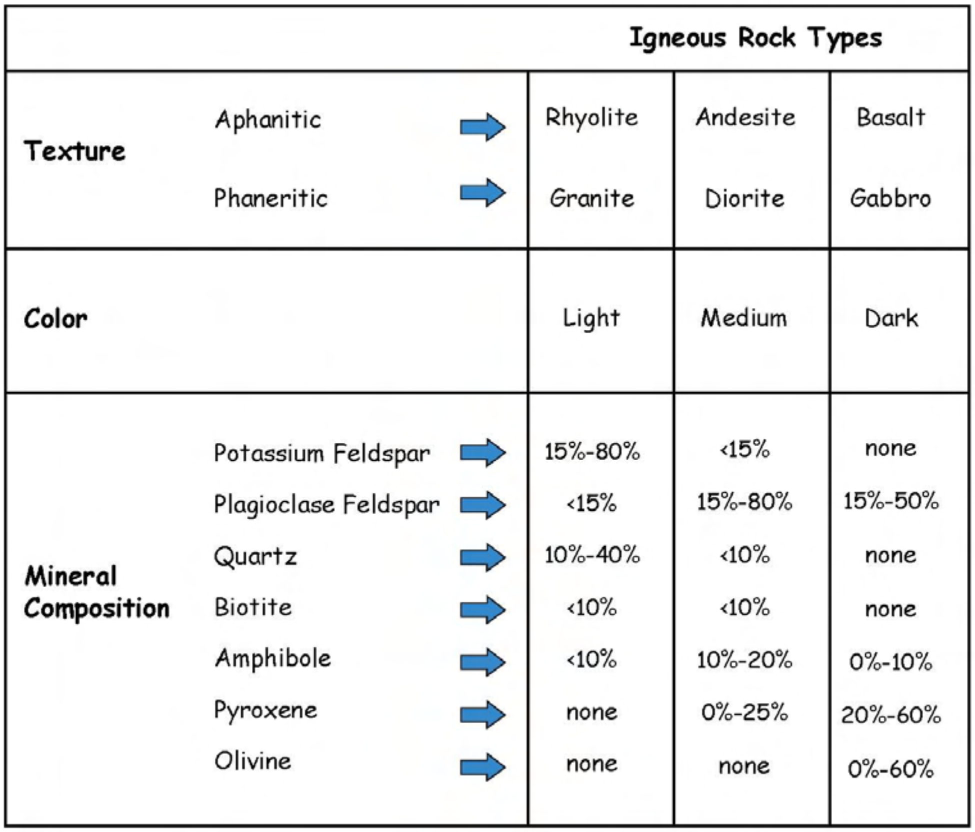
Obsidian displays excellent workability and production characteristics due to the chemical composition of the stone. Naturally occurring, obsidian contains a high level of silica. In fact, due to the silica content of obsidian, the material is considered a volcanic glass. According to Shackley (2005: 11), "Two factors control whether a magma [melt] will form a glass: the rate of cooling and its viscosity, which is hence determined by its chemical composition." However, the conditions favorable to the formation of obsidian are rare. Because most volcanoes contain water, eruptions usually result in pumice, vitrophyres (devitrified fabrics) or tuff (Shackley 2005:14), producing lithic materials unsuitable for tool manufacture. Fortunately for the prehistoric populations of northern Arizona, the eruptions of the Mount Floyd and San Francisco Mountain Volcanic Fields occurred “in very cold high-altitude environments that facilitated rapid cooling of large silicic lava flows” (Shackley 2005: 21). Such conditions produced toolstone-quality material in several instances.

According to Skinner (http://www.obsidianlab/terminology.html), “the name obsidian is one of the most ancient of rock names still in use today and was brought into the language by Pliny the Elder almost two millennia ago.” Prehistoric groups procured and used obsidian wherever the material occurred. In fact, many archaeologists cite obsidian as a major component of the emergence of social complexity, including market economies within the Maya (Braswell and Glascock 2002: 33), the earliest evidence for extensive maritime travel in the ancient Aegean (Renfrew, Cann, and Dixon 1965), the rapid and expansive growth of trade in Early Formative Mesoamerica (Pires-Ferreira 1976) and craft specialization at Catalhoyuk (Mellart 1967) and Teotihuacan (Spence 1981). Because of the importance of obsidian prehistorically, archaeologists have long considered the role of the material in society.

Fine-grained Volcanics (FGV’s)

Because the term obsidian refers to the texture of the material, obsidian varies in chemical composition between basaltic and rhyolitic (Figure 1). Throughout this thesis, I refer to such sub-vitreous igneous materials as fine-grained volcanics (FGV’s). Although lacking the superior knapping characteristics of certain high-quality obsidians, prehistoric people used FGV's extensively in northern Arizona. In addition, when compared to obsidian, FGV's are equally conducive to geochemical analysis. According to Andrefsky (1998: 47),

> There are three primary families of igneous rocks…the course grained member of the granite family is granite and the fine-grained member is rhyolite. Gabbro and basalt are the course- and fine-grained members of the gabbro family respectively, and diorite and andesite are the course- and fine-grained rocks of the diorite family. Members of the same family are composed of the same relative frequencies of minerals.



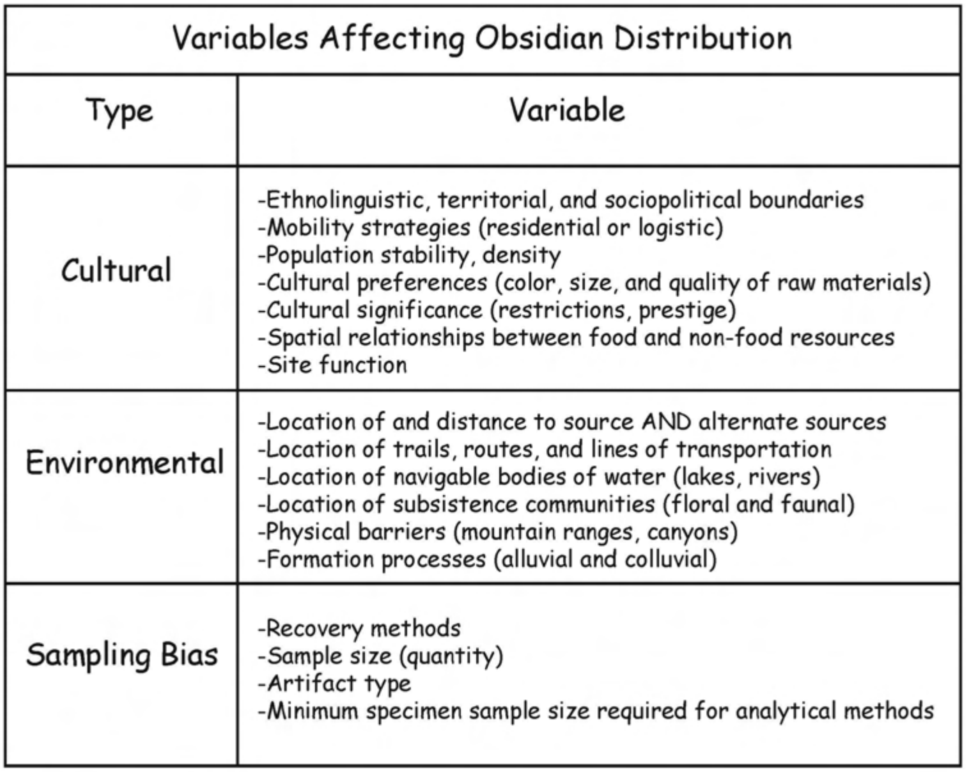
		Igneous Rock Types		
Texture	Aphanitic →	Rhyolite	Andesite	Basalt
	Phaneritic →	Granite	Diorite	Gabbro
Color		Light	Medium	Dark
Mineral Composition	Potassium Feldspar →	15%-80%	<15%	none
	Plagioclase Feldspar →	<15%	15%-80%	15%-50%
	Quartz →	10%-40%	<10%	none
	Biotite →	<10%	<10%	none
	Amphibole →	<10%	10%-20%	0%-10%
	Pyroxene →	none	0%-25%	20%-60%
	Olivine →	none	none	0%-60%

Figure 1. Table showing different igneous rocks and chemical compositions. Adapted from Andrefsky (1998: 48).

Project Overview

A clear understanding of the geochemical variability and spatial distribution of obsidian sources is a fundamental component of any obsidian procurement study (Skinner, personal communication 2007). With this goal in mind, I surveyed the eleven previously known obsidian sources in the vicinity of Flagstaff, Arizona. I collected representative samples of igneous raw material from the eleven sources as well as from two additional sources previously undocumented. Using a handheld global positioning systems (GPS) unit (Garmin GPSmap 60c), I recorded UTM coordinates for each source sample gathered. This allowed for the integration of GPS and geographic information systems (GIS).

The study area thus encircled a number of raw material sources bounded by spatial and geologic relationships. The igneous toolstone sources in the region occur within a lithic landscape occupied and exploited by prehistoric populations. In fact, the presence of high quality igneous toolstone and the occurrence of long term human occupation are undoubtedly linked. However, investigating the relationship between mobile human populations and immobile lithic sources requires knowledge of the precise geographic origin of stone tools (Figure 2). The volcanic fields of northern Arizona offer an unparalleled research opportunity because of the vast lithic raw material availability and the extensive prehistoric exploitation of obsidian and fine-grained volcanic toolstone.



Variables Affecting Obsidian Distribution

Type	Variable
Cultural	-Ethnolinguistic, territorial, and sociopolitical boundaries -Mobility strategies (residential or logistic) -Population stability, density -Cultural preferences (color, size, and quality of raw materials) -Cultural significance (restrictions, prestige) -Spatial relationships between food and non-food resources -Site function
Environmental	-Location of and distance to source AND alternate sources -Location of trails, routes, and lines of transportation -Location of navigable bodies of water (lakes, rivers) -Location of subsistence communities (floral and faunal) -Physical barriers (mountain ranges, canyons) -Formation processes (alluvial and colluvial)
Sampling Bias	-Recovery methods -Sample size (quantity) -Artifact type -Minimum specimen sample size required for analytical methods

Figure 2. Table adapted from Skinner (1983).

Lithic Analysis

Lithic analysis is the study of anthropogenic stone tools and the waste product (debitage) created during their manufacture. As Andrefsky (1994:1) points out, “chipped stone tools and debitage represent the most abundant form of artifacts found on prehistoric sites.” Since lithics constitute a significant portion of extant cultural material, archaeologists must be conversant in lithic analysis. Hence, lithic analysis seeks to link the tangible stone correlates of past human occupation with the behavior that created them. Lithic analysis involves the study of the manufacturing process of tools, use-wear, identification and classification, and sourcing of raw material, among other pursuits.

Because Archaic Period hunter-gatherer sites frequently lack perishable artifacts, and because the Archaic predates the advent of ceramics, lithic artifacts are often the only evidence archaeologists are able to use to elucidate prehistoric behavior. In fact, as Kamp and Whittaker (1999: 83) assert, “The study of lithic technology in the Southwest is itself only recently emerging from a stone age of neglect.” Since lithics constitute the bulk of data recovered at Archaic sites, researchers have developed many methods of lithic analysis in order to understand how humans lived and changed during that time. Indeed, in an effort to understand Archaic Period culture, archaeologists have performed a myriad of “investigations into strategies of raw material use, assemblage diversity, tool use-life, retooling, and tool design”(Amick and Carr 1996:42).

Traditionally, the majority of lithic analysis was macroscopic (i.e. visual) and included such techniques as identification and classification. More recently, lithic analysis has developed into a multi-tiered and highly specialized subfield of archaeology. Much recent research done in lithic analysis has been greatly enhanced by anthropological theory and sophisticated instrumental techniques. In order to answer complex questions about people that left little trace, archaeologists have adapted methods from many other disciplines.

I believe lithic analysis is most important when couched within questions concerning prehistoric human behavior. Such studies should not be undertaken as a means unto themselves. Only when lithic artifacts are approached in terms of their potential to shed light into cultural practices are such investigations worthwhile. The leap from lithic artifact to behavior is substantial when considering the complexity of technological organization, mobility patterns, trade, and discard practices and the effects of these factors on archaeological investigations.

Regionally, such factors are compounded by raw material geochemistry and the dynamic nature of northern Arizona geology, inhibiting behavioral inference. However, the capabilities of obsidian sourcing studies in the region are promising considering that, “San Francisco Volcanic Field obsidians exhibit little variability in trace element composition within individual sources, but relatively pronounced differences between sources” (Lesko 1989: 387). Several archaeologists (Shackley 1988, 1990, 1995, 2005; Skinner 1983, 2008; Hughes 1986) have established the importance of geochemical studies by applying these frameworks to anthropological questions.

However, “the anthropological problems on which obsidian source analysis has been focused remain surprisingly few, and consequently comparatively little of the potential of sourcing analysis has been realized” (Hughes 1986: 1). It was my plan to build upon the high-quality work already done by local researchers by adding resolution to the problem of prehistoric technological organization, lithic procurement choices, and mobility strategies in northern Arizona.

Geochemical Sourcing

The age-old archaeological method for determining type of stone is visual identification. While this method is effective in differentiating between different stone classes, i.e. gross petrographic classifications such as obsidian versus chert, it is problematic when identifying sources within a particular stone type. Visual analysis is unreliable and inaccurate due to material variability and relies heavily on the regional expertise of the archaeologist. Moreover, visual identification is a subjective process and thus resists replicability. To go beyond regional folk taxonomies, archaeologists must determine the chemical signature of specific rock outcrops if we hope to use raw material as an indication of mobility or changing procurement practices.

Geochemical techniques are used to determine the trace element composition of lithic artifacts. Trace elements provide the differentiating (unique) characteristics of a particular obsidian source. One of the primary purposes of geochemical analysis is to discover the provenance of stone used for stone tool manufacture. By matching the chemical signatures of artifacts to various raw material sources, the origin of the artifact can be determined. As Green (1993: 185) points out, “establishing points of origin for raw materials used in chipped stone artifact manufacture has been an archaeological concern since at least the mid-1800’s when Squier and Davis [1848] speculated on the source of Hopewellian obsidian.”

As noted, instrumental geochemical techniques often focus on trace elements, or those in concentration of less than 0.1% (Andrefsky 1998). Geochemical sourcing techniques identify the relative percentages of trace elements that are unique to each source. As Page (2008: 6) points out, “Comparison of element ratios across samples using both data tables and simple bivariate [XY scatter] plots provides distinction of various geochemical source groups.” According to Shackley (2005: 89), “Four major instrumental methods dominate the field today: INAA [neutron activation analysis], XRF [X-ray fluorescence spectrometry], PIXE-PIGME [proton induced X-ray emission – proton induced gamma ray emission], and ICP-MS [inductively couple plasma mass spectrometry]”. The current study employs XRF analysis (Figure 3).

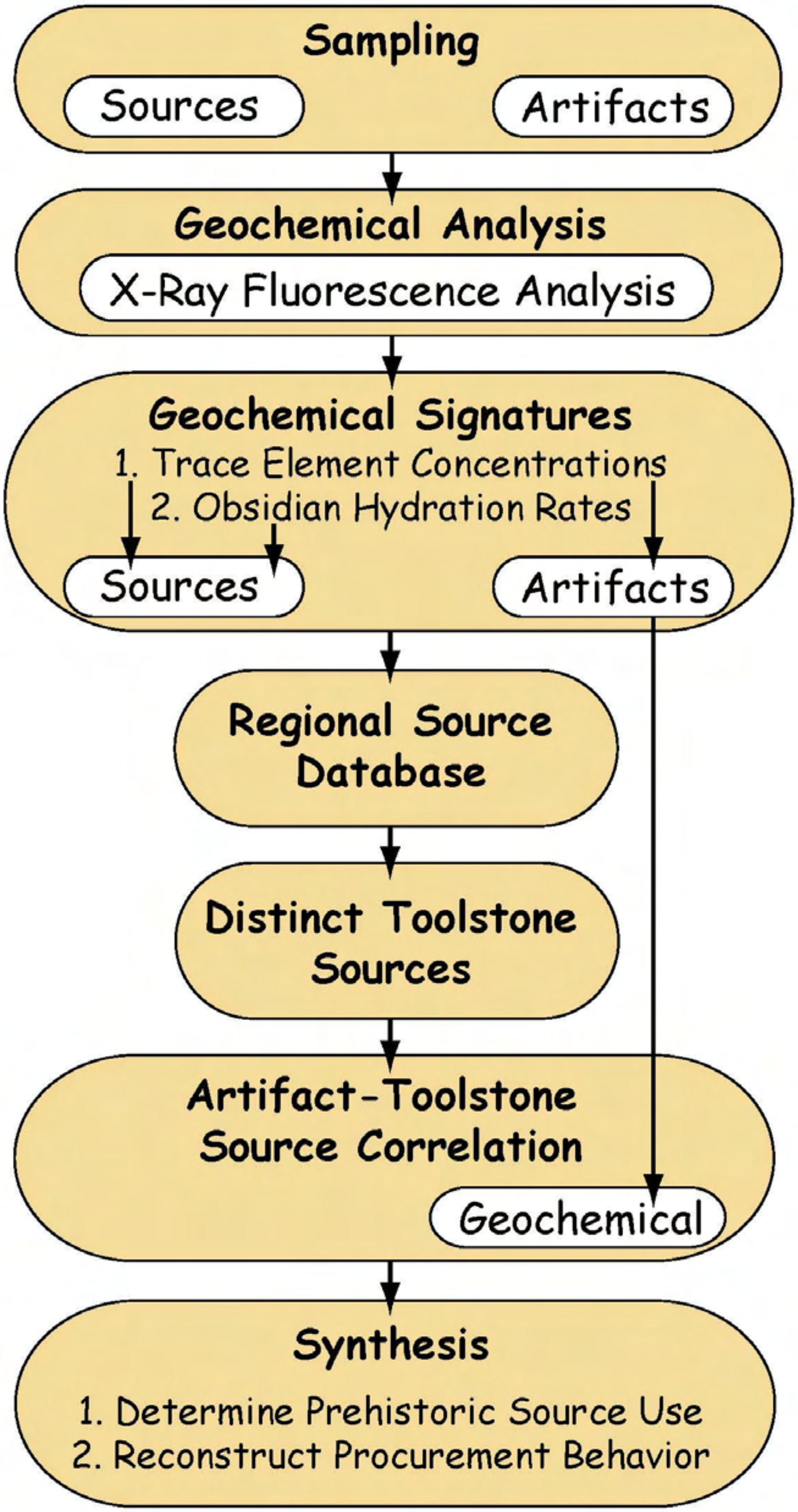


Figure 3. Flowchart showing geochemical analysis procedure. Adapted from Page (2008: 4).

Chapter Two: The Methods Behind the Material

In this chapter I describe the methods used to conduct the study. The chapter explains the source sampling survey used to establish new regional source standards. I then discuss X-ray fluorescence analysis and the application of the technique to the current projectile point assemblage. In addition, I present a pilot study testing the efficacy of visual sourcing of lithic raw materials.

Source Sampling Survey

I concentrated on understanding the correlation between the obsidian sources occurring in the San Francisco and Mt. Floyd volcanic fields in northern Arizona and Archaic Period diagnostic projectile points using geochemical sourcing techniques. While the San Francisco volcanic fields are well understood geologically (Robinson 1913, Bush 1986, Sanders 1981), additional work was needed to further develop a comprehensive chemical signature library of prehistoric obsidian quarry sites using XRF methods. I sampled both known prehistoric obsidian quarry sites as well as sources not known to be represented in the archaeological record, yet which bore toolstone-quality raw material. Ideally, this will not only serve as a control mechanism, but will also fill the gaps of data. In addition, these sources presented an option to Archaic Period hunter-gatherers regardless of whether or not such sources were actually used. Moreover, as there are over 40 “distinct artifact-quality obsidian sources” (Shackley 2005: 18) located across the Southwest, a clearer understanding of regionally-specific raw material use can be attained. A study of this type can add resolution to the body of knowledge concerning local hunter-gatherer adaptations as they reflect broader prehistoric mobility patterns.

The first portion of the study consisted of developing a comparative chemical signature library, or source standards, for the region (Appendix C). To accomplish this, I conducted a baseline obsidian source survey, as this has not been done recently or comprehensively in northern Arizona. While many people have conducted geochemical research in northern Arizona, including Schreiber and Breed (1971), Jack (1971), Findlow (1981), Cartledge (1985), Sanders (1981), Bush (1986), Lesko (1988), and Shackley (1986,1990,1995,2005), previous efforts were performed ad hoc under a myriad of research questions, different instrumentation, various analytical techniques, and invariably focused on only certain sources at a time. Each of the aforementioned people operated under specific research questions and contributed vital geographic and geologic information as well as material descriptions of northern Arizona obsidians used in the present study. Shackley (2005: 100) provides a useful explanation of current obsidian sourcing methodology that I attempted to follow. Shackley lists seven basic standards to ensure unbiased and representative results:

> “1. A thorough geological background search just as an archaeologist would perform a record and literature search before working in a new area…
> 2. Mapping and description of samples taken along transects from the entire area where artifact-quality obsidian occurs…
> 3. Where appropriate, determination of the limit of the secondary distribution of the raw material…
> 4. Analyzation of the proper number of samples…
> 5. Analytical sampling…
> 6. Reporting the data in a manner that is easy to interpret…
> 7. Assuring that all source standard analyses are reported regularly and shared freely…”

During this phase, I visited thirteen discrete obsidian sources in order to draw a sample “sufficiently large and physically widespread to contain the full range of internal, or intra-source variation” (Jarvis 1988:3). For the current study, this process entailed gathering samples ranging between 19-44 individual specimens from each source (Figure 4). A lithic source is defined as “a trace element group in close geographical and chemical proximity” (Shackley 1986: 3). The sourcing survey was opportunistic in nature yet every effort was made to collect from all available outcrops and secondary (erosional or alluvial) contexts yielding raw material. In addition, I attempted to minimize bias by “grab sampling” a sufficient number of individual nodules as to incorporate a wide variety of visually distinctive samples. In other words, I chose samples irrespective of idiosyncratic notions of workability, preferences of color or texture, or absence or presence of inclusions such as phenocrysts. I thought in order to draw inferences regarding mobility and procurement I must ensure the sampling strategy encompassed a representative sample, I believe I accomplished this. I also thought a sampling strategy capable of delineating between secondary and primary sources was important, in this my success was questionable due to the variation between sources. While not entirely systematic in nature, I believe the source sampling survey was representative and conformed to currently accepted standards of regional source surveys (Skinner, personal communication 2007).

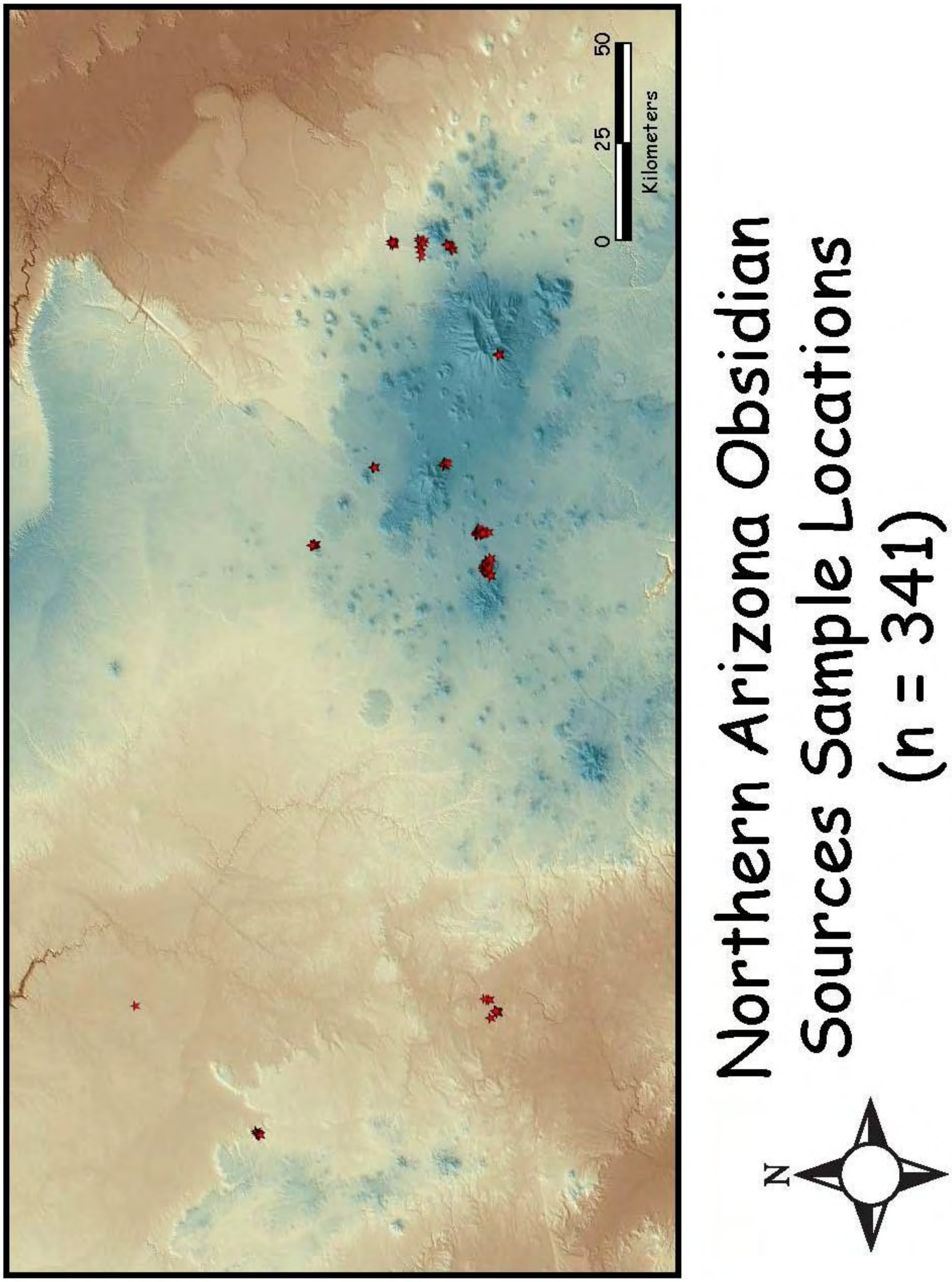


Figure 4. Map showing locations of source sampling survey.

X- Ray Fluorescence Analysis

Once I completed the source survey, I sent the samples (n=358) to Craig Skinner at Northwest Research Obsidian Studies Laboratory for X-Ray Fluorescence Spectrometry (XRF) analysis. Mr. Skinner performed XRF on all of the samples acquired from sources in the region. These included: Black Tank, Partridge Creek, Presley Wash, Sitgreaves Mountain, Robinson Crater, O'Leary Peak, RS Hill, Deadman's Mesa, Ebert Mountain, Government Mountain, Kendrick Peak, Slate Mountain, and San Francisco Peaks sources (Figure 5). Surprisingly, XRF analysis showed two sources (Presley Wash and Black Tank) carried two distinguishable geochemical signatures. Both sources produced an obsidian and a fine-grained volcanic material (FGV). In addition, it was determined that two distinct sources occur within the San Francisco Peaks, one of which was previously known. Also, the O'Leary Peak and Robinson Crater sources display more variability than formerly understood. These sources comprise the northern Arizona source standard library. The trace element concentrations, characteristic ratios, and collection locations are listed for all samples in Appendix C. This source standard library allows for quick reference and easy comparison for future archaeologists wishing to determine artifact "fingerprints". XRF has become a widely used instrumental technique for recognizing the unique chemical composition of many archaeological materials, including obsidian. The XRF analysis presented here contains data on all known obsidian and FGV sources in the Flagstaff area.

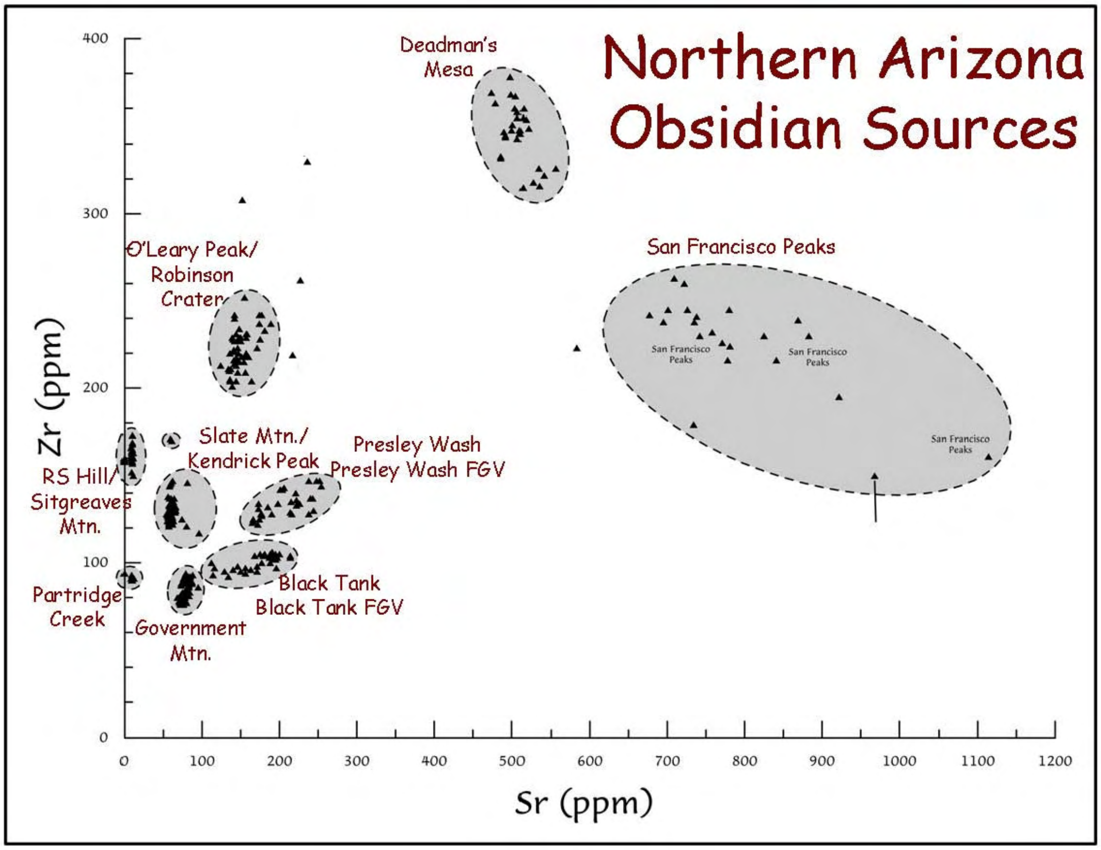


Figure 5. Scatterplot showing zirconium (Zr) and strontium (Sr) parts per million ratios of the sources included in the study. Note absence of Ebert Mountain, located behind O'Leary Peak/Robinson Crater.

During XRF, the artifact or obsidian sample is irradiated with X rays that elicit the emitance of fluorescent x rays consisting of wavelengths characteristic of the trace elements present in the specimen. Thus, the wavelength of the fluorescent radiation provides a qualitative indication of specific elements present while the relative intensity of each wavelength provides the quantitative measure of each trace element (Shackley 2005). Richard Hughes (1986: 22) describes the benefits of XRF analysis over alternate techniques when he writes, “1) it requires no special sample preparation 2) it is completely nondestructive 3) analysis of certain trace element concentrations can be completed in only a few minutes; and 4) data generated for significant trace elements are sufficiently precise to use in quantitative comparisons between laboratories.”

The next step in determining source and then applying the data to the question of Archaic mobility and procurement strategies was testing the artifacts themselves (Figure 6). The artifacts, recovered from the Coconino Plateau in the general area of Flagstaff, consisted of diagnostics (n=273). Smiley (1995: 28), defines projectile points as “completed triangular or subtriangular bifaces judged small enough to serve as points for a compound, hafted projectile such as a spear, dart, or arrow.” Archaic Period hunter-gatherers used projectile points for hunting animals with atlatl technology. Thus, point morphology reflects use as hafted hunting implements. Flenniken and Wilke (1989: 151) provide the following list as essential elements of projectile points:

> an acute tip to ensure quick and easy penetration of the hide of the prey animal; long, sharp lateral cutting edges to open a deep wound with a minimum of projectile energy loss; a broad blade to create a large wound channel; barbs to keep the point and foreshaft in the wound and actually cause it to penetrate deeper as the animal attempted to escape; and notches, which resulted from the formation of the barbs and constituted a potential fracture zone near the base of the point.

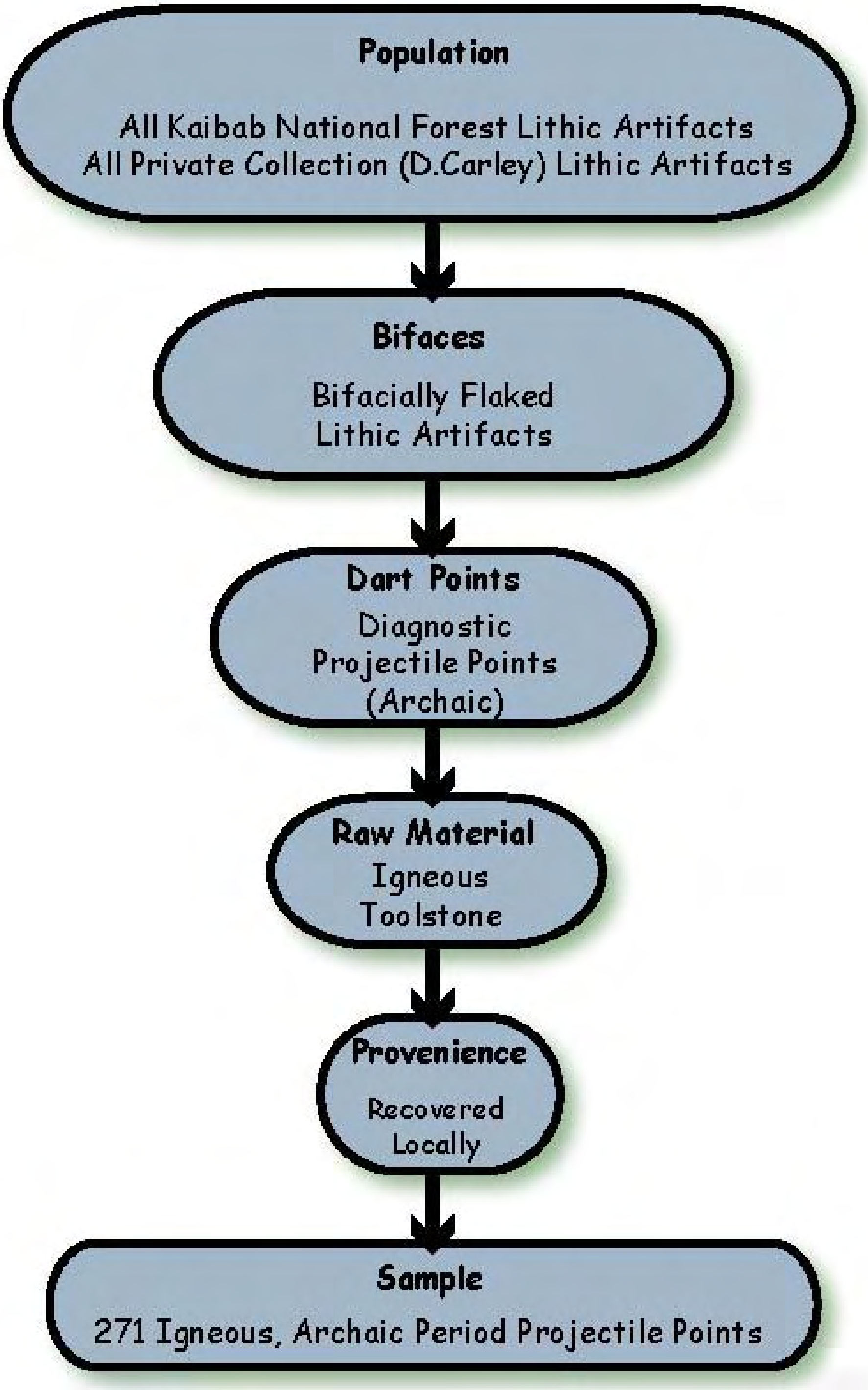


Figure 6. Flowchart showing criteria for selecting artifacts in this study. Adapted from Lyndon (2005: 33).

The assemblage contained surface points from Kaibab National Forest, Coconino National Forest, Partridge Creek Drainage near Ashfork, Arizona, areas north and west of the Coconino National Forest, and the Little Colorado River Watershed. All were subjected to the same XRF analysis as were the source samples. In addition, because the same spectrometer was used, inter-instrument error was virtually eliminated. Subsequently, the artifact characterizations were compared to the chemical signatures of sampled sources. The chemical signature library serves as the basis with which prehistoric artifacts can be compared to in order to verify their origin. As Jarvis (1995: 7) states, “Once a pattern, a sort of chemical blueprint, is established, theoretically the chemical composition of an artifact will clearly match its source outcrop and no other.”

Therefore, within the research area, both the chemical signatures of available raw material were determined and the artifacts found within the region have known points of origin (Appendix D). Thus, the previous discussion describes the baseline for my study. I then set out to develop a model of Archaic Period mobility and procurement practices based on spatial distribution of diagnostic projectile points and by synthesizing the geochemical data with theoretical models of hunter-gatherer technological organization, mobility, and subsistence patterns. Furthermore, the baseline survey served as an introduction to the vast diversity of northern Arizona toolstone sources. As Dibble (1991: 33) states, “archaeologists’ traditional concerns in explaining assemblage variability, are only visible once we are able to control for the effects of more fundamental factors like raw material variability.”

Eyeballin’ It: Visual (Macroscopic) Vs. Geochemical Sourcing

Establishing the geographic origin of lithic materials found in archaeological contexts is an essential step in understanding prehistoric mobility patterns, trade networks, and social complexity. A lithic artifact passes through many stages of manufacture, curation, rejuvenation, and use before ultimately being discarded or lost. When determining the geologic origin of a tool or flake scatter relative to the recovery location, archaeologists take a crucial step towards recreating prehistoric technological organization.

The ability to identify lithic raw material accurately and consistently using macroscopic methods remains of great importance to archaeologists. Not only is visual identification the quickest way of classification, the method also becomes necessary when time constraints and budget limitations preclude the use of microscopic, petrologic, or chemical characterization. In a perfect world, archaeologists could simply examine a lithic assemblage and quickly determine the geographic origins of the tools or debitage. Unfortunately, the complexity of stone geologic formation and erosion processes often makes it difficult to correctly identify source material through visual means alone. As Luedtke (1992: 63) reminds us, “Many of these identifications are surely correct, but others are wrong and there are few ways to be certain which is which.”

Compounding the problem of intra and intersource variation (and similarities) is the historic tendency for archaeologists to assign regional folk taxonomies to local lithic sources. Vernacular classification systems often result in typological inconsistencies, hindering discourse between archaeologists. Although a great many researchers display incredible skill in visual identification, examples of provincial nomenclature abound in the archaeological literature. Smiley (1995: 17) describes the problem:

> Much of the difficulty between investigators in archaeological analyses stems from the failure to explicitly define and assign meaning to analytical categories. In an almost infinite loop, investigators frequently fail to successfully create and communicate replicable, useful typologies.

During the last thirty years, archaeologists have increasingly recognized the need to apply geochemical characterization methods to archaeological problems. In an effort to standardize and legitimize raw material identification, archaeologists now use quantitative methods to ascertain artifact sources. Many geochemical techniques provide ways to empirically assign lithic artifacts to a geologic source. While some raw materials display more visual variability than others do, archaeologist's now prefer to err on the side of caution and employ geochemical characterization methods when possible. Indeed, as Shackley (2005: 105) points out, "the cost of XRF analyses of obsidian is so low, compared to other archaeometric techniques, that decisions to skip it seem hazardous at best."

Basis for Pilot Study Experiment

Macroscopic techniques remain the most common procedure for raw material identification for the reasons stated above. However, certain materials are more conducive to such techniques while others resist geochemical "fingerprinting". For instance, chert generally exhibits a great deal of variability in regards to texture, color, fabric, and inclusions within a single source, as can fine-grained volcanics such as dacite, rhyolite, and basalt, making visual identification tenuous. Moreover, chert presents additional problems because individual formations can display significant geochemical variability within a source, owing to the sedimentary origins of chert. In addition, “valid chert types from different formations can be visually identical” (Luedtke 1979: 745).

Similarly, archaeologists frequently experience varying degrees of success when distinguishing obsidian based on visual properties, though individual abilities and experience seem to play a large role. For example, Shackley (2005) describes an experiment designed to test visual identification against geochemical assignments using obsidian recovered from Late period Zuni contexts. As the premier archaeologist working with obsidian, one would expect good results. However, Shackley (2005: 104) admits, “we could not distinguish obsidian procured from Valle Grande in northern New Mexico from Cow Canyon in eastern Arizona, sources not only hundreds of kilometers distant, but in opposite directions from Zuni.”

A local example of experimentation with visual source identification appeared in a 1989 *Kiva* article. Lesko (1989: 387-396) presented the results of a pilot study conducted with hopes of determining the reliability of visual sourcing of northern Arizona obsidians. Lesko carried out an experiment comparing macroscopic methods with geochemical techniques and relied on Bettinger et al. 1984. Lesko found that results varied depending on source, however, overall, the Kaibab National Forest archaeologists participating in the study produced 65-90% percent accuracy in visual identification (Lesko 1989: 388-392).

Macroscopic Identification Experiment

My goal was to facilitate a replicable, empirical method of raw material identification in northern Arizona by testing Lesko's results. To do so, I conducted a similar experiment, but instead enlisted a group of non-experts to participate. Lesko's test population consisted of four experts in regional archaeology and lithic analysis. While this approach certainly produced favorable results, it did little to assist the general archaeological community lacking the proclivities of the test group. Instead, I carried out the experiment with the assistance of a graduate-level lithics class conversant, yet not expert, in local archaeology and lithic identification.

The guidelines and parameters for the experiment are as follows:

1) Labeled samples in nodule form bearing identification from each source, except San Francisco Mountain, (n=12) were distributed and examined by the each participant.

2) Unlabeled boxes of debitage along with stone tools (n = 28) manufactured by the author were circulated with a corresponding identification list. A hardcopy key of close-up photographs of the source material was provided to each individual. A single box containing labeled source nodules was made available.

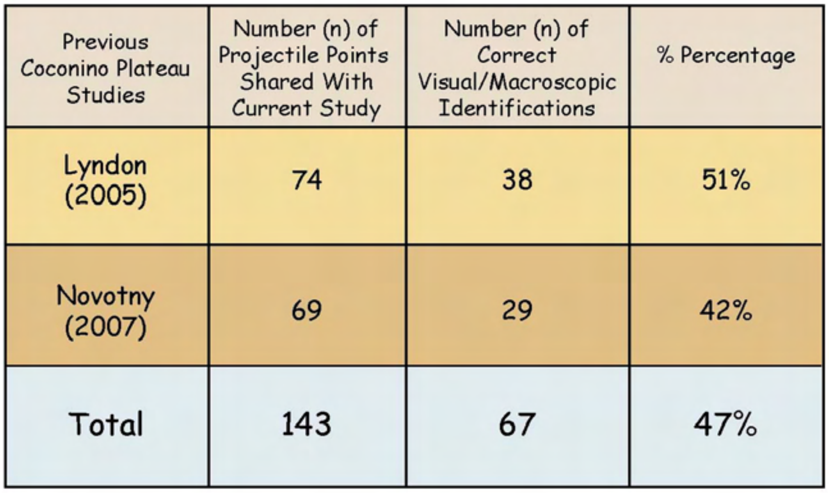
3) Results were evaluated using a nominal scale, where mutual exclusivity eliminated ambiguity. Only one source could be chosen.

I wanted to determine whether individuals could correctly identify discreet obsidian and fine-grained volcanic sources visually without the benefit of substantial personal experience. In addition, I hoped to find out whether the results were replicable and whether a user-friendly and intuitive system could be created to assist archaeologists in macroscopic identification.

Although highly variable depending on source material, participants were generally successful in visually identifying northern Arizona igneous toolstone sources within the parameters of the experiment. Correct identifications, listed in percentages, are as follows: Government Mountain (69% success rate), Partridge Creek (76%), Presley Wash (80%), Sitgreaves Mountain (68%), RS Hill (49%), Kendrick Peak (54%), Slate Mountain (80%), Ebert Mountain (80%), Robinson Crater (64%), O'Leary Peak (84%), Deadman's Mesa (52%), Black Tank (68%). The most difficult materials to differentiate, according to the participants, were the numerous fine-grained volcanics (FGV's). In fact, if not for the more distinguishable obsidians included in the Presley Wash and Black Tank experiment groups, the success rate percentage for each would have been much less favorable.

The results were promising. Given sufficient visual aids, archaeologists unfamiliar with certain toolstone varieties performed capably and achieved positive results. Although very small in scope (28 identifications), the results compare favorably with similar experiments performed by other researchers (Lesko 1989, Shackley 2005). However, misclassification is common and every effort should be made to minimize the potential for mistakes.

For example, archaeologists (Lyndon 2005, Novotny 2007) recently completed valuable thesis projects on the Coconino Plateau focusing on various research problems. A small portion of each study concentrated on raw material identifications. Lacking resources and avenues to pursue XRF analysis, both relied on visual identification of the source material used to manufacture the artifacts in their studies. While impossible to gauge each researcher's success with sedimentary rock identifications, the present study used many of the same igneous projectile points from the Kaibab National Forest as were used in the two previous studies. Therefore, with the chemical signatures of the projectile points now available, I tested the results against the visual identifications. Of the 143 projectile points shared between the current and previous studies, 67 (47%) proved to have been correctly identified using macroscopic methods alone (Figure 7).



Previous Coconino Plateau Studies	Number (n) of Projectile Points Shared With Current Study	Number (n) of Correct Visual/Macroscopic Identifications	% Percentage
Lyndon (2005)	74	38	51%
Novotny (2007)	69	29	42%
Total	143	67	47%

Figure 7. Results of the comparison between visual and geochemical identification.

However, important to note here is a recent example of a successful visual sourcing experiment. Working in the Maya region and testing results against geochemical characterizations, Braswell et al. (2000: 271) found "visual sourcing to yield generally consistent and reliable results…[with] accuracy rates upwards of 95 percent". The five authors developed categories based on visual criteria including refracted color, reflected color, the degree refracted color was diffused, degree of translucency and opacity, presence, frequency, size and color of inclusions, texture and luster, and color, texture and thickness of cortex (Braswell et al. 2000: 270-271). Archaeologists aiming to employ visual sourcing in northern Arizona need a coordinated effort, such as the one used in Guatemala, if such techniques are to be relied upon.

Chapter Three: The People and the Place

Chapter Three focuses on the environmental and cultural background of the research area. Because archaeology is a multidisciplinary science, topics covered in this chapter include geography, geology, ecology as well as several facets of archaeological theory. I discuss these subjects in order to present the parameters of life during the Archaic Period and to obtain a contextual understanding of lithic raw material use during this time in northern Arizona.

Geography and Environment

The Coconino Plateau (Figure 8) consists of approximately 9,300 square miles of arid land bounded on the north by the Grand Canyon and on the south by the Mogollon Rim and the Verde River drainage. On the west, the Coconino Plateau extends to the Aubrey Cliffs. On the east, the landform extends to the Little Colorado Drainage (Lyndon 2005: 15). The Coconino Plateau makes up the southwestern-most portion of the Colorado Plateau, a geographic region covering roughly 130,000 square miles of canyons, plains, mesas, and buttes (Bezy 2003: 11). The Coconino Plateau supports an evergreen woodland dominated by two cold-adapted coniferous trees, the juniper (*Juniperus*) and pinyon (*Pinus edulis*). As Brown (1982: 52) points out, "structurally, these juniper-pinyon woodlands are among the simplest communities in the Southwest."

Figure 8. The Coconino Plateau and San Francisco Peaks.

The Coconino Plateau conifer supports antelope, elk, two species of lagomorphs, fox, skunk, and porcupine, among others. Annual precipitation of the Coconino Plateau ranges between 14 to 18 inches (Tueller and Clark 1975: 34).

> Precipitation on the plateau is chiefly controlled by the interaction of two high pressure systems, the Bermuda High off the East Coast of the U.S. and the Eastern Pacific High off the West Coast (Hastings and Turner, 1980). Summer precipitation is produced by warm moist air generated by the Bermuda High, which creates northerly airflow patterns from both the Gulf of Mexico and the Gulf of California, creating a "summer monsoon"… Winter precipitation is produced by the passage of the Eastern Pacific High across the Plateau. [Patton et al. 1991: 374]

Winter precipitation often occurs as snowfall and constitutes nearly half of the regional annual precipitation. Winter storms are generally less intense and dispersed while summer storms are often violent and localized. Similar to contemporary indigenous populations of the region, the lives of prehistoric peoples were significantly affected by fluctuations in annual precipitation patterns.

Despite its placement within the arid Southwest, the Coconino Plateau experiences four seasons due to the increased altitude. Such conditions greatly affect the biotic communities it supports and provides a respite from the intense heat of more southerly environs. The San Francisco Peaks are the most highly conspicuous landform located on the Coconino Plateau, visible from the north for more than 120 miles and roughly fifty miles from the south. Because climate in the Southwest is influenced largely by altitude, the San Francisco Peaks contain an even greater number of different ecological zones and vegetation types than does the surrounding plateau. Conversely, the Coconino Plateau exhibits relatively little topographic relief compared to the Peaks, and thus is dominated primarily by pinyon and juniper forests (Figure 9).

Roughly five square miles of land comprising the San Francisco Peaks lie above timberline, beginning at roughly 3,500 meters and extending to the summit of Humphrey's Peak at 4,142 meters (Pase, 1982:30). Vegetation is rare in the high altitude zone but does include Gooseberry Currant (*Ribes montigenum*) and Bearberry Honeysuckle (*Lonicera involucrate*) (Pase, 1982: 31) as well as a few species of medicinal plants (Christian Downum, personal communication 2008). In addition, only two vertebrate species inhabit (breed) the San Francisco Peaks alpine tundra, the Water Pipit and the Deer Mouse (*Peromyscus maniculatus).* The paucity of subsistence resources located near the Peaks source precludes its casual or incidental exploitation. Indeed, the obsidian from the Agassiz/Fremont source encountered in archaeological context may suggest that the procurement of the toolstone was a primary reason for the trip.

Throughout the year one can expect a temperature gradient between areas south of the Mogollon Rim to the Flagstaff area ranging between 10 and 30 degrees Fahrenheit. In addition, the temperature at the summit of Mt. Humphreys oscillates between 20 and 40 degrees lower than Flagstaff itself. Thus, not uncommonly, the temperature in Camp Verde could be 60 degrees warmer than the high elevations of the Peaks, a distance of about 70 miles. The diverse seasonality of the plateau distinguishes the region from adjacent areas and presumably had appreciable effects on Archaic Period mobility strategies and ranges.

Ecotones

Many archaeologists recognize the close correlation between prehistoric settlement patterns, mobility strategies, and ecotonal environments. Odum (1959: 278) defines the term:

> An ecotone is a transition between two or more diverse communities as, for example, between forest and grassland or soft bottom or hard bottom marine community. It is a junction zone or tension belt which may have considerable linear extent but is narrower than the adjoining community areas themselves. The ecotonal community commonly contains many of the organisms of each of the overlapping communities and, in addition, organisms which are characteristic of and often restricted to the ecotone. Often, both the number of species and the population density of some of the species are greater in the ecotone than in the communities flanking it.

Thus, some researchers agree that the increased diversity in potential food resources located within ecotonal environments attracted prehistoric peoples. Because ecological communities result largely from changes in topography in the study area, presumably many such ecotonal situations exist in the highly mountainous region of northern Arizona. Localized areas exhibiting high topographic variation may have been attractive areas to forage for hunter-gatherers. Archaic Period populations presumably encountered a greater variety of food resources on the Coconino Plateau than in adjacent areas of the same geographic size. Moreover, the presence of such landforms as the Grand Canyon, the San Francisco Peaks, Oak Creek Canyon, and the Central Arizona ecotone (Mogollon Rim) likely represented a geographic region exhibiting great floristic diversity and hunting opportunities for Archaic bands in the area. The question of whether the ecotone effect resulted in smaller foraging ranges within the study area compared to adjacent regions awaits further study.

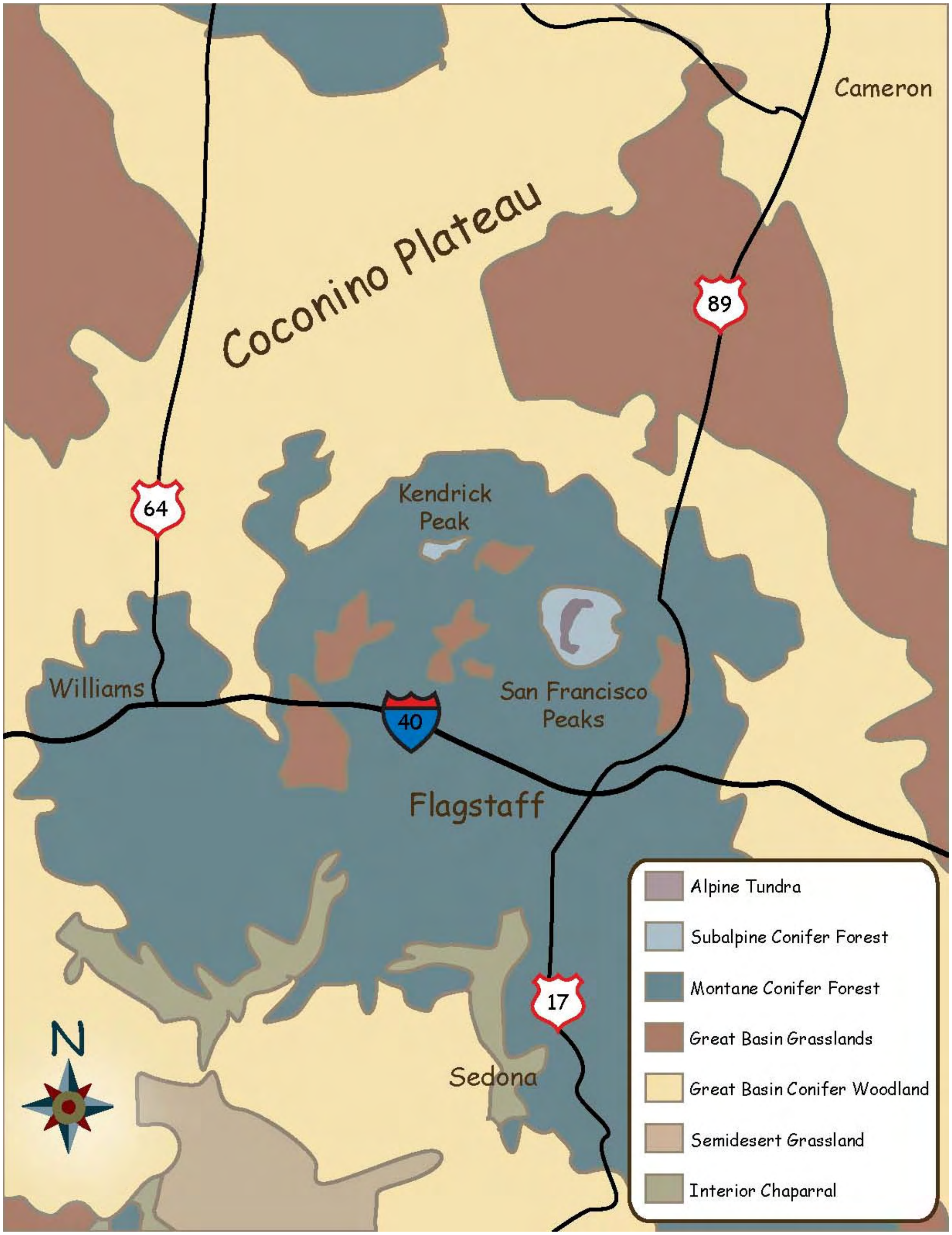


Figure 9. Map showing biotic communities of the study area. Adapted from Brown (1994).

Geology

The Southwest is a geologically complex region and in order to successfully exploit lithic raw material, prehistoric inhabitants identified “parent rocks and minerals to effectively trace and predict the location and depth of new sources of raw material. Native peoples of the Southwest exploited a considerable number of rocks and minerals for use” (Justice 2002: 26). Indeed, besides the widespread exploitation of igneous toolstone sources, indigenous populations throughout prehistory used virtually every lithic type available in the area. Sedimentary lithic materials used by prehistoric groups include Red Butte and Kaibab cherts, various jaspers, and chalcedony (Novotny 2007: 96-98).

The extinct volcanic mountain making up the San Francisco Peaks consists of five separate summits, the highest being Mt. Humphrey’s, which rises to 4,142 meters (12,633 feet). The Peaks, formed during the Quaternary epoch as volcanoes, are relatively young geologically. The Peaks lie within the San Francisco Volcanic Field, an area covering roughly 1,800 square miles. The eruptions began in the western part of the study area and migrated northeasterly over time (Bezy 2003: 15). More than six hundred individual volcanoes rise from the volcanic field, although relatively few produce artifact-quality toolstone. Together with the Mount Floyd Volcanic Field located to the west, the region contains thirteen known sources of obsidian and fine-grained volcanic material (andesites, basalts, dacites, and rhyolites) that were exploited differentially throughout prehistory by indigenous peoples. The toolstone sources are the result of certain magmas reaching the earth’s surface. According to

Bazy (2003: 15), “the magma appears to have broken through to the surface at vents aligned along preexisting cracks”.

Volcanism in northern Arizona began roughly 6 million years ago. The volcanoes developed due to the creation of faults resulting from the stretching, thinning, and breaking of crustal rocks across western North America (Bezy 2003: 12). Movement along the faults in the area allowed molten rock to flow onto the surface as lava flows. In addition to the flows, numerous other volcanic features sprang up over the course of millions of years, culminating in the eruption of Sunset Crater nearly 950 years ago (Abbott and Cook 2007: 149). According to Elson et al. (2002: 122) Sunset Crater, “produced the only eruption in the Southwest United States indisputably witnessed by surrounding prehistoric populations.”

Consequently, the numerous volcanic episodes in the region produced discrete deposits of obsidian, each with a unique chemical signature comprised of distinctive combinations of trace elements. The volcanic peaks, cones, and flows are underlain by Kaibab limestone bedrock (Lesko 1989: 385) and are the source of the thirteen obsidian sources considered in this study. Underlying the Kaibab limestone formation are numerous other strata comprising the multicolored layers visible in the Grand Canyon.

The San Francisco Peaks are the eroded remnants of an enormous stratovolcano that erupted between 1.8 and 0.4 million years ago (Lucchitta 2001: 116). Bezy (2003: 18) explains, “unlike most of the other volcanoes of the area, this cone is a combination of cinder and ash layers, lava flows, domes of highly viscous lava, and rock-filled conduits.” Thus, stratovolcanos such as San Francisco Mountain are composite volcanoes made up of lavas lower in silica content than other igneous rock. Because silica content determines workability in lithic raw material, (higher silica = better toolstone), the paucity of artifacts apparently manufactured from the Peaks material in the area is understandable. Yet, the variability of volcanic episodes and remnants of different types of volcanoes occurring in the northern Arizona volcanic fields allow for the presence of rare obsidians sufficiently high in silica content for use as toolstone (Figure 10).

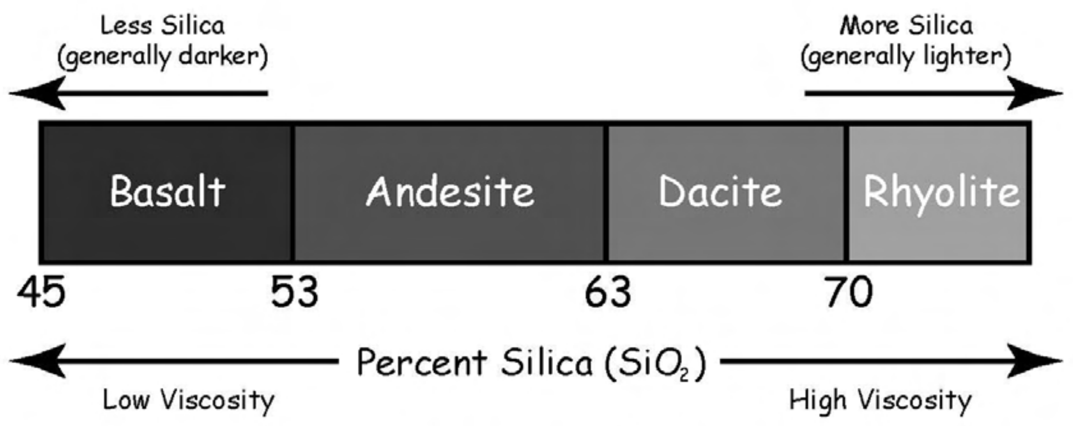


Figure 10. Diagram showing silica content of various fine-grained volcanics (FGV's). Adapted from Abbott and Cook (2007: 153).

Cinder cones are often the most common features in volcanic fields (Lucchitta 2001: 114) and such is the case in northern Arizona. The cinder cones of the San Francisco and Mt. Floyd volcanic fields are recent and thus “have not been significantly altered by weathering and erosion and appear as if they formed yesterday” (Bezy 2003: 23). Cinder cones form during eruptions when magma is expelled into the air and solidifies in flight. The magma pieces then fall around the vent from which they were ejected, forming a circular mound surrounding a crater.

Based on digital elevation modeling, researchers determined the visibility of the eruption of one such cinder cone, Sunset Crater. Elson et al. (2002: 122) assert, “on a clear day the ash plume could have been seen from high points near Palm Springs (California), Las Vegas (Nevada), Durango (Colorado)…and along the Arizona-Mexico border.”

Volcanic lava domes occur in two distinct fashions. The first happens when many cinder cones erupt in a localized area over millions of years. The second way lava domes occur is when “semi-solid, molten rock that is too viscous to spread out extrudes onto the land surface” (Bezy 2003: 17). Examples of lava domes bearing artifact-quality obsidian in the region are Round Mountain (Presley Wash-Partridge Creek), O’Leary Peak, and Sitgreaves Mountain. Alternatively, Government Mountain, Slate Mountain, and RS Hill represent cinder cones producing obsidian. These obsidian sources occur in secondary settings such as the stream deposits of Presley Wash and Partridge Creek, and primary settings such as the bedrock outcrops of Government Mountain and RS Hill. The obsidian sources considered in this study lie on land managed by the Kaibab and Coconino National Forests as well as state lands (Figure 11).

Figure 11. Government Mountain, a cinder cone, in the foreground and Sitgreaves Mountain, a composite lava dome, in the background.

The San Francisco Peaks have served an essential purpose for native populations in the Southwest for thousands of years, including serving as a source of high-quality lithic raw material, edible resources, and as a center of religious importance, among other uses. Perhaps due to the far-ranging visibility of the Peaks, the mountain is considered sacred by at least 13 modern Native American groups, including the Navajo and Hopi. In fact, today the Peaks are considered a traditional cultural property due to their central role in maintaining Native American traditional practices, including the gathering of wild plants and religious ceremonies. Evidence suggests occupational continuity from the Archaic Period until the present.

The Archaic Period

Before progressing any further, a discussion of the Archaic Period in North America is warranted. The Archaic Period was not only a North American phenomenon, but also a worldwide adaptation to Post-Pleistocene environmental change. The end of the Pleistocene brought about a drastic environmental change resulting in the large-scale extinction of several species of megafauna. Animals such as mammoth, mastodon, saber-toothed cat, and dire wolf all died out across North America. Accordingly, the Paleoindian Period Clovis peoples who presumably relied heavily on big game hunting during the Pleistocene were forced to adapt to the new climate no longer supporting these species. Because of the decrease in animal size, and therefore a decrease in edible faunal biomass, prehistoric Native Americans began to rely increasingly on plant foods for survival. As Reid and Whittlesey (1997: 43) assert, “Plant food gathering, so conspicuous in the seed-milling stones of the archaeological record, was the essential component of the Archaic economy.”

The Archaic is thus both a period and a lifeway, one in which displayed increased diversity and less specialization than that of the Paleoindian Period. As Walthall (1998: 232) asserts, “while migratory species were a focus of Paleoindian subsistence… early Holocene groups hunted a range of nonmigratory animals.” While it is undoubtedly true that Archaic Period hunter-gatherers practiced a more broad-spectrum subsistence strategy than did the Paleoindians, increasing evidence suggests a more generalist strategy for Paleoindian groups. Recent research includes evidence of significant plant and small mammal exploitation (Hill 2007, Kitchel 2008, Kuehn 1998) by Paleoindian populations. Such evidence is beginning to change the way we look at the Paleoindian Period. Indeed, Paleoindian culture likely exhibited comparable levels of diversity and variation as did the later Archaic Period. Still, Paleoindians certainly practiced extensive, year-round mobility similar to Archaic populations. Degree of mobility, however, likely changed gradually between the two periods. As Jones et al. (2003: 5) state, “changes in mobility appear to coincide with the changing climatic conditions and biotic reorganization during the early Holocene."

The difference between the Archaic Period and the Paleoindian Period in terms of breadth and scope of archaeological research is vast. The Paleoindian Period has often garnered considerably more attention from archaeologists due to questions surrounding the peopling of the New World. The debate over how, when, and why people first came to the Americas is a contentious one and is frequently fueled by politically charged rhetoric. The issue of "who came first" has profound implications for both contemporary Native American groups and religious organizations. This tends to catapult Paleoindian archaeology into popular culture, as indicated by the preponderance of television shows and magazine articles consumed and propagated by non-specialists. While I intend no indictment of the current situation (because certainly archaeologists confronting Paleoindian archaeology contribute enormously to our understanding of the past), therein lies a chasm in the archaeological literature.

As discussed further below, Archaic Period culture was organized into band level societies. Bands are typically comprised of less than 50 individuals who reside in temporary camps (Renfrew and Bahn 1996: 167). Temporary camps occupied by hunter-gathers undoubtedly occurred very sporadically across the landscape. Because of the low population density during the Archaic, camps at any given time were few and far between and consisted of both open-air sites and cave shelters (Walthall 1998). Archaic populations had no social differentiation or hierarchy, so the rare burials from the period are usually not endowed with rich grave goods (Plog 1997: 117). At different times throughout the year, and depending on availability of resources, Archaic bands coalesced to form macrobands (Anderson and Hanson 1988). Macrobands gathered in strategic locations and were made up of a constantly changing amalgamation of individuals and groups. Membership in either the band or macroband was fluid so change was probably frequent. Furthermore, this fluidity probably discouraged overt territorialism or “land skirmishes”.

During the Archaic Period across the North American continent, a tool industry developed which favored large side-notched, corner-notched, and stemmed projectile points. This lithic tool technology was adapted for use with the atlatl and dart as the bow and arrow had yet to be incorporated. Gone were the days when “Clovis style” points extended from coast to coast. In place of the ubiquitous and far-ranging “Clovis style” points, regional variants with smaller geographic distributions became common. The regional variation apparent in Archaic stone tool assemblages has led many archaeologists to propose a smaller, more specialized territorial range.

The Archaic Period Southwest

The Archaic Period in the Southwest spans several thousands of years. Various researchers have assigned an assortment of date ranges to the Archaic including 9,000 B.C. to 300 A.D. (Reid and Whittlesey 1997: 42), 5,500 B.C. to A.D. 100 (Cordell 1984: 153) and 8,000 B.C. to 1 A.D. (Fish and Fish 1977: 11). It is perhaps indicative of the general lack of knowledge about the Archaic that the disparity in dates is so large. However, recent publications of chronometric research on Black Mesa in northeastern Arizona provide increased resolution to the dating problem. Smiley (2002: 30) designates 9000 B.P. as the beginning of the Early Archaic Period, while the Middle Archaic lies between 6000 B.P. and 4000 B.P.

Lyndon (2005) built upon this research to establish the chronology for the Coconino Plateau discussed below.

The Archaic Period in the Southwest is underrepresented in the regional literature due to the paucity of data and previous researcher's emphasis on Basketmaker and Pueblo Periods. While this relative inattention is understandable considering the archaeological richness of these later periods, the problem still remains that relatively little is known about the Archaic in the Southwest. Moreover, the methods for studying later periods are often ineffectual when applied to Archaic populations due to lack of ethnographic analogies and relative deficiencies in artifact assemblages.

As mentioned above, the dates used for this period vary widely between researchers due to the immense time-depth of the Archaic Period in the Southwest. For this study I will use the dates most commonly cited for the Coconino Plateau (Lyndon 2005:58). The dates for the Archaic used in this study are 9000 BP- 2400 BP. The archaeological evidence for Archaic occupation in the Southwest is slight. The lack of knowledge stems from low site density and low artifact counts associated with them. Despite the shortage of known sites, many things are known about the Southwest Archaic. Across the region, (defined roughly as the area of land between Las Vegas, Nevada and Las Vegas, New Mexico and between Cortez, Colorado and Cortez, Mexico), Archaic bands of hunter-gatherers were small egalitarian groups that practiced residential and seasonal mobility, in order to "take advantage of seasonally available wild plant and animal resources in spatially separated ecozones" (Reid and Whittlesey 1997:43).

To successfully make the adjustment from the Pleistocene, Archaic peoples possessed a vast knowledge of the landscape and employed “a large but elastic network of social relations with bilateral kinship ties and marriage alliances as a foundation” (Martin and Plog, 1973: 72). Inherent in this knowledge was familiarity with the seasonal rounds of animals and the ideal times to gather wild plants within each ecozone. The Archaic diet in the northern Southwest was vast and opportunistic. For example, at Dust Devil Cave north of Navajo Mountain in southern central Utah, Van Ness (1986) analyzed coprolite evidence suggesting hunter-gatherers consumed a wide variety of plant foods. In deposits dating to 6,800 B.P. to 8,800 B.P., macrobotanical remains from desiccated feces contained sixteen species of plants including sunflower (*Helianthus annuus*), onion (*cf Allium sp*.), hackberry (*Celtis reticulate*), Indian ricegrass (*Oryzopsis hymenoides*), and stickseed (*cf. Lappula sp*.). However, the most abundant source of food was apparently dropseed (*Sporobolus cryptandrus*), prickly pear (*Opuntia polycantha*) and goosefoot (*Chenopodium cf. leptophyllum*). In addition, Van Ness (1986: 91-92) found that rabbits, rodents, and reptiles constituted the majority of faunal coprolitic remains for the Archaic assemblage. Another study produced similar results. Hansen (1994) analyzed coprolites recovered from Old Man Cave, located approximately 65 miles northwest of Dust Devil Cave. In addition to the above listed plant taxa, Hansen (1994: 61-75) also identified marshelder (*Iva spp*.) and beeweed (*Cleome serrulata*) as important components of the Archaic diet.

Beyond subsistence items, Archaic populations also needed to procure lithic raw material for use in stone tools. Successful group mobility needed to encompass both food and non-food resources necessary for survival. Often, these resources occurred at great distances from each other. The seasonal mobility strategies of Archaic peoples in the Southwest presumably included summer occupation in riparian areas, fall hunting in the higher elevations and winters spent in lower elevation rock shelters. Furthermore, as Martin and Plog (1972: 77) assert, "visits back and forth between various ecological and resource areas would have probably prevented any one group from claiming territoriality."

Because of the high mobility of Archaic peoples, sites dating from the period are ephemeral and lack the high artifact densities and standing architecture of later times. Despite evidence of increased Archaic occupation over time, deeply stratified and intact hunter-gatherer sites dated to the period remain elusive throughout the Southwest. A few notable exceptions are Ventana Cave in the Papagueria of western Arizona, the Glen Canyon region of southern Utah, and the Coffee Camp site between modern Tucson and Phoenix. While important sites, such occupations remain atypical because they yield diverse and diagnostic artifact assemblages, owing to the integrity of the deposits. Absent from many discussions of the Archaic in the Southwest are the innumerable lithic scatters that dot the landscape, many of which date to the Archaic Period. For example, Lyndon (2005: 4) recognizes 968 Archaic Period lithic scatters within the South Zone of the Kaibab National Forest alone. These sites remain theoretically untapped and underappreciated. In the area surrounding the San Francisco Peaks, such sites hold the potential for yielding insights into Archaic Period obsidian use, transport, and discard.

Somewhere between (both temporally and theoretically) the well-preserved, archaeologically rich sites of the Basketmaker and Pueblo Periods (or the Woodland and Mississippian Periods in the Eastern Woodlands) and the provocative realm of Paleoindian research, lies the relatively unknown Archaic Period. In North America, band-level social organization remains infrequently researched when compared to tribal and chiefdom level societies. This is probably due to the paucity of preserved material culture and the visibility of more complex societies in the archaeological record. Though exceptions may exist, sites dating to the Archaic Period generally do not contain standing architecture, lack evidence for broad regional trade networks, do not evidence giant leaps in technology, and possess no indication of complex, sedentary societies. In fact, as Amick and Carr assert, “the Archaic Period is often characterized as a period of stability with minimal cultural adjustments” (1996: 41). However, research into the Archaic Period does provide insights into thousands of years of prehistoric culture representing the most enduring and continuous cultural pattern ever practiced in North America. However, viewed differently, the supposed stagnancy of the Archaic Period could be viewed as evidence of a highly successful adaptation. As Sassaman (1996:73) asserts when describing the Archaic, “Social relations of obligation and reciprocity ensured long-term economic security in ways that no technological innovation, no matter how efficient, could do.” Therefore, partly because of the paucity of archaeological data and partly because of the relatively static nature of the period, the Archaic has often been given a negligible treatment in the literature.

Thus, my goal is to further our understanding of band-level societies by examining one aspect of culture that distinguishes the Archaic Period from later cultural traditions: high residential and logistic mobility. By shedding light on this adaptive strategy we can broaden our questions about the human condition and grasp the cultural processes necessary for the early prehistoric inhabitation of the northern Arizona environment. Anyone who has spent time in the region acknowledges the beauty of the landscape yet appreciates the tenacity needed for survival. Therefore, considering that different mobility practices required different adaptive strategies, investigations of obsidian procurement can be useful to infer Archaic Period social organization.

In order to fully understand Archaic mobility, one must first ascertain group territory and seasonal rounds. Archaeologists disagree about the relationship between source use and territory, but procurement ranges certainly reflect mobility ranges. Because Archaic peoples obtained stone depending on resource availability, differential access to those resources, as well as the relationship between subsistence and lithic resources, much can be gained from establishing the precise origin of the raw material used to fashion lithic tools. According to Amick (1994: 10), "the raw material used to manufacture a stone tool reflects toolstone sources, procurement activities, and mobility ranges."

Hunter-Gatherer Bands

Relying on ethnographic research done in the first half of the 20th century, anthropologists and archaeologists assume that before the Neolithic Revolution brought forward the origins of agriculture, all human populations on earth were organized into band-level societies. Similarly, archaeologists believe bands were the sole form of social organization before the adoption of agriculture in the New World during the terminal Late Archaic. However, as Ember and Ember (2007:419) point out, the source of much of our knowledge concerning band-level societies relies on ethnographic examples providing analogies for prehistoric bands. The applicability of such ethnographic analogies remain uncertain. Oftentimes, modern and historic hunter-gatherer groups are confined to marginal environments and spatially bound by nearby dominant societies. Therefore, “what we call ‘band organization’ may not have been typical of food collectors in the distant or prehistoric past” (Ember and Ember 2007: 420). Spurr, Geib, and Collette (2004:29) make a similar observation derived from their work in southern Utah when noting, “Sites from the two forager occupations (Archaic and Post-Formative) appear quite different, and raise the question of whether the Paiute ethnographic record provides an appropriate analogy for understanding Archaic hunter-gatherers.” Nonetheless, ethnographic analogy provides one viable way to understand hunter-gatherer lifeways in the past.

Prehistoric hunter-gatherer bands presumably contained relatively few people, rarely exceeding 50 individuals. Bands were politically autonomous and lacked designated leadership roles. Leadership was achieved through ability, influence, and personal strengths such as hunting proficiency; leadership was not ascribed through heredity or political office. Hunter-gatherer bands likely practiced economic reciprocity and communal decision making and are thought to have displayed egalitarianism. Cohen (1985: 99) summarizes prehistoric bands when he writes, bands are “characterized by fluid group organization, individual freedom of movement and group membership… immediate consumption, simple division of labor, and relatively direct personal leverage on individuals."

Thus, egalitarianism remains a defining characteristic of band-level societies. Such band egalitarianism varied substantially throughout time as did gender roles. While neither gender universally exercised control of the group, "sexual division of labour made the family the main self-sustaining economic, political, and social unit for most of the year" (Myers 2004: 178). Thus, bands comprised of only a handful of relatives may have operated as relatively autonomous entities during certain times of the annual cycle.

Despite the small size of bands throughout much of the year, Wobst (1974: 154-163) determined the minimum equilibrium size of band societies as varying between 175 and 475 people. Thus, for group members to consistently gain access to suitable mates, bands must gather together periodically to meet several needs. Such meetings of bands resulted in temporary "macrobands" where important information, such as resource availability, environmental knowledge, and cultural reaffirmations were transmitted while also solidifying social ties. As Anderson and Hanson (1988: 271) explain, "Periodic aggregation appears essential in very low-density settlement systems, where social groups move largely as units. The need to find and exchange mates in a cultural environment characterized by an extremely low population density" presumably instigated these movements. In Indiana, Moore (2008:80) found that hunter-gatherers used areas providing "contexts for information sharing and mate exchange" that occurred near high quality lithic raw material sources and "regional landmarks."

Another factor initiating mobility of hunter-gatherers throughout prehistory was the need to follow game, sometimes for great distances. As Walthall (1998: 232) summarizes, “Holocene hunter-gatherers appear to have been highly mobile foragers who followed an annual round dictated by topographical and seasonal changes in resource distribution.” An additional concern was non-food resource acquisition, often located at far distances from seasonal habitats of animals. As Kelly (2000) points out, no necessary relationship exists between the locations of food resources and lithic raw material sources on the landscape. Indeed, often such necessities occur long distances from one another. Thus, most archaeologists believe hunter-gatherer bands moved often and extensively year round in order to effectively forage needed resources.

Bands occupied every habitable ecological niche on earth through time and thus, “exhibit considerable variation in terms of their settlement systems, hunting strategies, subsistence logistics, patterns of mobility, use of space, butchery practices, and responses to fluctuations in the seasonal availability of resources” (Lane and Schadla-Hall 2004: 146). Furthermore, given that a great many factors influenced the kinds of band-level sociopolitical units, including environmental features (topography, resource density and location, temperature, and precipitation) and social arrangements (marriage, kinship, territoriality, and warfare), “No single interpretive model of hunter-gatherer behaviour, therefore, is likely to fit all archaeological manifestations of this mode of subsistence” (Lane and Schadla-Hall 2004: 156).

Archaeologists agree that hunter-gatherers during the Archaic likely practiced shamanism, though recent research (Coulam and Schroedl 2004) suggests bands in the northern Southwest organized themselves religiously into “communal cults”. According to Coulam and Schroedl (2004: 43), “These groups employ symbolic representations of natural species or phenomena to identify group members and symbolize group unity.” In the Grand Canyon region during the Late Archaic, such totems take the form of split-twig figurines thought to represent bighorn sheep. The authors believe “shamanic beliefs and practices…cannot account for the consistent and repetitive manufacturing of split-twig figurines over many generations” (Coulam and Schroedl 2004: 58). Thus, Coulam and Schroedl (2004: 44) interpret such artifacts as representing membership in the “bighorn sheep clan”. The authors further posit that the spatial distribution of split-twig figurines roughly approximates the original geographic territory of the clan. Because the split-twig figurines occur in the Grand Canyon to the north and in Walnut Canyon to the southeast of the research area, perhaps the “bighorn sheep clan” used the San Francisco and Mt. Floyd volcanic fields as sources for lithic raw material during the Late Archaic.

Goin’ Mobile: Hunter-Gatherer Mobility

Highly mobile hunter-gatherer bands were common throughout prehistory and employed a myriad of mobility strategies. Kelly (1983: 277) defines mobility strategies as “the seasonal movements of hunter-gatherers across a landscape: mobility strategies are one facet of the way in which hunter-gatherers organize themselves in order to cope with problems of resource acquisition.” Thus, in reconstructing mobility strategies, we can shed light on prehistoric behavior and processes.

Binford has identified two such mobility strategies, which he terms "residential" and "logistic" (1980: 7). He distinguishes between "foragers" who move consumers to resources and practice residential mobility, and "collectors" who move resources to consumers through logistically organized resource procurement parties. Residential and logistical mobility among hunter-gatherer groups reflect patterns of seasonal movements across the landscape and relate to the structure of resources in the environment. As Young (1994: 143) points out, "logistic mobility is favored in areas where resources are spatially incongruous."

Mobility strategies consist of the nature of seasonal movements across the landscape and indicate ways in which bands organize for resource acquisition (Kelly 1983). Moreover, considering the differential placement of resources across the landscape, long-term mobility probably reflects a response to subsistence stress (Kelly 1992). Hunter-gatherers likely anticipated the spatial fluctuations in subsistence resource availability by developing mobility strategies well-suited for such changes.

Kelly (1992) states that mobility is universal, variable, and multi-dimensional, possessing a cultural component as well as behavioral implications. Mobility studies need to include cognitive and cultural factors and should consider the possibility that residential mobility may possess cultural value, though such intangible determinants are often difficult to ascertain archaeologically. The importance of investigating mobility acknowledges the fact that the ways in which people moved influenced social organization. Kelly (1992: 43) asserts, "it is important that we learn to recognize the various forms of mobility archaeologically, because the ways people move exert strong influences on their culture and society.” Many researchers have used prehistoric mobility as an avenue for reconstructing band-level social organization and hunter-gatherer behavior. The contributions of such archaeologists as Binford (1977, 1979, 1980) Cowan (1999), Kelly (1983,1992), and Lovis (1977, 1981, 2005) have been invaluable in increasing our knowledge of the variability of hunter-gatherer mobility, yet a testable and comparative explanation of how and why bands practice such intensive mobility has proved elusive.

Hunter-gatherer bands practiced high levels of mobility depending on differential resource availability (Figure 12). Access to various resources presumably influenced different mobility strategies. Binford (1977, 1979, 1980) reasoned that disarticulated floral and faunal resources mainly determined these behaviors. Many archaeologists (Shackley 1991, Andrefsky 1994, Amick 1994) agree that lithic raw material procurement was probably incidental to food hunting and gathering activities. In fact, Binford (1979:259) states, “very rarely, and then only when things have gone wrong, does one go out into the environment for the express and exclusive purpose of obtaining raw materials for tools.”

Binford’s (1980) dichotomous mobility model outlining logistic versus residential strategies undoubtedly grades between the two adaptations and possessed many variants including components of both. While archaeologists agree that spatial arrangements of subsistence resources conditioned whether a logistic or residential adaptation was employed, many researchers also cite a temporal component as the underlying cause for the difference. As Smiley (2002: 26) explains, “populations appear to change from subsistence/mobility strategies that require hunter-gatherer groups to map onto resources over large areas through residential mobility toward modes of organization that require logistical structure.” Thus, as group size increased and bands became more entrenched in a region, mobility strategies presumably changed from primarily residential to mainly logistical. Instead of entire bands moving to resources, small groups of band members began to leave for short periods of time to obtain resources to bring back to the group. Therefore, embodied in this view hunter-gatherer bands during the Early Archaic contained fewer members than bands in the Middle and Late Archaic and likely moved more frequently as an entire group.

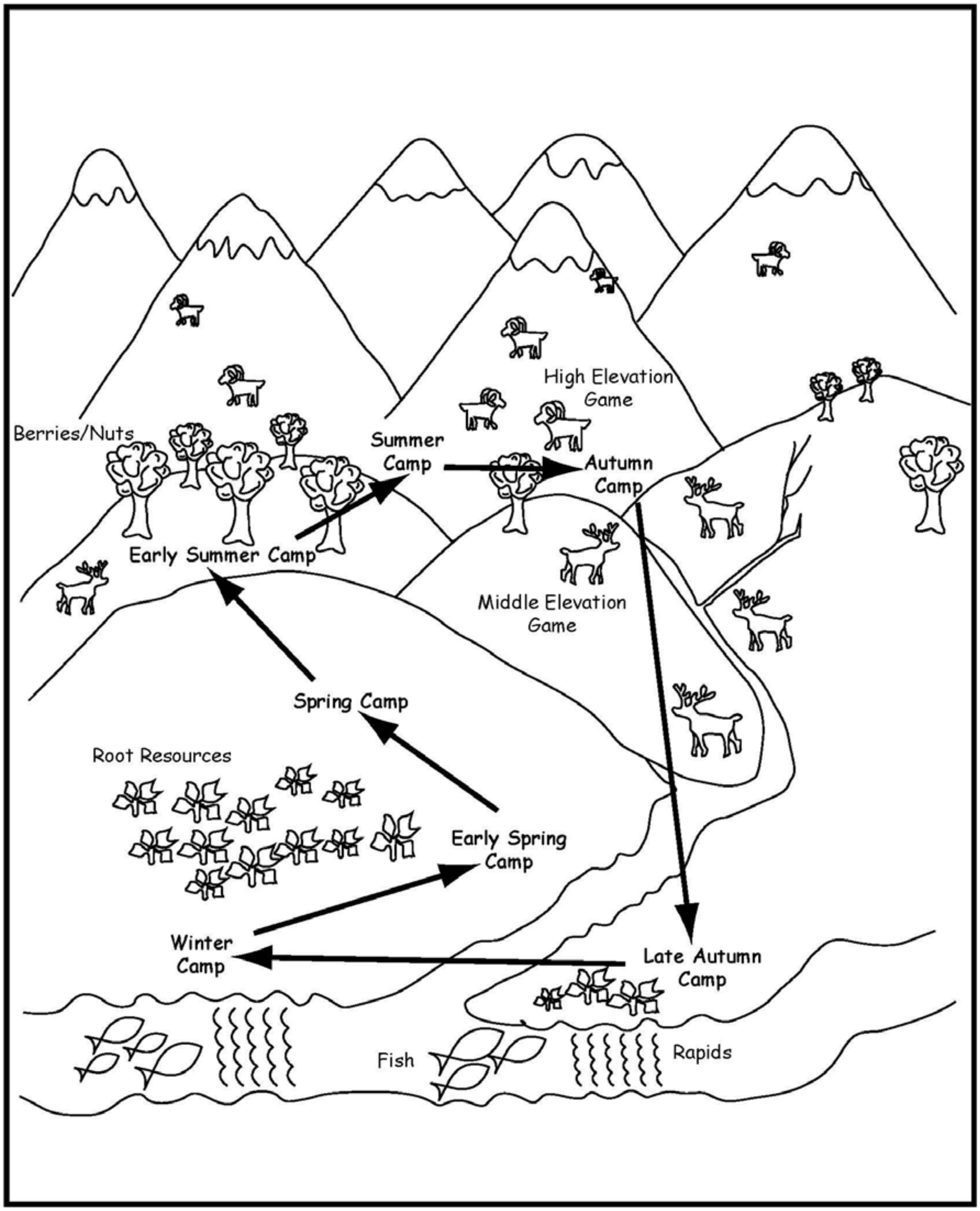


Figure 12. Hypothesized model based on Binford's ideas of residential mobility. Redrawn from Andrefsky (1998: 199).

In this thesis, I evaluate the proposition that access to lithic resources, which serve as the toolstone necessary in manufacturing hunting implements (and, in turn, make hunting possible), was essential to the subsistence strategies of pre-agricultural populations and thus influenced mobility strategies. As Daniel (2001: 237) argues, “high-quality stone plays a more significant role in settlement adaptations than previously recognized.” Therefore, I asked the question whether Archaic Period mobility was conditioned by the procurement of a suite of competing resources, and if so would such a mobility strategy always incorporate the natural occurrence of exploitable toolstone? Moreover, to what extent does access to lithic raw material sources influence mobility strategies? In addition, how would an embedded procurement strategy look different in the archaeological record than a strategy organized explicitly around obtaining lithic raw material?

Mobility strategies likely reflect the importance of the resource as well. Hunter-gatherers presumably weighed such resources economically and decided the most efficient way to meet group needs. Thus, when investigating resource exploitation diachronically, archaeologists often focus on the degree to which a resource is present in an assemblage. Change in relative frequencies suggests procurement dynamism either as a reflection of resource availability fluctuations, changes in the importance of the resource to the overall success of the group or indeed, as a marker of shifts in social organization. Conversely, observed resource stability within a diachronic assemblage may reflect constancy in any or all of these factors.

Chapter Four: Previous Research and Current Units of Analysis

Chapter Four provides the details of pertinent previous research in northern Arizona. I also briefly define certain terms and archaeological concepts used throughout. In addition, I discuss the tools of the study including units of analysis such as projectile point types and chronology. Lastly, I describe the igneous toolstone locations and explain the characteristics of each material.

Northern Arizona Archaeologists and Previous Research

H.H. Robinson, with the United States Geological Survey, conducted the first systematic survey of the San Francisco volcanic field in 1913. The study provided the geologic history of the area as well as a description of the local igneous rock. Robinson (1913:86) wrote, “The lavas range in composition from andesites to rhyolites”. Robinson determined the obsidian outcrops in the region resulted from the second general period of eruptions during the Quaternary Epoch. Robinson (1913: 86) states, “San Francisco Mountain, Kendrick Peak, and Sitgreaves Peak are distinctly symmetrical in form, because the eruptions were predominantly from central vents.” Nearly fifty years passed before researchers began synthesizing quantitative geologic and archaeological data in the region.

The first study aimed to locate and describe obsidian source localities in the San Francisco volcanic field for the purposes of archaeological research was carried out by Schreiber in 1967. The report also served as the initial attempt at differentiating source materials. Because x-ray fluorescence technology was in its infancy and had yet to gain broad acceptance, and because Schreiber maintained “that physical characteristics will give the best basis for differentiation" the study relied on macroscopic (visual) and microscopic identification. Schreiber primarily focused on identifying the presence of phenocrysts, or inclusions within obsidian comprised of crystals of feldspar, through visual inspection of hand samples. Schreiber also used a microscope in order to differentiate the raw materials, again mostly concentrating on phenocrysts as identifiers. While Schreiber concentrated on macroscopic identification in the baseline study, a later collaboration with Breed (1971) initiated geochemical application in archaeology in the region. For nearly two decades, Schreiber's studies (1967 and 1971) constituted the seminal references for the majority of local archaeologists interested in obsidian studies as well as local flintknappers in efforts to collect toolstone.

Following Schreiber's early efforts, Robert Jack conducted the first widely accepted study employing geochemical methods. As Shackley (2005: 9) points out, "Schreiber and Breed's [1971] and Jack's [1971] studies in the San Francisco Volcanic Field…with few exceptions, are the only attempts to chemically detail Southwestern obsidians for archaeological problems before the 1980's." Jack first collected comparative samples from 9 obsidian localities within the San Francisco volcanic field. From this initial source survey, Jack determined that the 9 sources "fall into five clearly defined trace element groups: 1)Sitgreaves Peak-Government Mountain 2) RS Hill 3)Kendrick Peak-Slate Mountain group 4)San Francisco Mountain (Fremont-Agassiz saddle and 5) the O'Leary Peak-Robinson Crater-Fish Sawmill group" (1971: 105). Unfortunately, Jack's source sample comparative library consisted of only 18 samples from the 9 obsidian outcrops.

With assemblages provided by the Museum of Northern Arizona, Jack (1971: 103) performed XRF analysis on 217 artifacts recovered from 16 sites across northern Arizona. All of the obsidian assemblages used in the study were recovered from Pueblo Period sites, primarily within the “Sinagua Heartland” (Lesko 1986: 2). One site located outside of this area, NA 8656, located on Tyende Mesa near Kayenta, Arizona yielded seven artifacts used in the study. The seven obsidian flakes analyzed from NA 8656 revealed a chemical signature indicative of the Government Mountain source, suggesting a “transport of about 135 miles” (Jack 1971: 112). In fact, 178 of the 217 artifacts submitted for XRF analysis were identified as coming from Government Mountain (82%). Interestingly, 31 of the artifacts that could not be assigned a source designation came from four sites outside the Sinagua area. This is probably due to the lack of a comprehensive source sample at the time, as subsequent researchers (Lesko 1986, Nealy 1986) visually identified the material as Mt. Floyd obsidians. Of the remaining artifacts, only RS Hill (n=7) and Slate Mountain (n=1) were represented.

As a result of Jack’s study, “Government Mountain obsidian has become nearly a legend among southwest obsidian sources” (Lesko 1986: 1). In fact, since 1971 many archaeologists have accepted the study uncritically, assuming the majority of obsidian recovered from northern Southwest sites originated from Government Mountain. To test Jack’s conclusions, Suzanne Sanders (1981) carried out thesis research relying on eight samples from each source locality, stating, “the sample size in the earlier investigation was hardly sufficient” (Sanders 1981: 51). Sanders sampled the same sources as Jack, yet neglected to collect from the San Francisco source due to its supposed absence in the archaeological record. Sanders applied more sophisticated geochemical techniques than did Jack, who “relied solely on the concentrations of Zr, Rb, and Sr.” (Sanders 1981: 2). Instead, the analysis included twenty minor and trace elements because “Although the major elements in obsidian (Si, Fe, Ca, Mg, O, K, Na) show little variability among samples, the minor and trace elements demonstrate unique patterns” (Sanders 1981: 6).

Despite Sanders misgivings about the validity of the earlier methods, the study essentially confirmed the obsidian use pattern reported by Jack. Sanders, however, submitted only thirteen obsidian samples from a single site, probably because the study focused primarily on the geochemistry of obsidian as opposed to its archaeological use. The obsidian assemblage used for the study came from NA 10101, “a site about 20 miles east of Flagstaff near Young’s Canyon.” J. Richard Ambler of Northern Arizona University excavated site NA 10101, a Northern Sinagua masonry pueblo occupied between 1100-1225, in the years 1968-1970. http://www.nps.gov/history/nagpra/fed_notices/nagpradir/nic0176.html

Meanwhile, several researchers were developing a regional obsidian hydration rate for Government Mountain toolstone. Calvin Jennings’ doctoral dissertation (1971) focused on establishing a chronology of the preceramic Coconino Plateau based largely on obsidian hydration rim dates. Jennings analyzed 105 obsidian artifacts recovered from Harbinson Cave in northern Arizona that he believed were made from Government Mountain material. Using the hydration dates, Jennings established three preceramic phases for the Coconino Plateau. The Red Butte Phase, dating from 3,900 to 3,000 B.P. was marked by the presence of the diagnostic Pinto projectile point. The subsequent Red Horse Phase, dating from 2,700 to 1,750 B.P., saw an increase in several types of milling tools. The final preceramic phase, dating from 1,800 B.P. to 1,300 B.P., was called the Hupmobile Phase (Jennings 1971).

Unfortunately, Jennings lacked a regionally specific hydration date and thus "applied a rate established … for central California" (Cartledge 1985: 13-14). This is a critical error because "Obsidians from different sources hydrate at different rates, and it is essential in dating a specimen to know its source" (Cartledge 1985:13) Therefore, because the artifacts submitted for hydration rim measurements were never subjected to geochemical analysis to determine the source, Jennings' dates were found to lack validity.

Following the earlier attempts at establishing an obsidian hydration rate for the region, Frank Findlow began a research program using Government Mountain obsidian rim thicknesses as the source for determining an accurate chronology. Findlow, et al. (1975: 345) chose the Government Mountain source because "it was the most heavily exploited obsidian source in the Southwest." Findlow repeatedly revised (1977, 1978, 1979) the hydration rate until the final formula was established: "y = 125.01 (x2) (+/- 0.2 microns measurement error) where y = years B.P. and x = observed hydration" Cartledge 1985: 16). Findlow stressed (1977: 30) the rate "can only be applied to obsidian from the Government Mountain-Sitgreaves Peak source within the given time range of A.D. 1700 TO 4000 B.C."

Gary Brown conducted another study concentrating on the archaeological use of Government Mountain obsidian. Brown led a several year archaeological project on Anderson Mesa, a lava flow originating near Flagstaff and extending 100 miles southeast to Chavez Pass (1981: 2). Brown focused on Sinagua craft specialization and trade between A.D. 1100 and 1500 and used obsidian assemblages recovered from thirty-two sites across Anderson Mesa. The study applied “distance-decay or ‘fall-off’ models to explore the effect distance from source has on the amount of obsidian found at sites” (Brown 1981: 6). Brown visually identified “94% of the 1,163 obsidian artifacts” (1981:5) as Government Mountain obsidian. Brown found the relationship between individual Sinagua site distances to Government Mountain and percentages of such obsidian within the overall lithic assemblages to be “generally inverse” (Brown 1981: 7). In other words, Brown determined the greater the distance to the source, the less material present.

As part of the Transwestern Pipeline Expansion Project performed by the Office of Contract Archeology and the Maxwell Museum of Anthropology at the University of New Mexico, Burchett et al. (1994) performed XRF analysis on 131 obsidian artifacts from Archaic contexts. Sites located in the San Francisco Mountain and Western Arizona Upland Regions comprised 123 of the sites (Burchett et al. 1994: 386). Project archaeologists confirmed previously documented patterns of obsidian use in the San Francisco Mountain Region. As Burchett et al. (1994: 392) assert, “Government Mountain obsidian dominates the lithic assemblages in these assemblages.” In addition, researchers confirmed the early use of Government Mountain obsidian in the Hopi Buttes area as evidenced by tools and flakes recovered at Site 442-33, a Middle Archaic site.

M. Steven Shackley (1986, 1989, 1995, 2003, 2005) has conducted more research aimed at obsidian use, procurement, and geochemistry in the Southwest than any other individual archaeologist. Much of our current understanding of obsidian source locations and information, including prehistoric exploitation, can be directly attributed to Shackley's contributions. Shackley has worked with obsidian assemblages in virtually every region of the Southwest covering the entire breadth of prehistoric occupation. For example, in research centered on ethnicity and exchange in the Tonto Basin during the Classic Period, Shackley (2005: 139) found "Coconino Plateau obsidian (Government Mountain and RS Hill/Sitgreaves)…constitute 11.9 percent of the basin assemblage."

Shackley's dissertation entitled ***Early Hunter-Gather Procurement Ranges in the Southwest: Evidence from Obsidian Geochemistry and Lithic Technology*** focused on the same time period as the present study, though on a much larger geographic scale. Included among hunter-gatherer sites yielding obsidian artifacts analyzed by Shackley for this research are six sites located north of the Mogollon Rim in northern Arizona. Collectively referred to as the Mormon Lakes Sites due to their "association with an early shoreline of Mormon Lake approximately 15 miles south of Flagstaff" (Shackley 1990: 284), these sites represent short-term summer and fall hunting camps occupied during the Middle to Late Archaic. Together with the sites investigated by members of the Transwestern Pipeline Expansion Project, the Mormon Lake Sites represent some of the only Archaic Period sites in northern Arizona yielding artifacts that have undergone geochemical analysis.

Shackley (1990) analyzed 31 obsidian artifacts from the Mormon Lake Sites, including debitage, utilized flakes, and general bifaces, using x-ray fluorescence techniques. Unlike many Archaic Period sites in other areas of the Southwest, "only one source is present in this assemblage; Government Mountain" (Shackley 1990: 286). Shackley acknowledges that because the source is less than 40 kilometers northwest of Mormon Lake, the sole presence of Government Mountain obsidian is not surprising. Shackley (1990: 287) writes, "It would be tempting to infer that, given the lack of material from any other source, the Archaic inhabitants of this site were northern Arizona hunter-gatherers."

In addition, Shackley (1986) analyzed 20 obsidian artifacts from the Kaibab National Forest and found eight (40 %) as having been made from Partridge Creek obsidian from the Mount Floyd volcanic field. Interestingly, only three (10%) were sourced to Government Mountain while six (30%) were determined to be from unknown sources. Shackley believed the majority of the unknowns were probably from southwestern Utah near the present-day town of Modena, roughly 350 miles northwest of Flagstaff. Worthy of mention here is the Presley Wash source was unknown to researchers until Larry Lesko reported it in 1989 (389-390), so the artifacts listed as unknown may well have originated from Presley Wash. Unfortunately, I could find no reference to the contexts of the artifacts. Therefore, within which period the obsidian is associated remains unclear.

Shackley (1995: 532) states, "obsidian source standard data must be available to all interested archaeologists and archaeometrists and be presented in a form internally valid as well as reliable." My thesis rests upon the foundation laid by Shackley's publications and was completed with this goal in mind. Much of Shackley's career has focused on disseminating such information and archaeologists working with obsidian in the Southwest owe much to his research.

Typology and Relative Dating

Typology is one of the cornerstones of archaeological method and theory. Indeed, “Typological dating is as basic to archaeology as is the principle of superposition” (Flenniken and Wilke 1989: 149). Renfrew and Bahn (1996: 547) define typology as “The systematic organization of artifacts into types on the basis of shared attributes.” Archaeologists create types based on overall morphological similarities among artifacts and rely on such attributes as length, width, color, material, and design. For example, “several pots with the same attributes constitute a pot type, and typology groups artifacts into such types” (Renfrew and Bahn 1996: 114). Of course, archaeologists often disagree about typologies because of variation within a type (for a discussion questioning projectile point typologies as a whole, see Flenniken and Wilke 1989). As Adams and Adams (1991: 22) explain, “archaeological types are usually determined by central tendencies, or modalities, rather than by hard-and-fast boundaries.”

Researchers often develop temporal projectile point typologies as a first step towards investigating the culture history of a region (Lyndon 2005). Regional projectile point typologies become the lingua franca of local archaeologists but terminology is often borrowed from neighboring areas. As such, many of the point types currently used for the Coconino Plateau derive from the Great Basin. Thomas (1979: 220) explains, “Archaeological convention dictates that the points receive first and last names. The first term generally refers to the site or region in which they were first recognized, and the second term describes some obvious morphological characteristic.” Projectile point typologies often serve to establish or augment a chronological sequence. As Justice (2002: 3) points out, “most projectile points were made following specific rules of manufacture dictated by a particular Native tradition”. Because styles and manufacturing techniques change through time, the creation of temporal typologies serves as a relative dating technique (Figure 13).

Relative dating relies on temporal typologies to order artifacts and features into sequences. Such techniques are especially useful when dealing with surface finds lacking datable context, such as those in the current study. When chronometric techniques, such as dendrochronology, radiocarbon dating, and thermoluminescence dating are not possible, archaeologists rely on relative dating. Typology and relative dating work in tandem to allow archaeologists to determine the general age of surface projectile points by matching a point to one “already recognized within a well-established typological system” (Renfrew and Bahn 1996: 115). The importance of regional typologies cannot be overstated. Indeed, as Thomas (1986: 619) asserts, “the overall success of regional archaeology depends, in large measure, on the strength of the underlying chronologies and typologies.”

Thus, using established typologies from adjacent regions (Berry 1987, Tagg 1994) and relying on the assistance of local archaeologists (Ahler, Downum, Geib, Pilles, Robins, Smiley) participating in a typology workshop, Lyndon (2005) developed the Coconino Plateau projectile point typology used in the present study. When creating the typology, Lyndon (2005: 48) set out to “synthesize what is already known in areas surrounding the research area to develop an intuitive typology so that research can progress.” Novotny (2007: 21) later refined the typology by “adding four new type classes… includ[ing] Rocker Side-notch…I also split the Gypsum Cave type class into two varieties.”

Figure 13. Chronology of the Research Area. Created from Lyndon (2005).

Coconino Plateau Point Typology

Although the Coconino Plateau typology developed by Lyndon (2005) contains 35 projectile point types and Novotny (2007) included another five, I will restrict the following brief discussion to the types included in the present study (Figure 14). On the southern Coconino Plateau, 12 types of projectile points arose throughout the Early, Middle, and Late Archaic Periods. During the Early Archaic Period (6200 B.P. – 9000 B.P.), three types are present: the Jay, Bajada, and Northern-Side Notched. The Jay and Bajada represent stemmed varieties. These types differ from projectile points recovered from the adjacent northern Colorado Plateau. As Geib (2000: 511) asserts, “On the southern Colorado Plateau, stemmed points persist throughout much of the Archaic sequence from at least 8000 cal B.C. until about 2500 cal. B.C.” while “on the northern Colorado Plateau, long-stemmed points (representing Jay or Bajada) are poorly represented.”

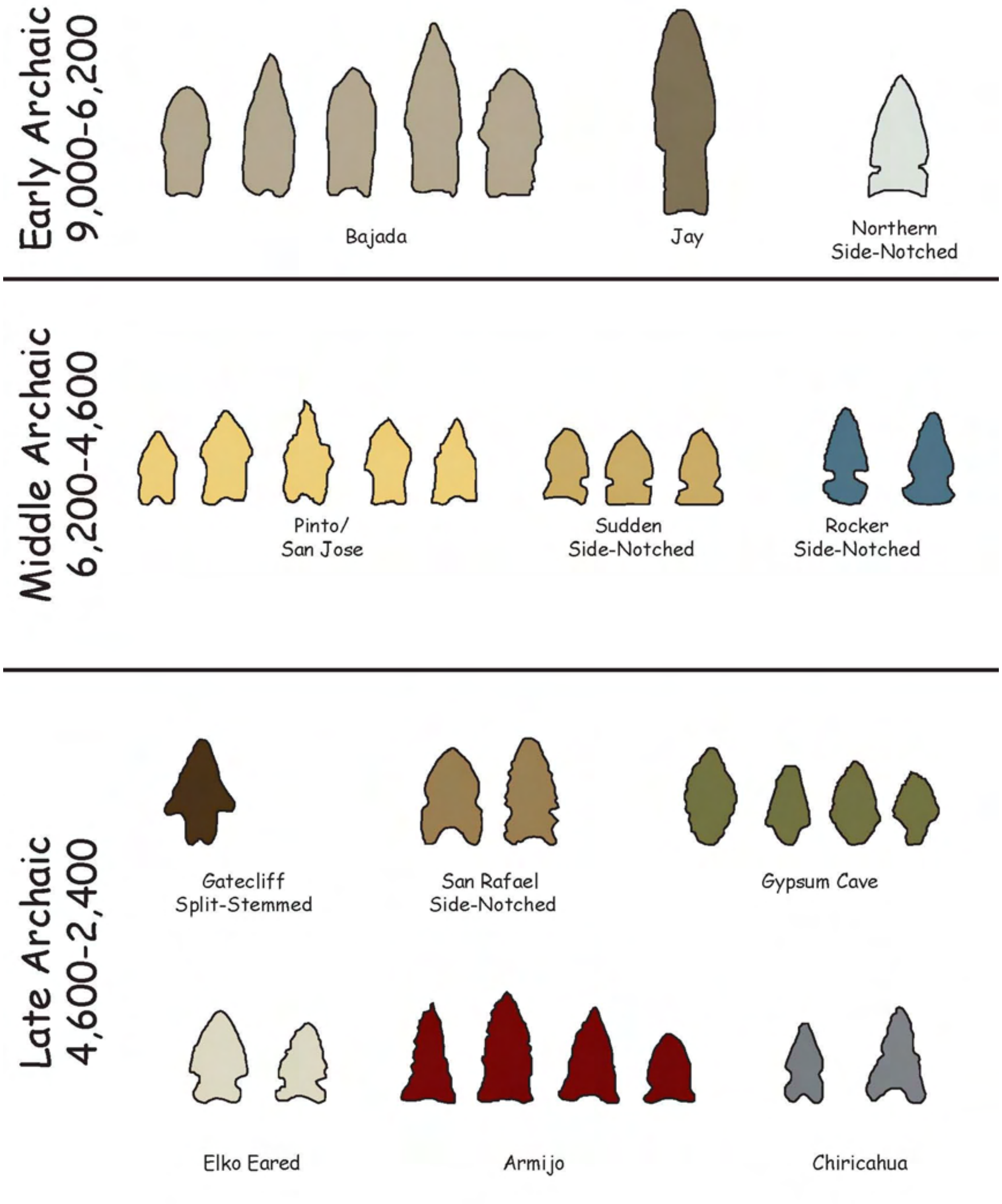


Figure 14. Projectile point types used in this study.

Jay (Terminal Paleoindian-Early Archaic)

Also known as Lake Mohave points, Jay points (Figure 15) are a large type exhibiting "straight to very slightly contracting stems" (Moore and Brown 2002).

According to Justice (2002: 106), Jay points belong to the Great Basin Stemmed cluster and commonly occur across Arizona and into western New Mexico. Jay points characteristically display ground edges on the basal and lateral edges. Justice (2002: 98) considers the Jay type a transitional point between Paleoindian and Early Archaic forms.

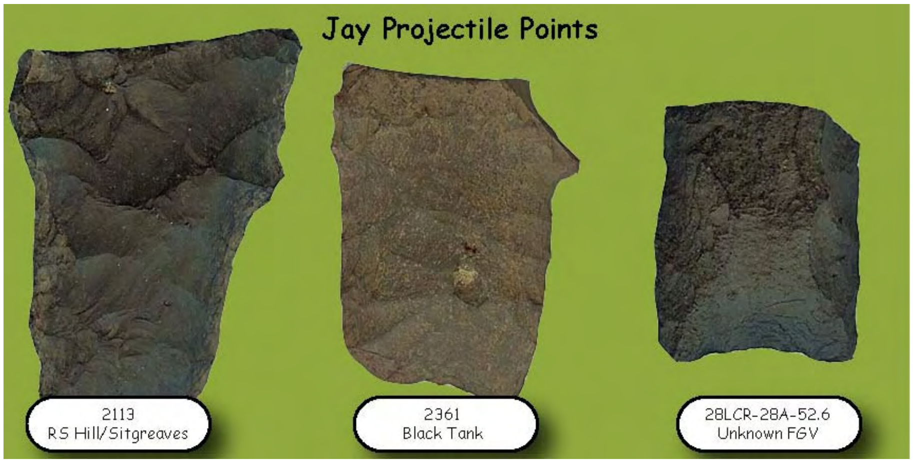


Figure 15. Examples of Jay points points and different toolstone sources used in their manufacture.

According to Moore and Brown (2002: 4), the stem of Jay points are “normally 20mm long or greater” making the Jay the largest type on the Coconino Plateau. Jay points resemble the later Bajada points, only slightly larger. Jay points are extremely rare within the current sample. The three Jay points analyzed demonstrate the range of toolstone procured by Early Archaic hunter-gatherer groups in the area. The three sources used for Jay points are Government Mountain, RS Hill/Sitgreaves Mountain, and the Unknown FGV.

Bajada (Early Archaic)

Bajada points, also relatively large and stemmed, postdate the Jay type and exhibit “straight to expanding stems” (Moore and Brown 2002: 4). Bajada points regularly show signs of basal grinding and “most Bajada specimens are found in an advanced state of resharpening” (Justice 2002: 123). According to Novotny (2007: 52), “Bajada points have a mean neck width of 17.37 mm, a mean base width of 18.02 mm, and a mean shoulder width of 19.48 mm.” Irwin-Williams (1973: 7) defined the type and initially placed the Bajada in the 6,800 to 5,200 B.P. range, though recent radiocarbon dates from Black Mesa (Smiley: 1995) suggest a more appropriate date of 9,000 B.P. for the introduction of Bajada points. Lyndon (2005: 59) assigns a start date of 8,000 B.P. in order to account for the disparity.

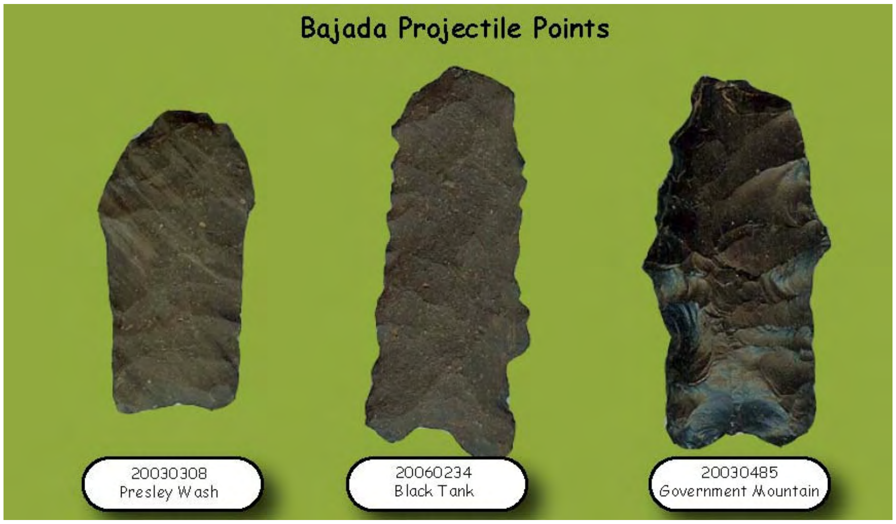


Figure 16. Examples of Bajada points and different toolstone sources used in their manufacture.

The current collection contains 25 Bajada points (9% of total) manufactured from seven obsidian sources in northern Arizona. The sources include Black Tank (n = 4), Government Mountain (n = 7), Partridge Creek (n = 1), Presley Wash (n = 7), RS Hill/Sitgreaves Mountain (n = 1), Unknown FGV (n = 1), and Unknown FGV A (n = 4). The additional number of exploited toolstone sources used for Bajada points represents an increase of 233% over the three used for Jay in the current sample.

Thus, I suggest that as Early Archaic populations increasingly occupied the area, groups began using additional obsidian sources as familiarity with the resources grew. The question of whether this trend is due to sampling bias, evidence of greater occupational intensity or evolving procurement strategies awaits further geochemical research.

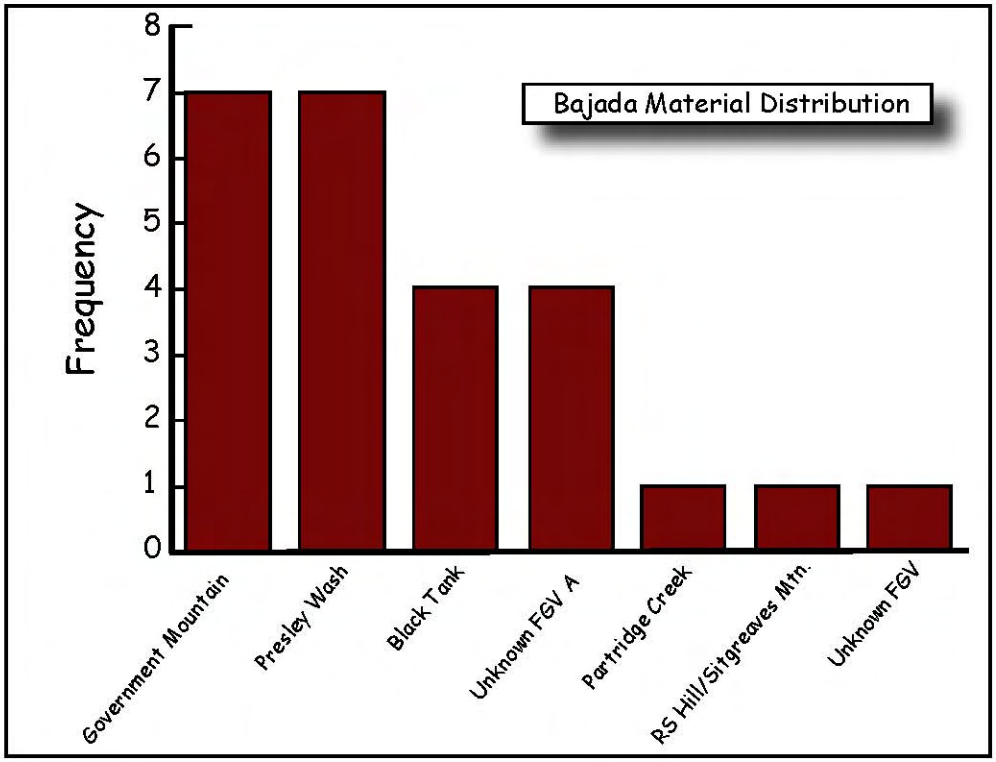


Figure 17. Toolstone frequencies within the Bajada projectile point type.

Northern Side-notched (Early Archaic)

The Northern Side-notched projectile point type is "the most widely recognized side notched type of the Archaic period in the West" (Justice 2002: 151). According to Lyndon (2005: 60), "the Northern Side-notched point type was defined by Gruhn [1961, cited in Holmer 1986: 104] and consists of medium to large points with notches placed high on the sides." This type generally is triangular to lanceolate in shape and exhibits a thin, biconvex cross-section (Justice: 151). Base morphology differentiates Northern Side-notched from the later Sudden Side-notched. Northern Side-notched points differ primarily because of basal concavity and more proximal side notches than the Sudden Side-notched type (Lyndon 2005: 60). Northern Side-notched points date from approximately 7,500 B.P. to 6,400 B.P. The current collection included only 5 points (.03% of total). However, four obsidian sources were used to manufacture the Northern Side-notched points. The sources include Government Mountain (n = 2), Partridge Creek (n = 1), Presley Wash (n = 1), and Unknown FGV A (n = 1).

Figure 18. Examples of Northern Side-notched points and different toolstone sources used in their manufacture.

The restricted number of sources presumably exploited for use in Northern Side-notched points compared to Sudden Side-notched undoubtedly reflects the very small sample size. However, the source distribution mirrors that of the Southern Kaibab National Forest assemblage as reported by Lyndon (2005: 60). In the sample (n = 5) analyzed by Lyndon, one was manufactured from obsidian, one from chalcedony, one from rhyolite, and two were chert points. A much larger sample of

Northern Side-notched points is necessary in order to deduce any empirical cultural behavior. Nevertheless, based on current data I infer the prehistoric people manufacturing Northern Side-notched points likely practiced wide-ranging procurement behavior.

Gradually, these three types were replaced by three new types beginning roughly 6200 B.P. While overlap certainly existed, archaeologists generally agree that each projectile point type provide chronological control. The projectile points manufactured throughout the Middle Archaic (4600 B.P. – 6200 B.P.) include the Pinto/San Jose, Sudden Side-Notched, and the Rocker Side-Notched.

Pinto/San Jose (Middle Archaic)

Following Lyndon (2005), I have combined Pinto and San Jose points into one type (Figure 19). While researchers disagree about the parameters and mutual exclusivity of the Pinto/San Jose classification (see Lyndon 2005:61-62 for a discussion of the debate), I chose to combine them for consistency. Moore and Brown (2002: 4) describe San Jose points as “large to medium-sized stemmed points [with] straight to expanding stems.” These characteristics apply equally well to Pinto points as does the presence of concave bases. As Lyndon (2005: 63) points out, the Pinto/San Jose type represents “a descendant of the Bajada point” and thus firmly date to the Middle Archaic. Precise date ranges for Pinto/San Jose points remain elusive. The dates generally accepted for the Coconino Plateau extend between 5,200 B.P. and 3,200 B.P.

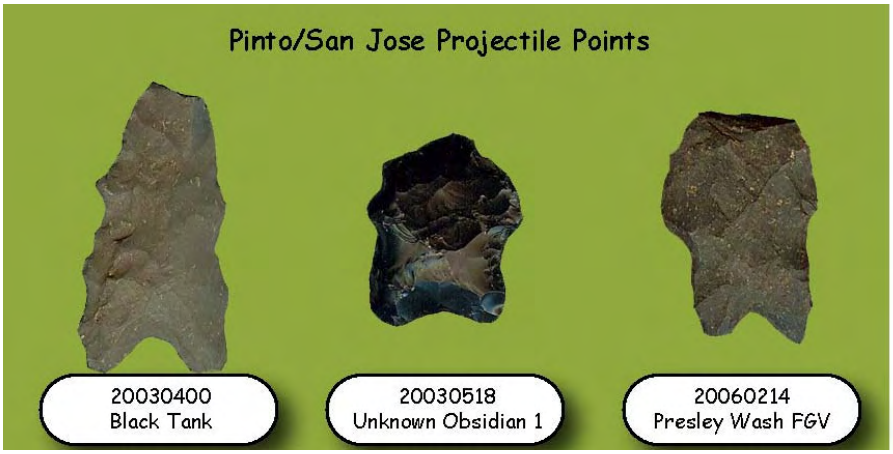


Figure19. Examples of Pinto/San Jose points and different toolstone sources used in their manufacture.

Points classified within the Pinto/San Jose type constitute the largest number (n = 83) of any in the sample (31% of total). I added 27 points, recovered from the Flagstaff area, to the 56 Pinto/San Jose from the South Kaibab collection. As such, Pinto/San Jose points evidence the greatest number of individual sources used for any point type. In fact, of the 18 toolstone sources present in my study (12 geochemically characterized, 6 unknowns), 11 were used to manufacture Pinto/San Jose points. Middle Archaic hunter-gatherers used the following sources for this type: Government Mountain (n = 43), Black Tank (n = 3), Deadman's Mesa (n = 1), Presley Wash (n = 15), Partridge Creek (n = 8), RS Hill/Sitgreaves Mountain (n = 1), Unknown Obsidian 1 (n = 2), Unknown Obsidian 2 (n = 1), Unknown Obsidian 4 (n = 1), Unknown FGV (n = 5), Unknown FGV A (n = 3).

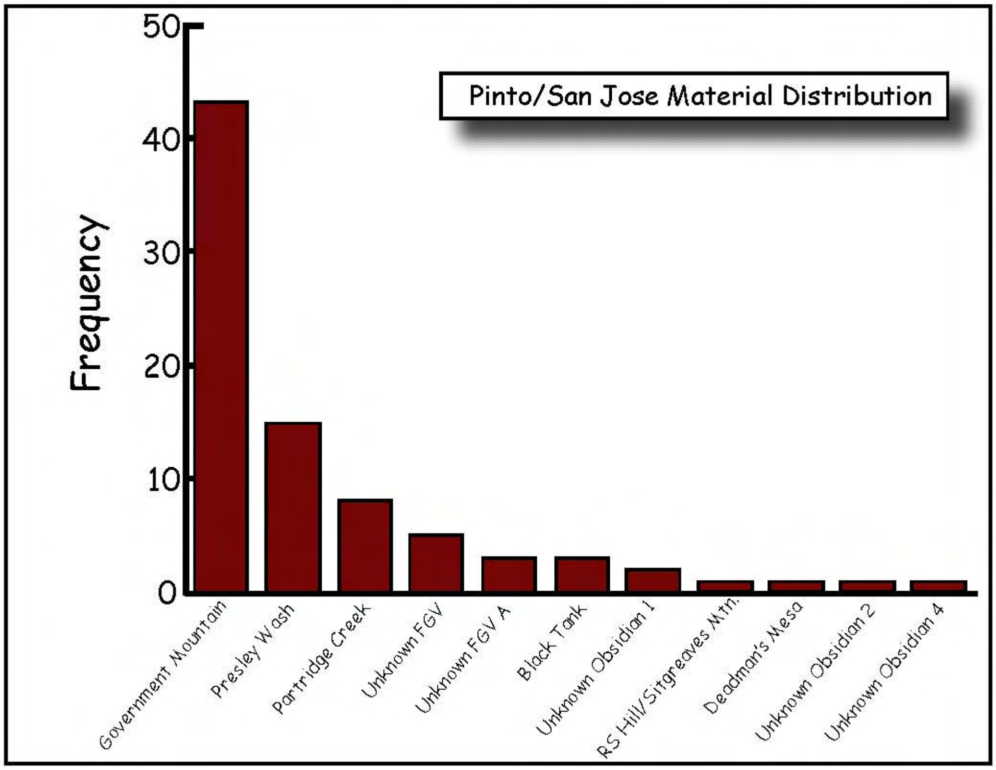


Figure 20. Toolstone frequencies within the Pinto/San Jose projectile point type.

Sudden Side-notched (Middle Archaic)

Sudden Side-notched points remain one of the lesser known in the typology. However, Lyndon (2005: 64) provides a brief description: "Sudden Side-notched points replace the Northern Side-Notched form around 6,400 B.P. and continue until 4,400 B.P." Named after Sudden Shelter, Utah, the Sudden Side-notched variety appears to occur only on the Colorado Plateau (Justice 2002: 163). Interestingly, no sites have yielded a good sample of Sudden Side-notched points besides Sudden Shelter (n = 18) though the type occurs in fewer numbers across the northern Southwest (Justice 164-165). As noted, the Sudden Side-notched type differs from the Northern variety based on bases and notches. Ten Sudden Side-notched points (3.5% of total) exist within the current sample, representing six obsidian sources. The points were made from Government Mountain (n = 3), Partridge Creek (n = 1), Presley Wash (n = 3), RS Hill/Sitgreaves Mountain (n = 1), Unknown Obsidian 1 (n = 1), and Unknown FGV (n = 1).

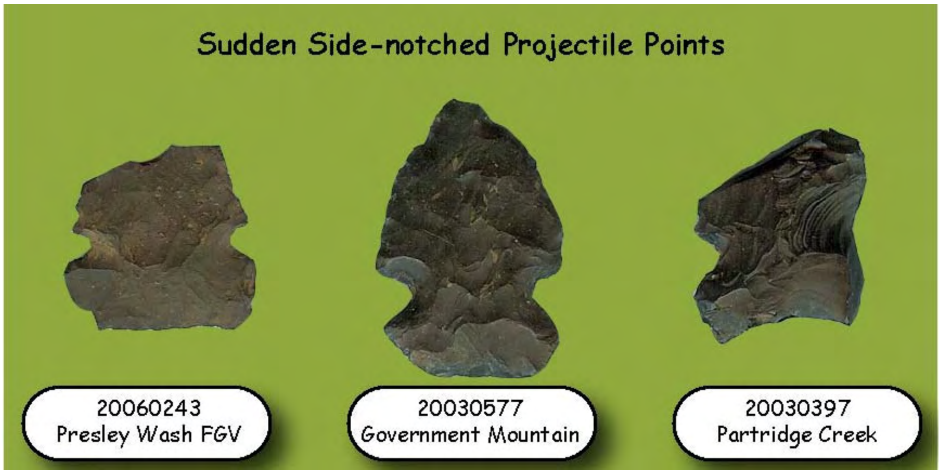


Figure 21. Examples of Sudden Side-notched points and different toolstone sources used in their manufacture.

Rocker Side-notched (Middle Archaic)

The Rocker Side-notched point type represents one form added to the typology by Novotny (2007). Novotny (2007: 55) defines the type based on the presence of two distinguishing attributes, "high U-shaped notches and well-rounded, long stems." Because of the type's scarcity in the local archaeological record, few researchers mention Rocker Side-notched points. According to Novotny (2007: 55), the type dates from 6,400 B.P. to 4,400 B.P.

Rocker Side-notched points constitute less than 2% (n = 5) of the current sample. Three obsidian sources were exploited for the five points, including Government Mountain (n = 3), Presley Wash (n = 1), and Unknown FGV (n = 1). Interestingly, all five of the Rocker Side-notched points were recovered from off-site contexts. Both points within the Kaibab collection were manufactured from Government Mountain obsidian, one (20060560) displaying heavy patination. The remaining three points from the private collection originated from three separate sources. While Novotny (2007: 55) holds "prehistoric people reworked point 20060555 for hafting purposes", the previously mentioned patinated point certainly was not. Based on the recortication and the medial impact fracture, it appears the point was lost in use and never reused by later peoples. The Rocker Side-notched type may represent a point style used by a small population or for specific purposes.

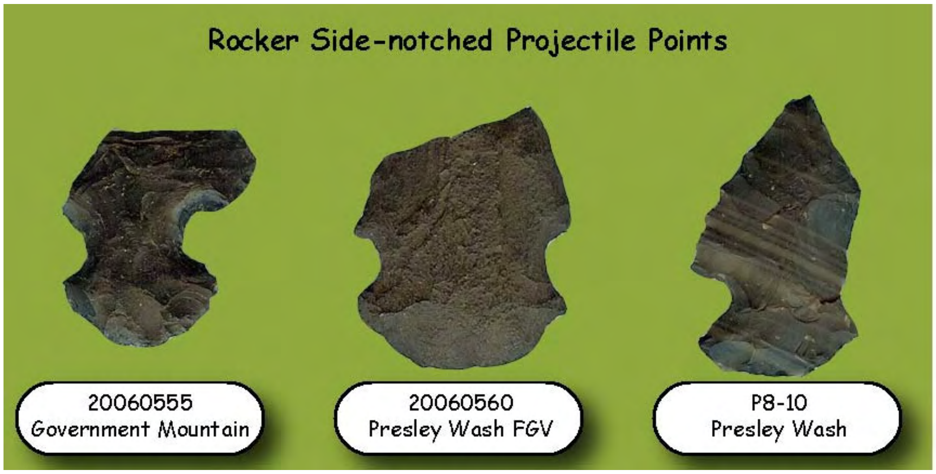


Figure 22. Examples of Rocker Side-notched points and different toolstone source used in their manufacture.

The suite of projectile points developed in the Late Archaic Period (2400 B.P. – 4600 B.P.) increased in diversity and appearance. Late Archaic projectile points include the Armijo, Chiricahua, Elko-Eared, Gatecliff Split-Stemmed, Gypsum Cave, and San Rafael Side-Notched.

Gatecliff Split Stemmed (Late Archaic)

Gatecliff Split Stemmed points exhibit concave bases on the stem with prominent shoulders. The contracting stems of the Gatecliff Split Stemmed dart point are similar to the Pinto/San Jose type but differ due to the large, triangular blade (Lyndon 2005: 66). Holmer (1986: 97) assigns the date range of 5,000 B.P. to 3,300 B.P., securing the temporal range of the type at the terminal Middle Archaic and lasting well into the Late Archaic. The geographic distribution of the Gatecliff Split Stemmed variety spans from the California coast east to the Continental Divide (Justice 2002: 147).

Figure 23. Examples of Gatecliff Split-stemmed points and different toolstone source used in their manufacture.

The current sample contains five Gatecliff Split Stemmed projectile points. The five points represent four obsidian sources. The sources include Partridge Creek (n = 3), Government Mountain (n = 1), and Unknown Obsidian 1 (n = 1). All three points within the Kaibab collection were manufactured from Partridge Creek obsidian. The Gatecliff Split Stemmed exists as the only type in the current study not primarily manufactured from the Government Mountain source.

San Rafael Side-notched (Late Archaic)

The San Rafael Side-notched point type exhibits a unique appearance due to “notches placed high on the side and deeply concave bases” (Lyndon 2005: 66). According to Holmer (1986: 104), San Rafael Side-notched type replaced the Sudden and Rocker Side-notched forms by 4,400 B.P. Slight disagreement exists between archaeologists about the exact date range of the type (Lyndon 2005: 67), though all confidently place the San Rafael Side-notched within the Late Archaic. The San Rafael Side-notched variety occurs across the northern Southwest and has been recovered from surveys south of the Grand Canyon, at Point of Pines, along the Little Colorado River, and in Chaco Canyon (Justice 2002: 165-166).

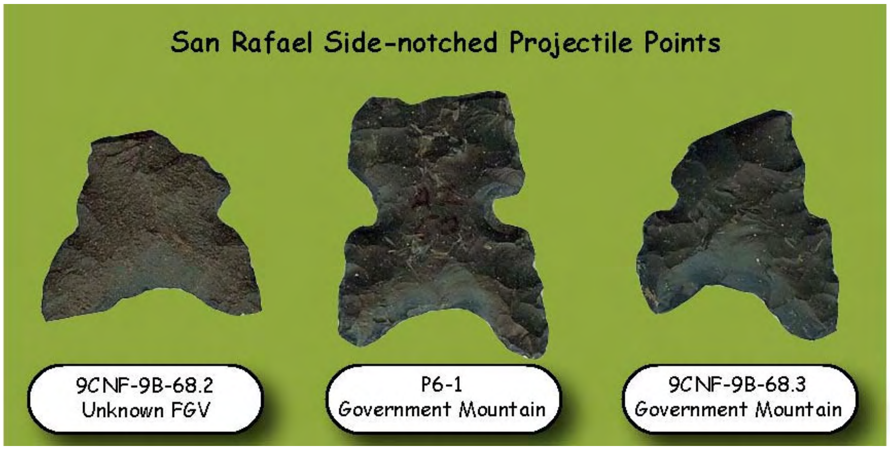


Figure 24. Examples of San Rafael Side-notched points points and different toolstone sources used in their manufacture.

San Rafael Side-notched points are exceedingly rare in the current sample. Only three points occur, representing three obsidian sources. Government Mountain, Presley Wash, and Unknown FGV were exploited to manufacture San Rafael Side-notched points.

Gypsum Cave (Late Archaic)

Gypsum Cave points take on a variety of morphological forms, prompting some archaeologists (Dick 1965, Novotny 2007) to divide the type into separate varieties. I decided to follow Lyndon (2005) and place all Gypsum Cave points together for standardization and simplicity. Lyndon (2005: 67) describes Gypsum Cave points as “large, stemmed, shouldered points with convex bases” though because many Gypsum Cave points exhibit evidence of extensive re-use, certain points lack the stem and instead appear bi-pointed and leaf-shaped (Novotny 2007: 58-59). The variation in the Gypsum Cave type often creates confusion when attempting to identify the distal and proximal ends. Lyndon provides the following discussion of Gypsum Cave chronology:

> “Gypsum points are commonly associated with split twig figurines and appear to be well accepted as diagnostic of the Late Archaic Period. Holmer (1986: 105) notes that the ‘temporal placement [of Gypsum points] is remarkable consistent’ and posits a date range of 4,500 – 1,450 B.P. However, it is important to note that Gypsum points appear to be continually produced into the Basketmaker II period…Considering the fact that the start date for the Basketmaker II period may be as early as 4,000 B.P. (Smiley 2002), it may be helpful to view Gypsum points as Late Archaic to Basketmaker transitional points”

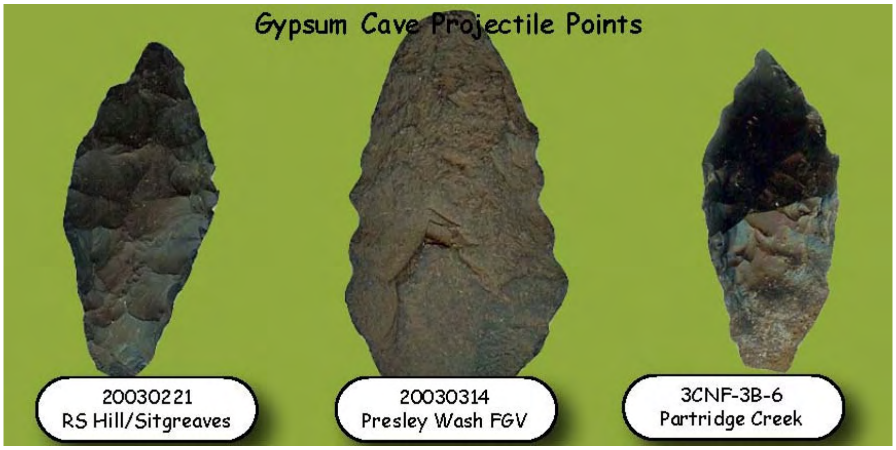


Figure 25. Examples of Gypsum Cave points and different toolstone sources used in their manufacture.

Lyndon’s (2005: 67-68) contention that “obsidian is overwhelmingly favored as a material for this type” is supported by the number of Gypsum Cave points (n = 74) contained within the current study. Late Archaic hunter-gatherers procured toolstone from eight obsidian sources for use in Gypsum Cave points. The toolstone sources include Government Mountain (n = 27), Partridge Creek (n = 14), Black Tank (n = 4), Presley Wash (n = 21) RS Hill/Sitgreaves Mountain (n = 3), Unknown Obsidian 3 (n = 1), Unknown FGV A (n = 3), and Unknown FGV (n = 1).

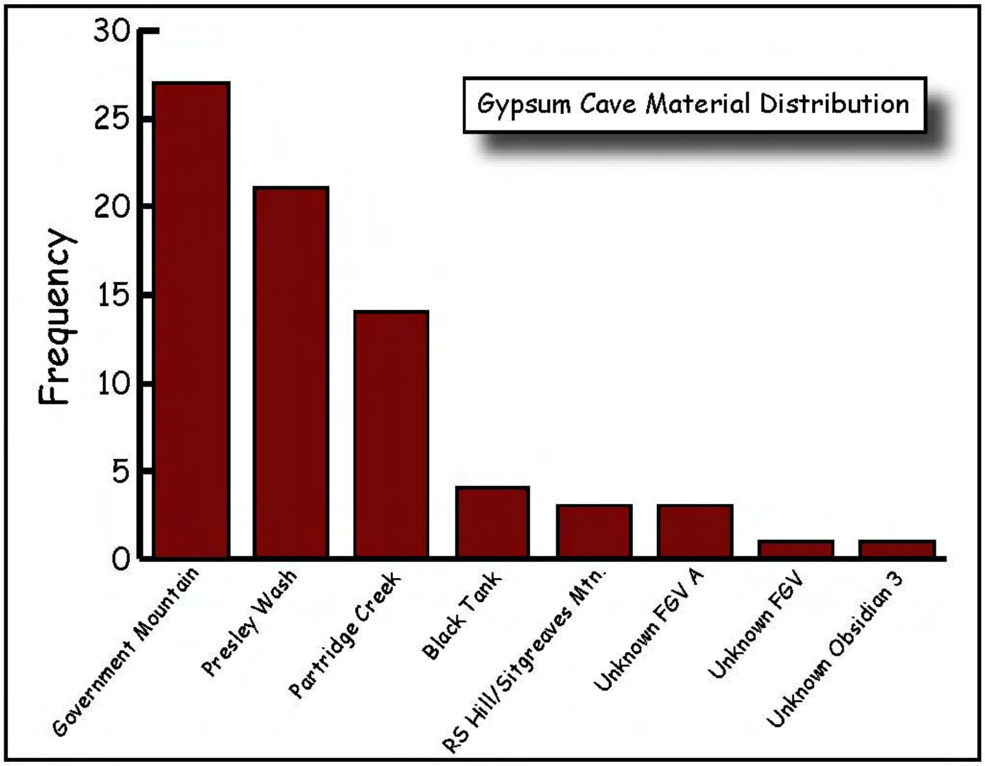


Figure 26. Toolstone frequencies within the Gypsum Cave projectile point type.

Elko Eared (Late Archaic)

Elko Eared projectile points represent another fairly common type in the study. Justice (2002: 298) defines the type as “corner notched points made from a trianguloid perform with indented or concave bases and basal ears.” Although several types belong to the Elko family, only the Elko Eared type possesses tight chronological control. Thomas (1981:20) places the Elko Eared type between 3,740 B.P. and 3,300 B.P., making the Elko Eared the most temporally diagnostic point in the study. In addition, the Elko Eared type displays unique morphological characteristics, facilitated the identification and classification process.

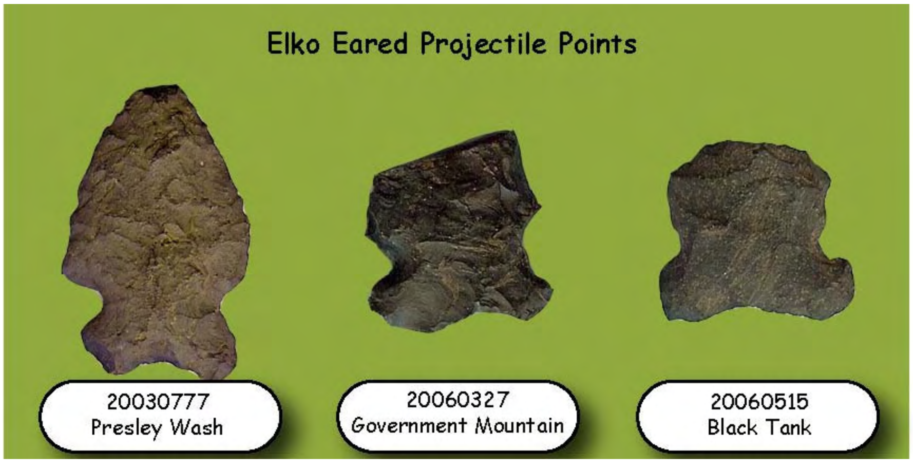


Figure 27. Examples of Elko Eared points and different toolstone source used in their manufacture.

Thirty-two Elko Eared points exist within the current sample, 25 recovered from the southern Kaibab National Forest. Of these, nearly half are manufactured from Government Mountain obsidian (n = 15). Four other obsidian sources are represented in the type, including Presley Wash (n = 9), Partridge Creek (n = 5), RS Hill/Sitgreaves Mountain (n = 2), and Black Tank (n = 1). Relatively few sources were utilized for the number of Elko Eared projectile points included in the study. In comparison, the 25 Bajada points in the sample were manufactured from seven different sources while the ten Sudden Side-notched points herein represent six obsidian sources.

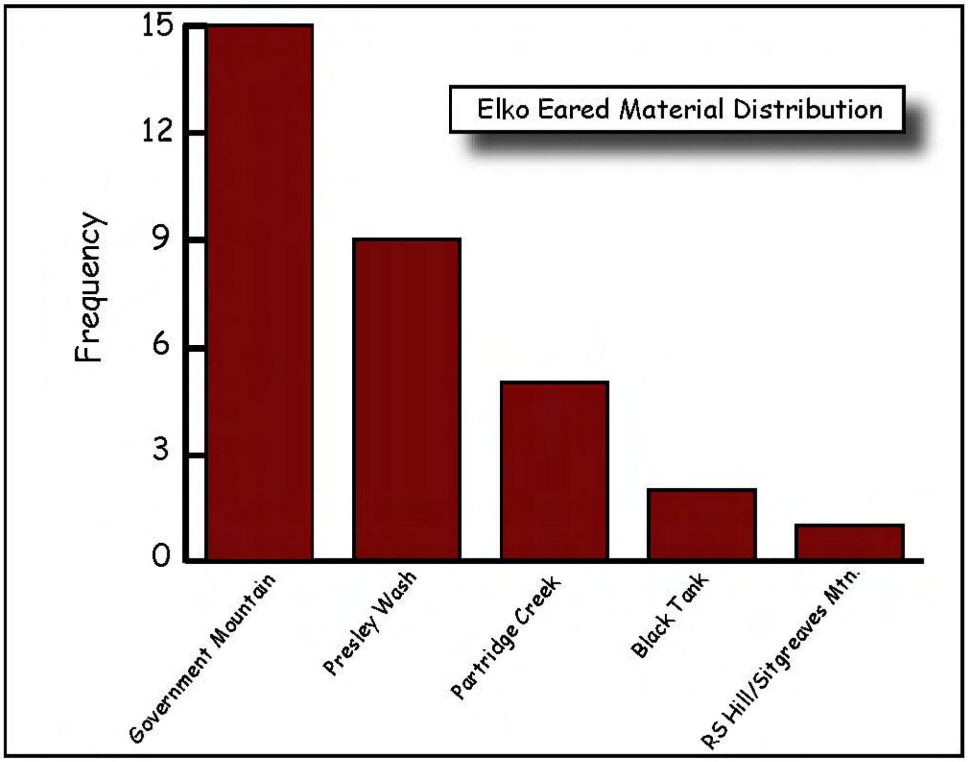


Figure 28. Toolstone frequencies within the Elko Eared projectile point type.

Chiricahua (Late Archaic)

Chiricahua projectile points correspond to the middle phase of the Cochise cultural sequence (McGregor 1965: 126). The Chiricahua type is characterized by the presence of side notching and deeply concave bases. Chiricahua points resemble Elko Eared except possess more lanceolate blades and longer bases. In addition, Chiricahua points appear to exhibit generally thinner neck width and weight (Novotny 2007: 62-63). Most archaeologists agree about the temporal range of Chiricahua points lasting from 4,800 B.P. to roughly 2,500 B.P.

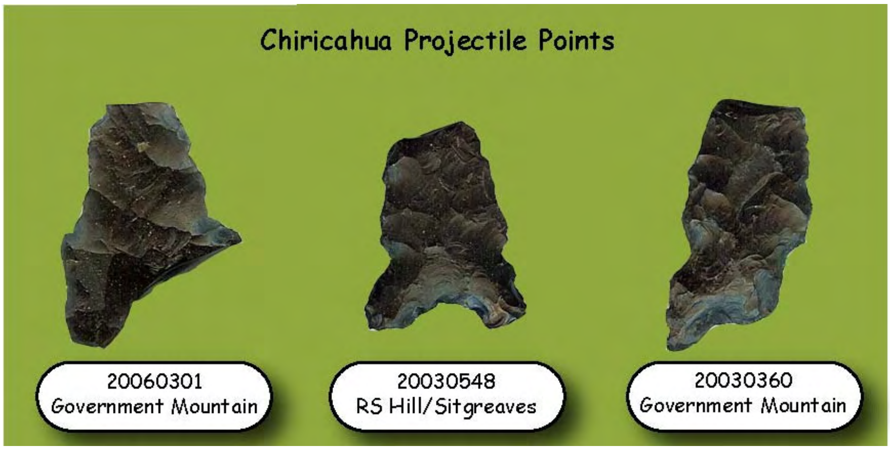


Figure 29. Examples of Chiricahua points and different toolstone source used in their manufacture.

Projectile points classified as Chiricahua type numbered only nine in the data set. Chiricahua represents the fewest number of exploited obsidian sources. Two igneous toolstone sources were used to manufacture the points, Government Mountain (n = 7) and RS Hill/Sitgreaves (n = 2). Chiricahua thus is the only point type in the study made only from sources within a source patch. The Spring Valley Group of obsidian sources, which includes Government Mountain, RS Hill, and Sitgreaves Mountain, all lie directly adjacent to one another. Moreover, the three volcanic features produce similar toolstone.

Armijo (Late Archaic)

Armijo points are medium-sized dart points exhibiting relatively short concave bases with “basal ears that protrude from the hafting element, often at nearly right angles” (Lyndon 2005: 73). Justice (2002: 137) describes Armijo points as “basically a diminutive form evolved from San Jose”. Originally defined by Irwin-Williams (1973) as part of the Oshara Tradition, the Armijo type remains “poorly defined and notably absent from most…typologies” (Lyndon 2005: 72). The temporal problems likely stem from the fact that the Oshara Tradition was based on archaeological work performed in the "Arroyo Cuerva region of northwestern New Mexico" and has subsequently "been used over much of the northern Southwest. Most Oshara applications are a function of the absence of local chronological information" (Smiley 2002: 27-28). Nevertheless, I include the Armijo type in order to remain consistent with the current typology.

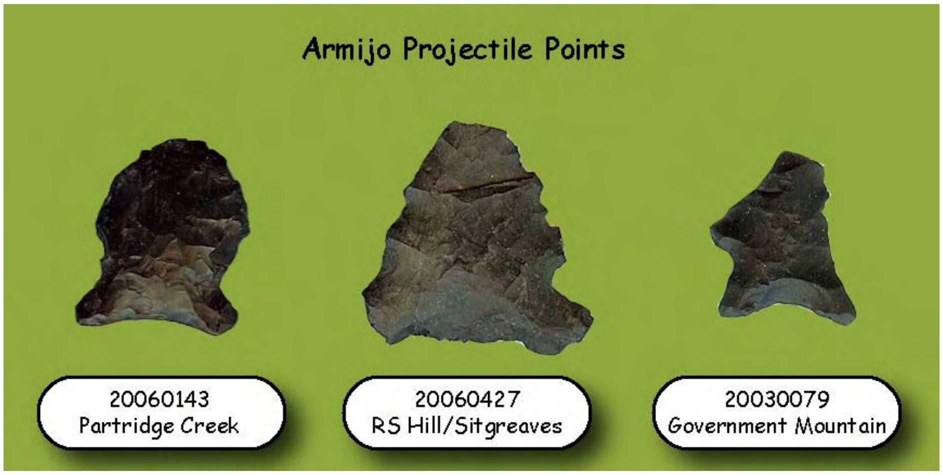


Figure 30. Examples of Armijo points and different toolstone source used in their manufacture.

The current sample contains 17 Armijo points manufactured from four obsidian sources. The sources are Government Mountain (n = 9), Partridge Creek (n = 5), RS Hill/Sitgreaves (n = 2), and Unknown FGV A (n = 1). The assemblage includes 10 Armijo points recovered from the Kaibab National Forest and seven from the private collection. Armijo joins Chiricahua (n = 9) and Gatecliff Split Stemmed (n = 5) lacking points manufactured from the Presley Wash source.

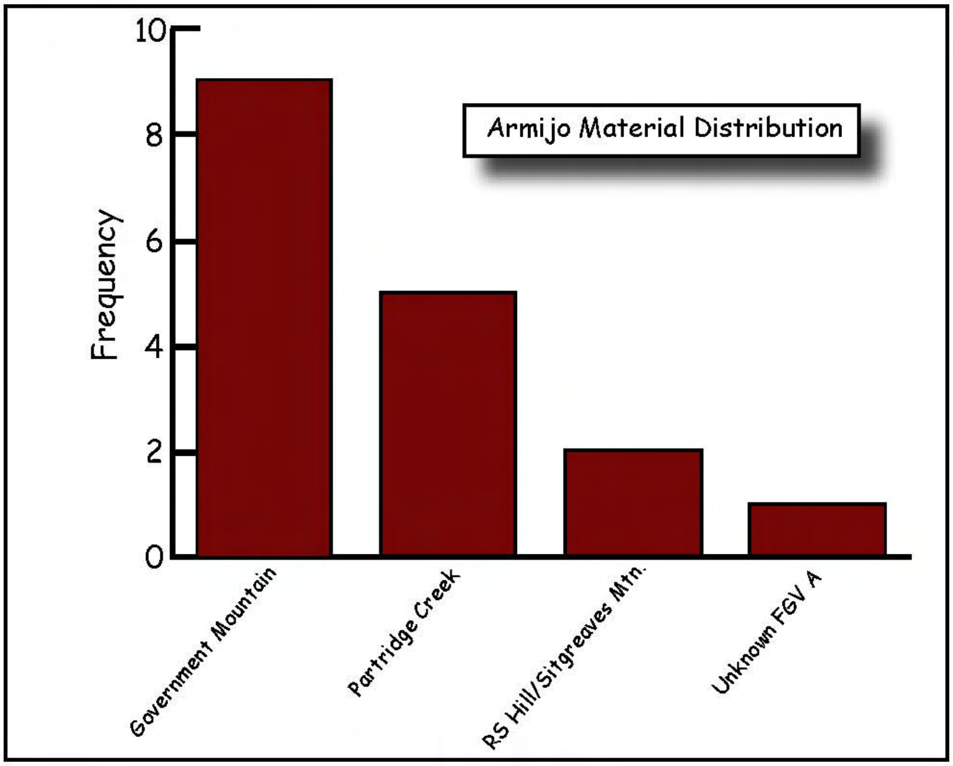


Figure 31. Toolstone source frequencies for Armijo projectile points.

Source Locations and Material Descriptions

Hunter-gatherers occupying northern Arizona during the Archaic Period were confronted with a vast array of resource procurement decisions. Hunter-gatherers presumably integrated such decisions to maximize foraging efficiency. A necessary balance was attained when relatively unpredictable and dynamic resources (such as food), was exploited within a strategy that also allowed for lithic raw material procurement. Thus, we should expect a spatial correlation between both types of resources. In order to understand the complexity of such behavior, the geographic and environmental setting of each obsidian source must be taken into account (Figure 32). In addition, because the material quality of the various obsidians also conditioned foraging behavior, brief descriptions of each ought to be known. Therefore, if lithic raw material procurement was incidental to a generalized subsistence strategy, then the most frequently exploited obsidian source (Government Mountain) should display a greater variety of desirable resources in close proximity. Was the best set of lithic source options located within more suitable foraging areas?

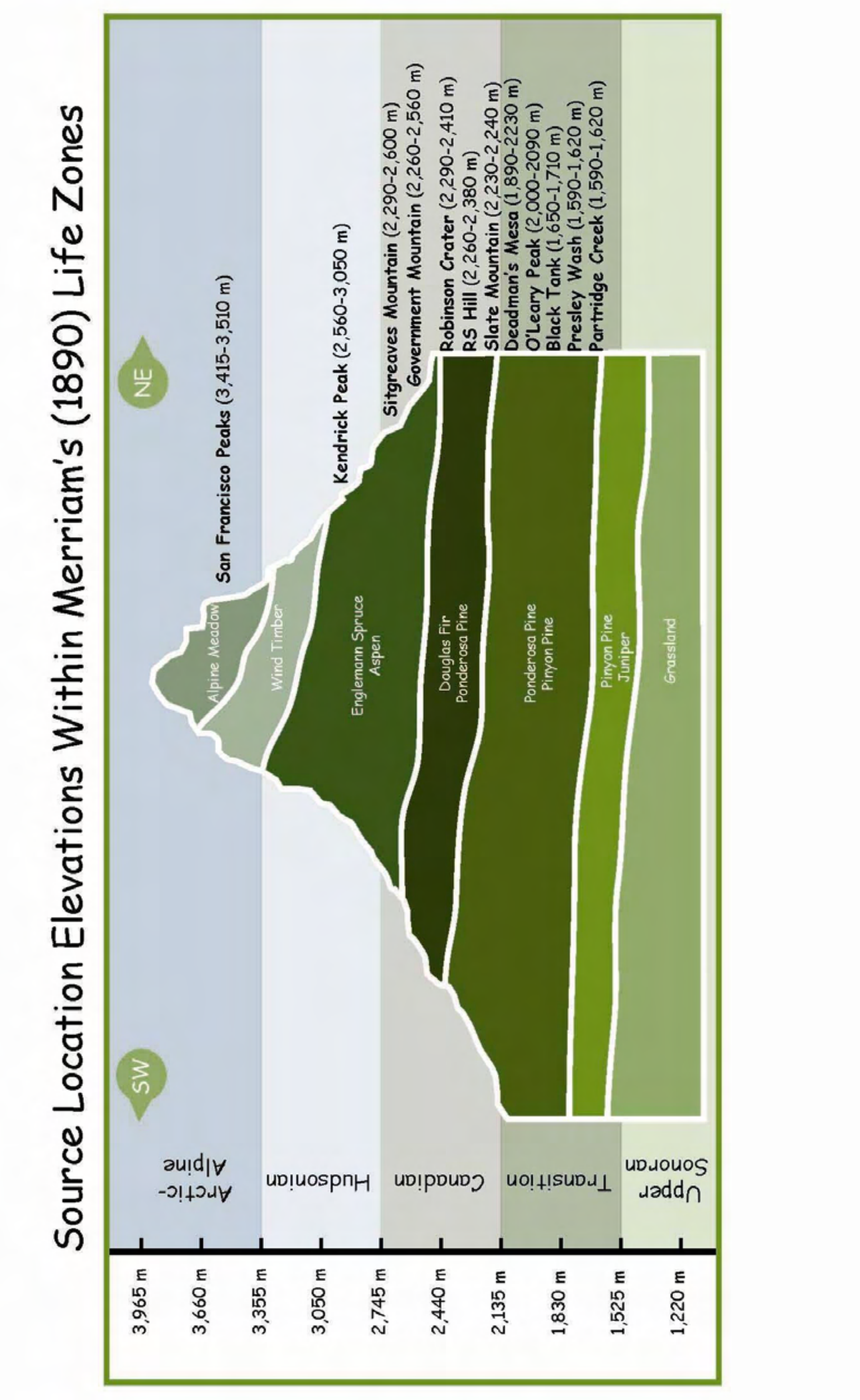


Figure 32. Diagram of Source Elevations Within Merriam's Life Zones.

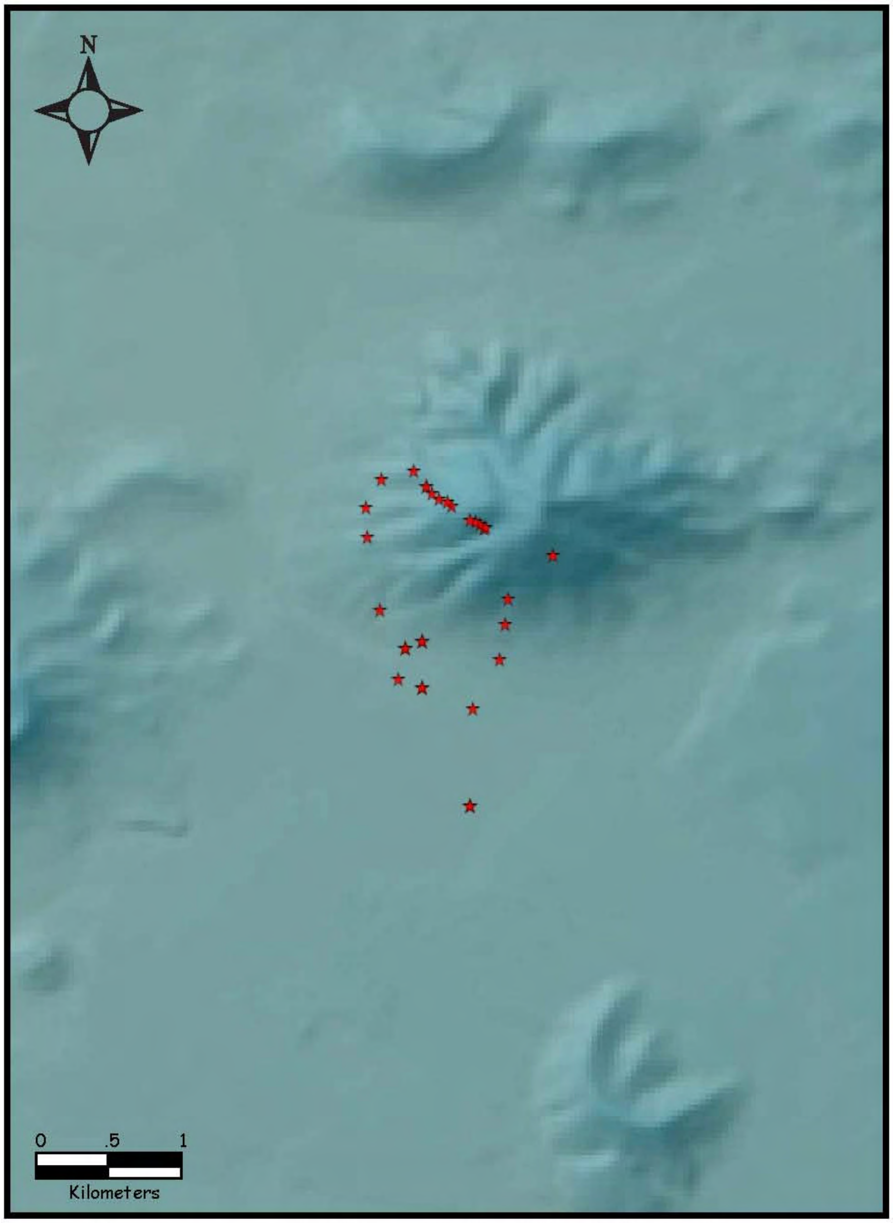
Government Mountain

Government Mountain obsidian was the preferred lithic raw material in northern Arizona throughout prehistory and is still exploited today by experimental archaeologists. In fact, as Wiegand (1990: 1) explains, the obsidian was “exploited long after the Flagstaff/San Francisco Peaks cultural system collapsed.” As such, Government Mountain remains the most well known obsidian in the northern Southwest. However, the current study shows evidence of significant changes in use of the material through time, providing a much more sophisticated look at the use of the obsidian. Government Mountain is included in the Spring Valley group of obsidian sources along with RS Hill and Sitgreaves Mountain, all situated in close proximity.

Government Mountain lies roughly 25 miles northwest of Flagstaff. The mountain exhibits the classic cinder cone shape with the 33 degree slope of all faces broken up by numerous ravines. One such ravine, located on the southwest slope, carries the majority of obsidian at the source. Although nodules occur everywhere on the mountain and onto the surrounding plateau, the highest density and largest size nodules found at Government Mountain occur in this ravine at roughly 2,500 meters. Government Mountain rises above the sparsely vegetated Government Prairie at great enough elevation (800 feet) to support a dense Ponderosa Pine forest. Due to the Ponderosas, the surface of Government Mountain is covered by a thick layer of duff, obscuring archaeological evidence.

Government Mountain is a black, aphyric obsidian with a distinctive smooth-medium texture. Researchers have described the material in various ways, reflecting the difficulty of such descriptions. For example, Sanders (1981: 7) states, "Government Mountain obsidian generally has a light gray weathered appearance." Alternatively, Shackley (2005: 116), states "the material is opaque and exhibits conchoidal fracture properties." This obsidian usually lacks phenocrysts, though some nodules may contain small infrequent inclusions. Government Mountain is slightly subvitreous and has a waxy luster. This obsidian displays excellent workability. The obsidian is often successfully identified due to the unique oily/shimmery appearance on its surface.

Although Jack (1971: 105) places Government Mountain and Sitgreaves Mountain in the same trace element group, the current XRF analysis successfully isolates Government Mountain from RS Hill/Sitgreaves Mountain based on quite different strontium (sr) and zirconium (zr) ppm ratios. Unfortunately, RS Hill and Sitgreaves Mountain cannot, at this time, be differentiated. Thus, Appendix C refers to both sources as RS Hill. Likewise, Slate Mountain and Kendrick Peak share similar geochemical signatures as well.



Government Mountain Obsidian Source
Sample Locations
(n = 34)

Figure 33. Digital Elevation Model showing sample locations at Government Mountain obsidian source.

Black Tank

Black Tank refers to the general area where the obsidian is found, not to a visually unique raw material. Although Black Tank has traditionally been identified as the source of a distinctive mahogany obsidian, very little of this material remains. Indeed, nearly two decades have passed since Lesko (1989: 390) wrote, "Local ranchers witnessed larger nodules in the past but rock hounds have apparently carried off much of this attractive material." During source sampling survey, I encountered very few nodules of mahogany obsidian.

Archaeologists have long referred to the mahogany glass as Rose Well. The area surrounding Black Tank, however, proved to include more than one type of igneous toolstone. Because the area is at a confluence of several drainages, four varieties occur. The obsidian located in the vicinity of Black Tank is abundant and presumably originated at Round Mountain (Bush 1986). The obsidian occurs as non-localized, large surface nodules at an elevation of about 1,700 meters. The area, dominated by pinyon/juniper woodland, lies between two mesas, Rose Well and Pinkley.

The first type of Black Tank obsidian is black and brick red with a smooth texture. This is the material with which Black Tank has been associated. The aphyric material is translucent when very thin. The red and black variety exhibits a waxy luster and is slightly subvitreous. Lesko (1989:389-390) describes the mahogany nodules as originating in an area disturbed by a cattle tank. However, the present survey failed to locate abundant material in that area. In addition, the obsidian described by Shackley (1995: 537) as the "black material nearly identical megascopically to Partridge Creek glass." was not encountered.

The second variety of Black Tank obsidian is dark gray with a medium grainy texture. This type is completely opaque and displays slightly uneven fracture properties. The dark gray variety lacks inclusions and appears basaltic. The third variety is rhyolitic and gray or greenish gray with smooth texture and waxy luster. The gray type is opaque yet lacks phenocrysts. This variety fractures conchoidally and is subvitreous. The fourth variety is a flow-banded version containing the black grainy basalt and the gray basalt. Both the gray and flow-banded varieties look very similar to Presley Wash obsidian and care should be exercised when identifying such material. Researchers have had success in visually differentiating the two sources (Lyndon, personal communication 2008) based on differing surface lusters.

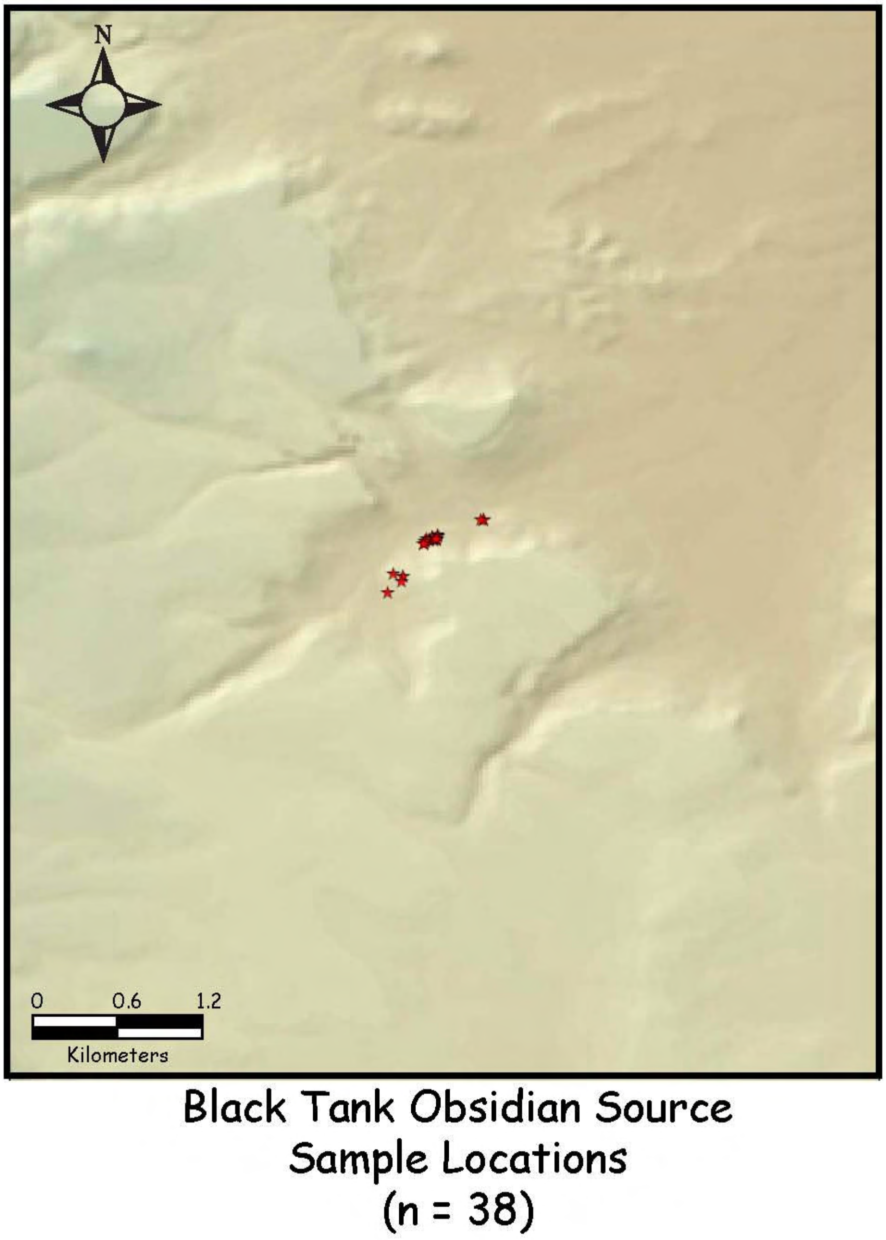


Figure 34. Digital Elevation Model showing sample locations at Black Tank obsidian source.

Deadman's Mesa

Deadman’s Mesa fine-grained volcanic material had yet to be documented or geochemically analyzed when Dr. Christian Downum informed me of its existence. Deadman’s Mesa protrudes as a large fan-shaped mesa extending from the north slope of O’Leary Peak. The mesa stretches approximately 3 kilometers to the northeast of the summit of O’Leary Peak and rises roughly 300 meters from the surrounding countryside. The mesa is dominated by pinyon-juniper woodland and exhibits good ground visibility. Obsidian occurs along the northern extent either as bedrock outcrops or eroded nodules at elevations ranging from roughly 1,900 to 2,200 meters. The material was encountered primarily along the slope and around the flanks of the northwest side of the mesa. The nodules remain close to the mesa due to lack of significant colluvial movement. Visually, two varieties occur. The first, poor-quality granular basalt contains brick red flow banding within a dark gray matrix. The flow-banded type exists primarily as large outcrops. The second variety is dark gray to black and exhibits a medium grainy texture. This obsidian is basaltic and is thus completely opaque. The variety exhibits predictable fracture properties, making the material quite suitable for biface manufacture. Both varieties of Deadman’s Mesa generally lack inclusions. The cortex is frequently brown and highly textured. The material is not vitreous and lacks phenocrysts. Deadman’s Mesa material resembles the fine-grained volcanic material at Presley Wash. During source sampling, I gathered both varieties totaling 23 samples. Interestingly, the two visually distinct types exhibit the same geochemical signature.

Ebert Mountain

Ebert Mountain lies roughly 35 miles northwest of Flagstaff in a pinyon and juniper woodland. I encountered the material in a drainage and along a dirt road running northeast of the mountain and the primary outcrop was not located. The material is a low-quality black material occurring as small nodules. The obsidian contains numerous phenocrysts, displays uneven fracture properties, and exhibits a waxy luster. Slightly subvitreous, Ebert Mountain is notable for its freckled appearance. Ebert Mountain obsidian exists today as the smallest nodules and least abundant source material in northern Arizona. Interestingly, Ebert Mountain material is nearly identical to O’Leary Peak and Robinson Crater obsidian geochemically except exhibits a higher titanium PPM ratio. Therefore, reliability of the material as a unique source remains in doubt.

Figure 35. Digital Elevation Model showing sample locations at Ebert Mountain obsidian source.

Kendrick Peak

Kendrick Peak lies roughly 22 miles to the northwest of Flagstaff, about five miles east of Government Mountain. The mountain is the second largest in the region and is visible for nearly 90 miles. The material outcrops on the southeast slope near 9,000 feet, though has eroded down a prominent gulley onto the surrounding Crowley Park. Most commonly, Kendrick Peak obsidian occurs as very black, vitreous material with abundant sanidine feldspar phenocrysts measuring 2 mm in diameter (Shackley 2005: 34). However, the material also exists in grey and mahogany varieties (Mike Lyndon, personal communication 2007). Occasionally, the black variety of Kendrick Peak obsidian occurs with gray flow-banding. The variability in the material likely owes to the fact that the large composite cone consists of five lava flows (Robinson 1913).

Figure 36. Photo showing Kendrick Peak surface obsidian.

This obsidian exhibits a smooth texture and is translucent when very thin. Kendrick Peak contains numerous internal flaws, including fracture plains and inclusions of ash. Despite these shortcomings, the obsidian is extremely sharp when broken. While extremely sharp, “Kendrick is not a good raw material for tool production and has not been detected in any archaeological contexts” (Shackley 2005: 34). However, as noted by Shackley (2005: 34), prehistoric peoples “tested” the material frequently as evidenced by abundant shatter and debitage occurring on the mountain. Because of the internal flaws, Kendrick Peak obsidian appears less than suitable for formal tools such as projectile points. Conversely, because of its sharpness, this material seems ideally suited for use as scrapers and flake tools. Kendrick Peak obsidian is very similar geochemically to Slate Mountain obsidian and also shares several visual characteristics with that source material.

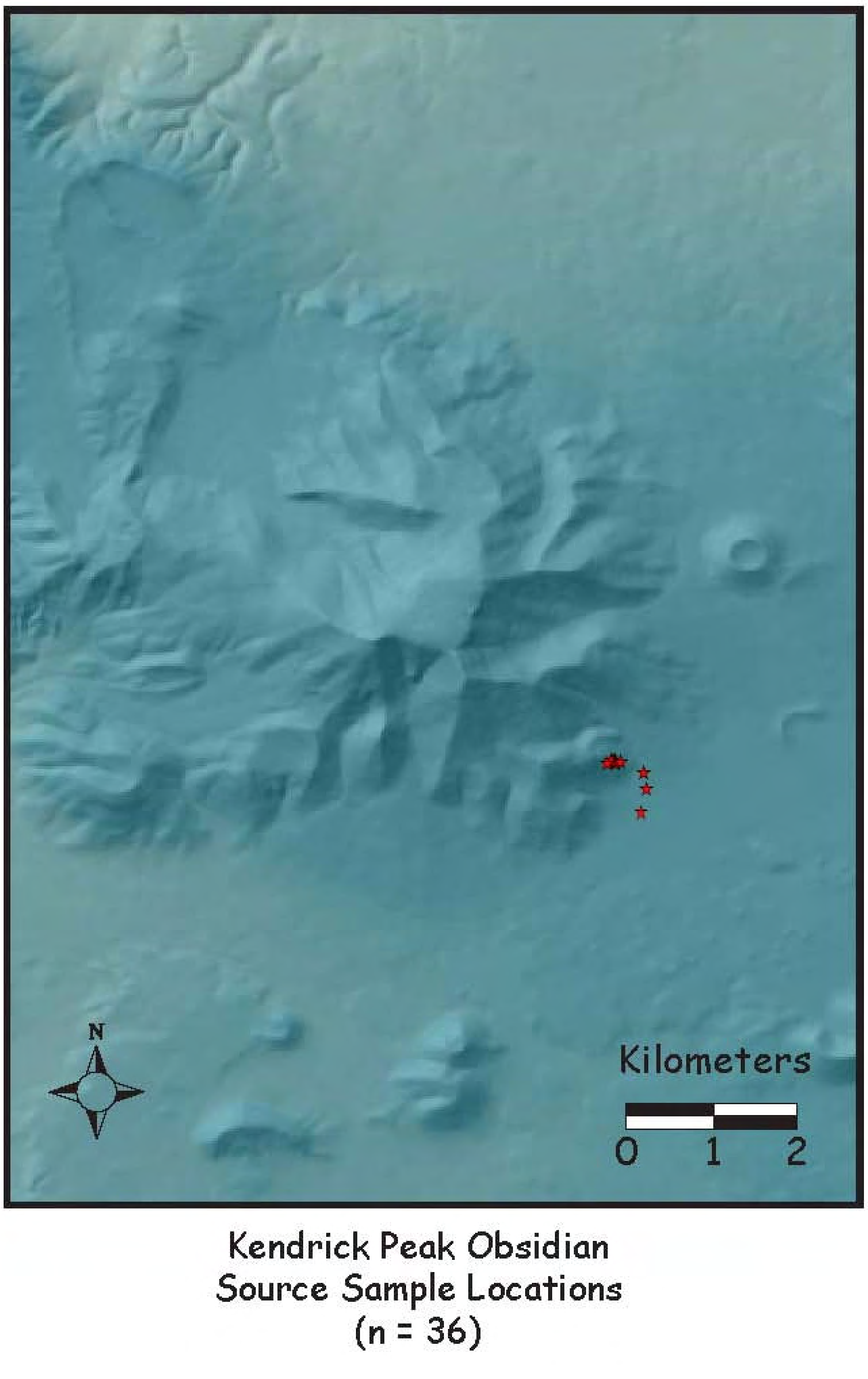


Figure 37. Digital Elevation Model showing sample locations at Kendrick Peak obsidian source.

Partridge Creek

The source of Partridge Creek obsidian lies in the west central section of the Coconino Plateau, approximately 80 kilometers west of Government Mountain (Lesko 1989: 388). Bush (1986: 31) identifies a small hillside south of Round Mountain as the geologic source of Partridge Creek obsidian. During the source sampling survey portion of my research, I discovered the material throughout the entire Partridge Creek drainage system. The area where the obsidian naturally occurs is quite large and attempts at differentiating primary and secondary deposits were not successful. Shackley (1988: 754-755) offers the following description of the Partridge Creek obsidian source: “The nodules are found in a rhyolite ash flow distributed mainly to the southeast of Round Mountain. The obsidian occurs as secondary deposits along Partridge Creek drainage for at least 15-20 kilometers.”

Partridge Creek obsidian is the highest-quality material in northern Arizona. The material is highly vitreous and lacks inclusions of any kind. This obsidian is invariably very dark black with a smooth texture. The translucent material lacks the internal flaws and color variation common in northern Arizona obsidians and resembles the very glassy material often associated with “classic” obsidian. Partridge Creek fractures conchoidally, further increasing its workability. Nodules occur in large sizes and the cortex exhibits fingernail-like depressions. As mentioned by Shackley (2005: 30), “Partridge Creek … seems to have been nearly as important as Government Mountain, and indeed is a good-quality large nodule source.”

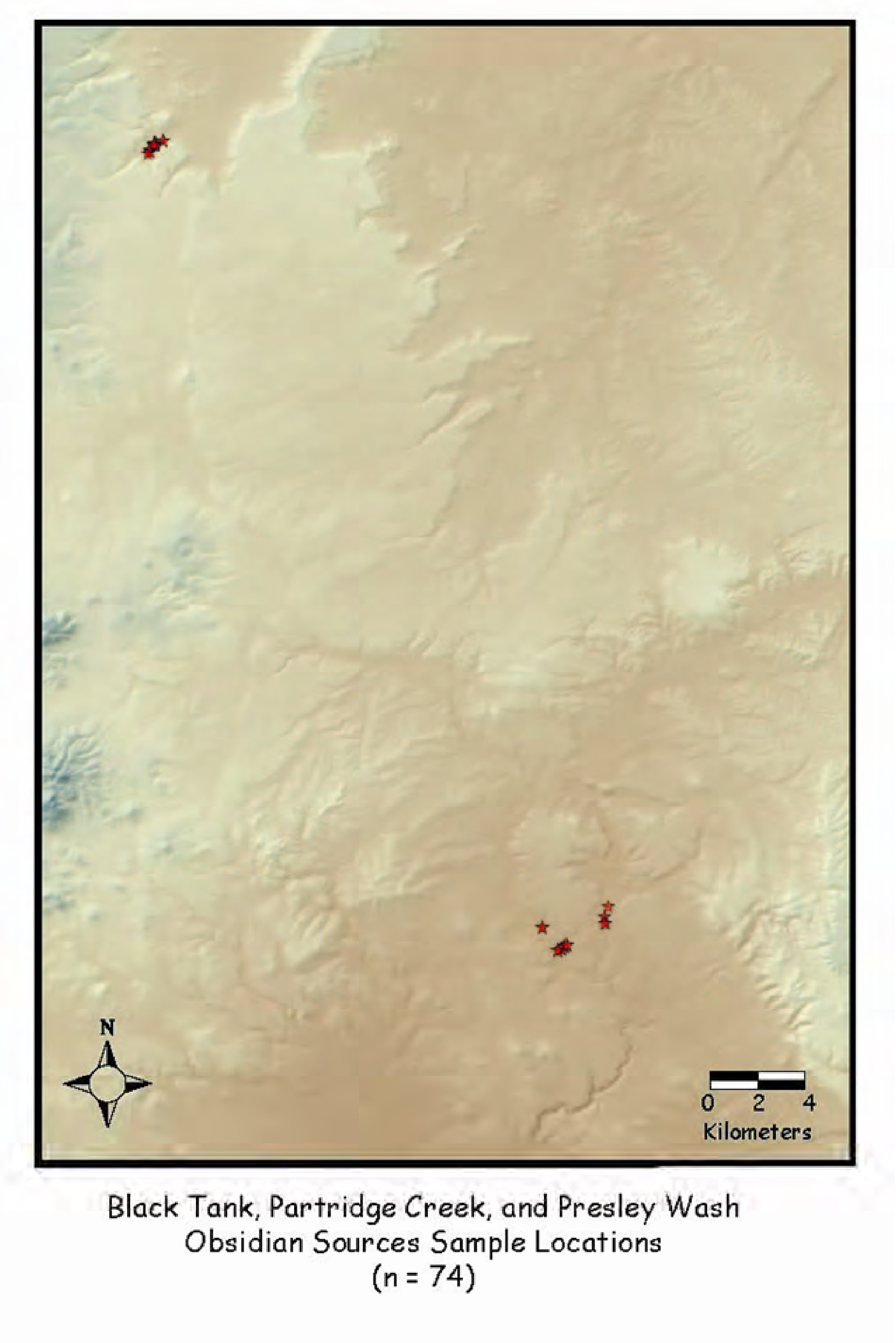


Figure 38. Digital Elevation Model showing the sample locations at Black Tank, Partridge Creek, and Presley Wash obsidian sources.

Presley Wash

Presley Wash obsidian originates near Round Mountain and exists today as rounded river cobbles exhibiting small incipient Hertzian cones, resembling crescent-shaped indentations on the cortex. According to Shackley (1995: 537),the material contains sanidine or plagioclase phenocrysts. Presley Wash obsidian displays the greatest visual variability of any northern Arizona igneous toolstone and "all varieties…are found in the alluvium" (Shackley 1995:537). One variety is a gray-green subvitreous rhyolite exhibiting a waxy luster and lacking phenocrysts. This variety is opaque with a smooth texture. A second type is very dark gray with a medium grainy texture and appears basaltic. A third variety is black and aphanitic, containing sparse phenocrysts. This type exhibits uneven fracture properties and is also opaque. In addition, several varieties occur as gradations between these types. Archaeologists should proceed with caution when classifying material as Presley Wash due to the variability of the material.

Shackley's (1995:537) contention that Presley Wash obsidian is "not well suited to the production of small bifaces", did not hold up in the current study. In fact, certain varieties of the material ranked among the finest source material for Archaic projectile points. While much of the material exhibits excellent workability, the abundance of the material also likely encouraged prehistoric exploitation. As Lesko (1989: 389) notes, "Presley Wash obsidian is considerably more plentiful at the geologic source than Partridge Creek and nodules as large as 30 centimeters in diameter may be observed”. According to Shackley (2005: 30), “a few pieces have been recovered as far south as Phoenix, but it seems to be a locally used stone.”

O’Leary Peak

O’Leary Peak, located approximately 35 kilometers northeast of Flagstaff is a large composite volcano dating to the second period of eruptive activity (Robinson 1913: 65). The obsidian occurs as eroded nodules along the east and northeast slopes. According to Schreiber (1967:15) obsidian outcrops “on the northeast side at an elevation of 6550 ft.” Although I failed to locate the primary source, I encountered the material along the base of the mountain. O’Leary obsidian is a gray to black, smooth-textured obsidian with abundant phenocrysts. The material is opaque with a waxy luster. This material exhibits uneven fracture properties and is not vitreous. When broken, O’Leary displays jagged edges and veiny white inclusions. The sample used for this study lacked O’Leary Peak obsidian. However, prehistoric populations exploited material originating from O’Leary during later Pueblo Periods. For example, at a site dating to the Angell/Winona-Padre (900 B.P.) Phase and located roughly 25 miles northwest of the source, Tsouras (2008) recovered debitage geochemically characterized as O’Leary material. In addition, Larue (personal communication, 2007) discovered a Late Archaic San Rafael point above 7,000 ft. on O’Leary Peak that looks like the material.

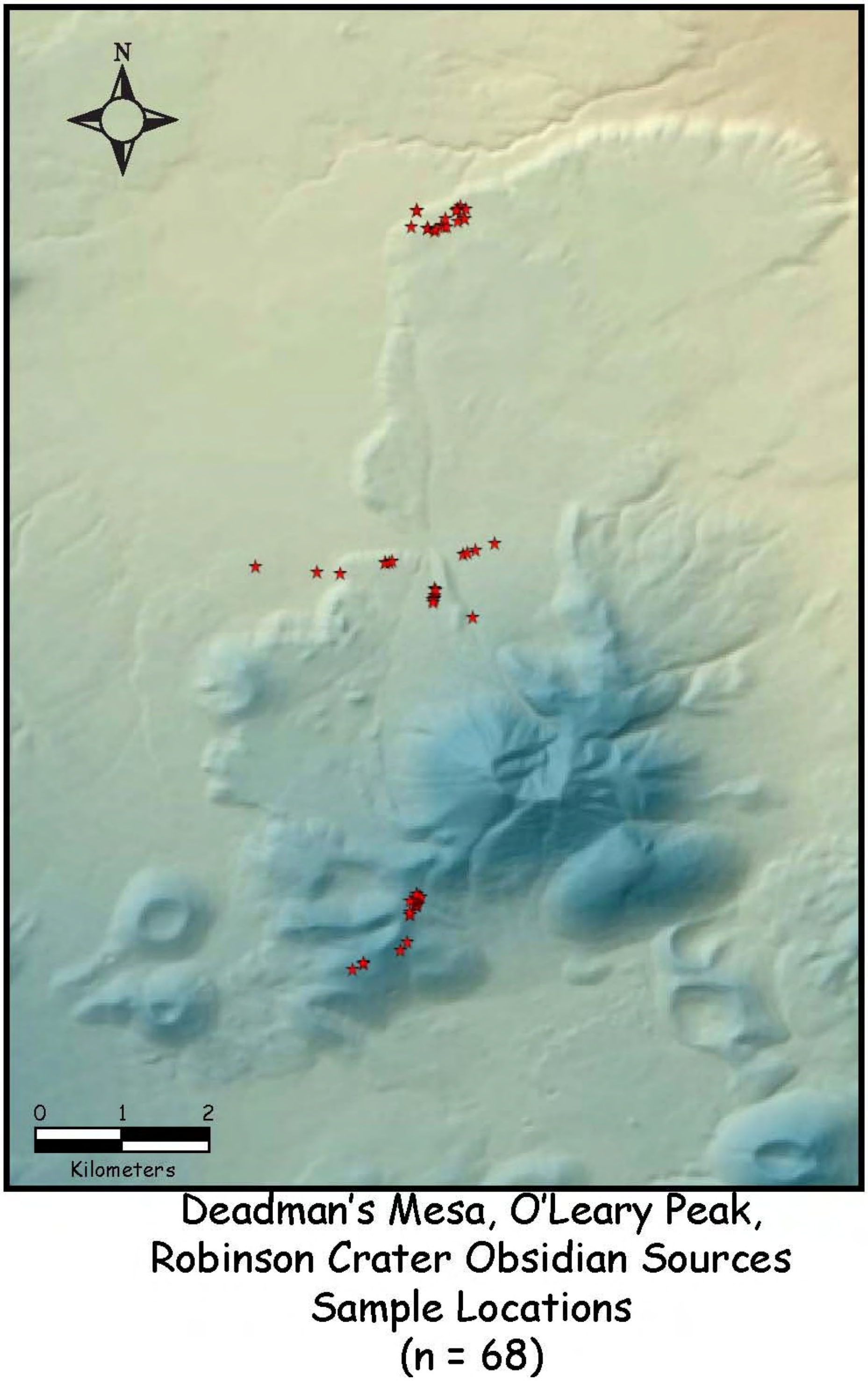


Figure 39. Digital Elevation Model showing sample locations at Deadman's Mesa, O'Leary Peak, and Robinson Crater obsidian sources, north to south.

Robinson Crater

Robinson Crater lies on the southwest face of O'Leary Peak at an elevation of roughly 2300 meters. The material is visually and geochemically similar to O'Leary Peak, in fact the two cannot be differentiated by XRF analysis. Scheiber's (1967: 19) contention that "the obsidian examined proved to have the greatest variety" of local obsidian sources was not substantiated by the current study. The material occurs as large surface nodules and is abundant on the interior west and northwest slopes. Like O'Leary Peak, the material is also gray, though slightly lighter in coloration than O'Leary. Robinson Crater exhibits abundant phenocrysts and has a smooth texture. This obsidian is opaque with a waxy luster and also displays uneven, angular fracture properties. Robinson Crater obsidian has a smoother, more polished cortex than O'Leary. Like O'Leary, archaeological evidence of prehistoric exploitation of Robinson Crater obsidian did not exist in the current sample. However, according to Colton (1967), the material was "used for arrow points by Indians who dwelt in this neighborhood in the 900's A.D."

RS Hill

RS Hill, a small rhyolite dome, lies northeast of Sitgreaves Mountain among the Spring Valley group of obsidian sources. RS Hill lacks the defining shape of a classic cinder cone, looking instead more oblong with gently sloping sides. The hill rises approximately 200 meters above the surrounding plateau and obsidian was gathered between 2,260 and 2,380 meters along the north slope and adjacent plateau. According to Robinson (1913: 67), RS Hill erupted at the same time as Government Mountain.

RS Hill is similar to Government Mountain but instead can contain abundant phenocrysts, although not always. The obsidian is generally black, highly vitreous and translucent but can also appear as a “dull black, very fine grained glass” (Schreiber 1967: 4). The material displays uneven fracture properties due to the large number of phenocrysts, yet otherwise is a very sharp, high-quality glass. Based on the current samples, RS Hill can easily be mistaken for Sitgreaves Mountain, even with extensive experience with northern Arizona obsidians. In addition, a cursory examination of certain nodules of RS Hill could be mistaken for Slate Mountain or Kendrick Peak. Archaeologists should be aware of these ambiguities when identifying this material.

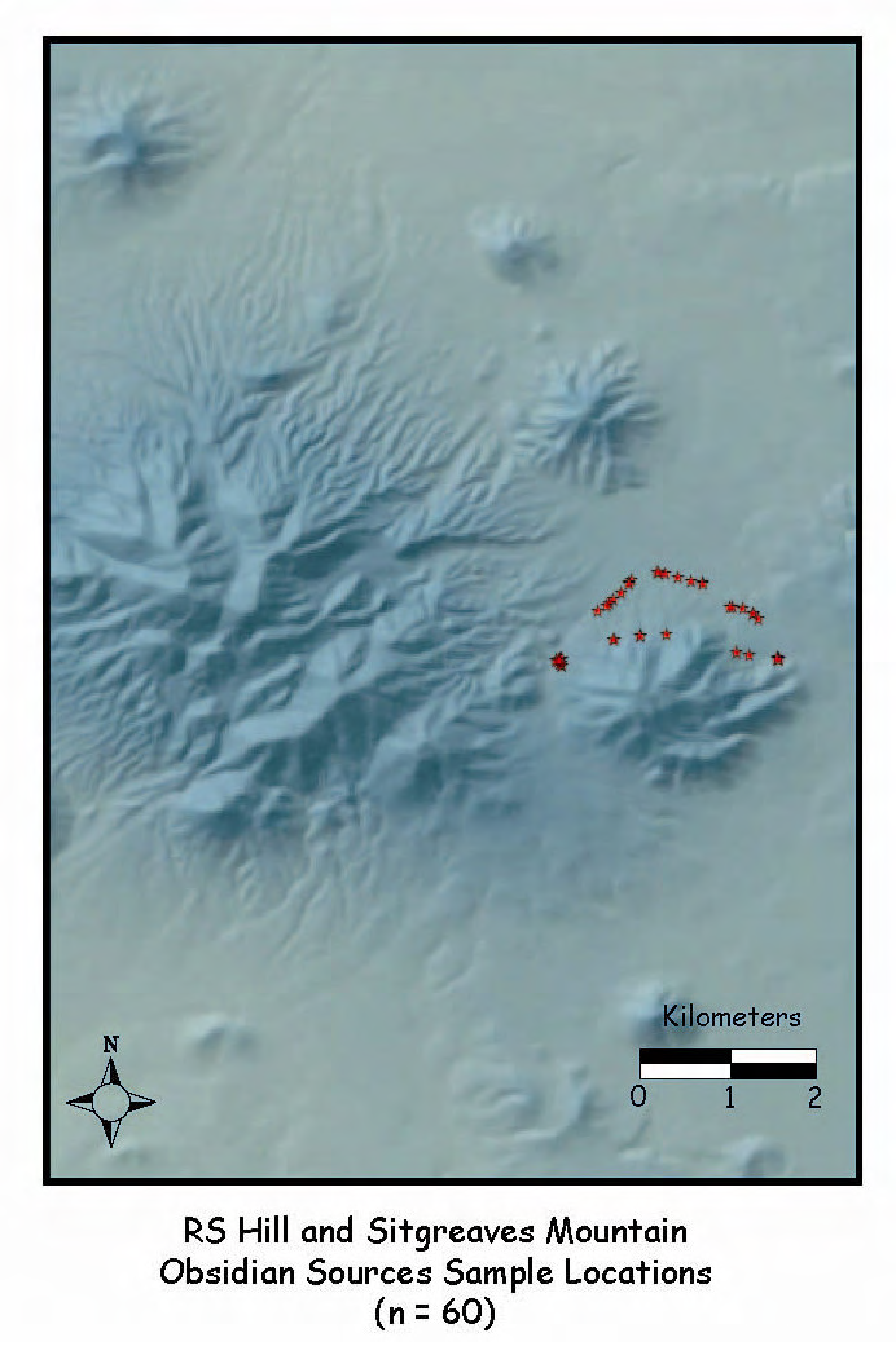


Figure 40. Digital elevation model showing location of RS Hill and Sitgreaves Mountain sampling locations.

San Francisco Peaks

San Francisco Peaks obsidian is very low-quality and contains abundant phenocrysts. The material is very dark gray to black and exhibits a medium grainy texture on the cortex. The material is generally opaque although freshly broken edges are translucent. Shackley (2005: 35) states, “The cortex is variable from ashy-rhyolite to weathered glass, and the glass itself is extremely vitrophyric.” In addition to the phenocrysts, San Francisco Peaks also displays numerous inclusions of ash, greatly affecting its workability. This material is perhaps the lowest quality obsidian in northern Arizona.

Figure 41. The San Francisco Peaks as seen from the top of Government Mountain.

Located within the alpine tundra of the Peaks, the primary obsidian outcrop rests in the saddle between Agassiz and Fremont Peaks at 3,300 m. However, obsidian can also be found as a secondary source in the form of cobbles on all faces of Agassiz surrounding the summit, including directly opposite the Inner Basin flow on the southern slope. The immediate area encompassing the obsidian source is a barren boulder field consisting of talus and discontinuous Bristlecone Pine (*Pinus aristata*). In addition, the Peaks material occurs throughout the Shultz Creek drainage system, including the numerous intermittent streams feeding the creek. I encountered the obsidian as low as 7,000 ft., a vertical distance in excess of 4,200 ft. from the primary outcrop. Despite the wide distribution of the Peaks obsidian, hunter-gatherers apparently deemed the material insufficient for biface manufacture.

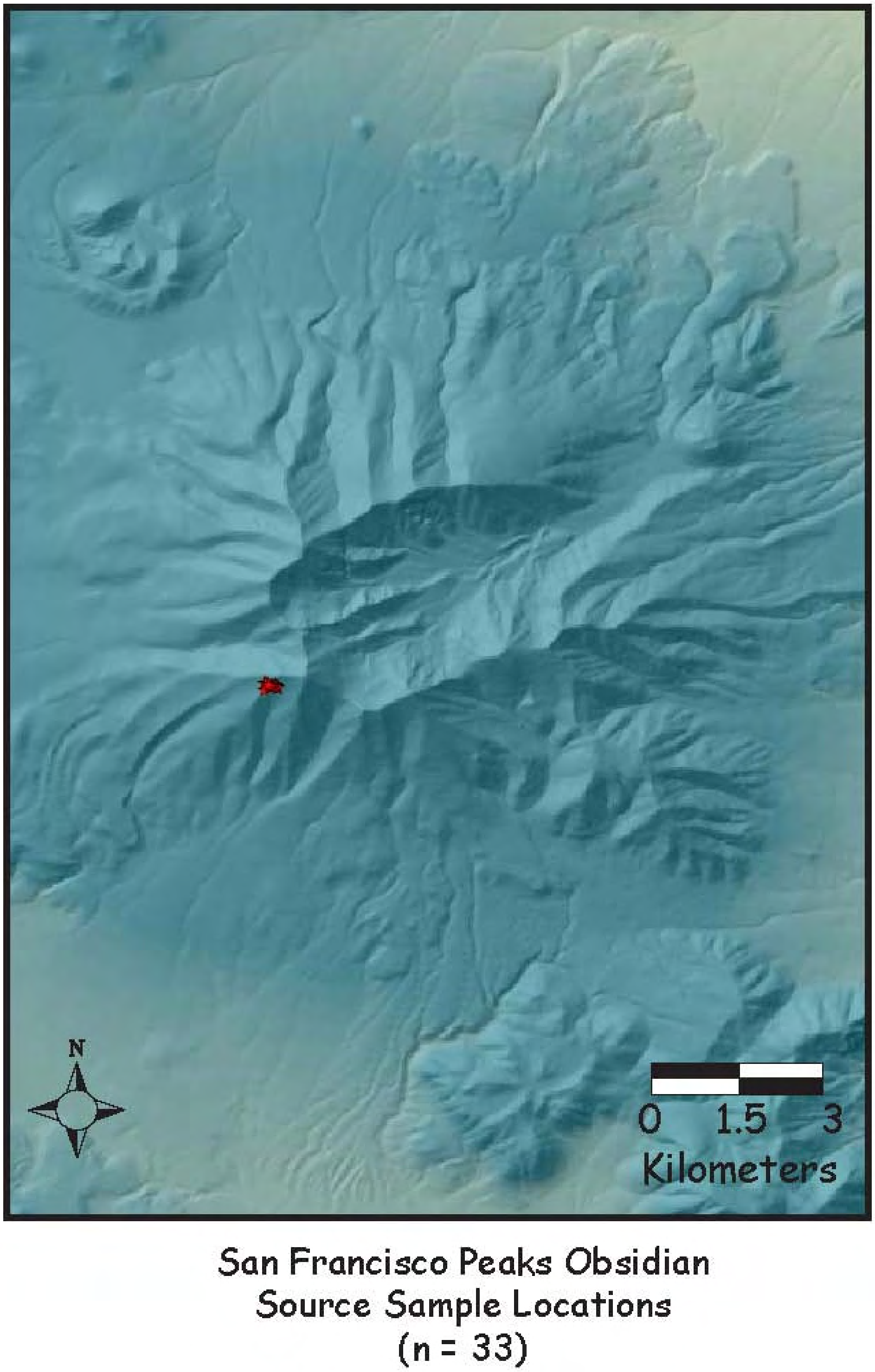


Figure 42. Digital elevation model showing location of one of the San Francisco Peaks sampling locations.

Sitgreaves Mountain

Sitgreaves Mountain is also very similar geochemically and macroscopically to Government Mountain and RS Hill. Indeed, the three sources comprise the Spring Valley group of obsidian sources, thus are all of the same relative geologic age (Robinson 1913: 66). Sitgreaves is the largest rhyolite dome in northern Arizona. During source sampling survey, I collected from the southeastern slope though “abundant eroded cobbles of obsidian are present around all flanks” (Shackley 1988:167) The black obsidian contains sparse phenocrysts, exhibits a smooth texture, and is slightly subvitreous. The material displays a luster ranging from waxy to aphanitic. The fracture properties of Sitgreaves Mountain is conchoidal and generally of high workability.

Perhaps more impressionistic than empirical, Sitgreaves appears to grade between Government Mountain and RS Hill in phenocryst frequency. Some researchers have identified both Sitgreaves Mountain and RS Hill based solely on the presence of phenocrysts. While useful as a guideline, archaeologists should be aware that phenocrysts also are disseminated throughout the Government Mountain matrix.

Slate Mountain

Slate Mountain obsidian source lies not on Slate Mountain but instead on a small, highly eroded dome approximately 1.2 kilometers southeast of the mountain. I gathered the obsidian from the entire surface of the dome, an area roughly 100 meters square. The obsidian occurs in two distinct varieties. Both types are highly vitreous, translucent when thin, and display a smooth texture. However, one type is orange-red, while the other is black. Both varieties contain abundant phenocrysts and occur as small nodules. Although the material was generally of high quality, the nodules encountered during the survey were comparatively small. The size of Slate Mountain obsidian nodules currently is not conducive to manufacture of Archaic Period projectile points, however, this may not have always been the case.

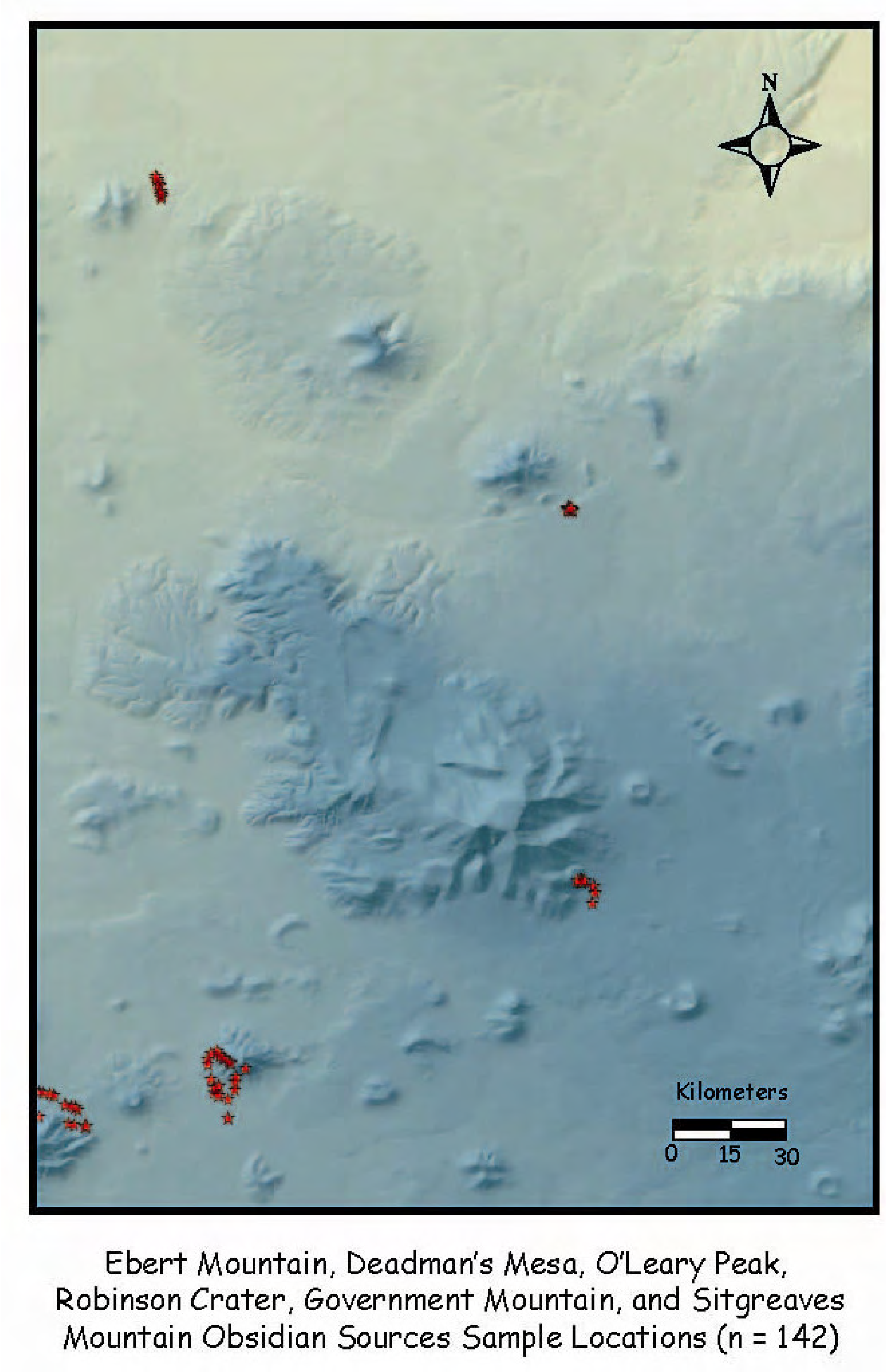


Figure 43. Digital elevation model showing sampling locations at Ebert Mountain, Deadmans Mesa, O'Leary Peak, Robinson Crater, Government Mountain and Sitgreaves Mountain, north to south.

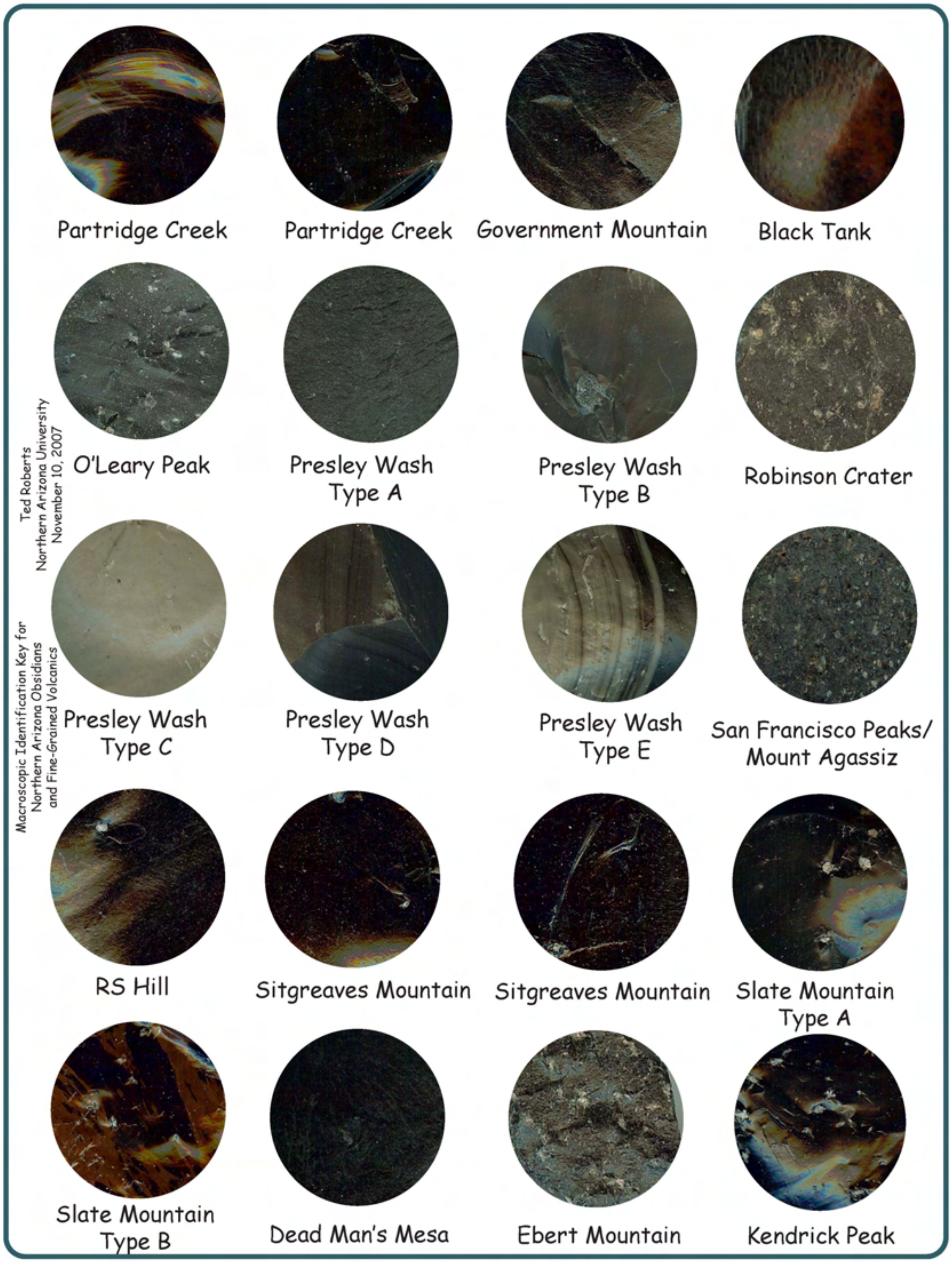


Figure 44. A key to some of the visual variation of northern Arizona source material.

Chapter Five: Out of Many, Only a Few: Theoretical Perspectives on Lithic Procurement

Chapter Five provides the theoretical foundations of this thesis. I discuss past and current archaeological theory and propose a model to serve as an explanatory device working in conjunction with the highly patterned data of the archaeological record of northern Arizona. I have adapted the procurement preference model (PPM) from earlier optimization theory. Specifically, I modeled the lithics-based PPM on diet breadth models dealing with edible resources.

Middle Range Theory

The concept of middle range theory in archaeology arose from the "New Archaeology" of the 1960's. Middle range theory rests between the directly observable facets of archaeological inquiry such as typology and chronometric dating that comprise low range theory and the overarching paradigms such as post-processual archaeology that make up high range theory. Middle range theory assists researchers in converting "the observationally static facts of the archaeological record to statements of dynamics" (Binford 1977: 6). Similarly, Thomas (1986: 245) states middle range theory "seeks invariant linkages between the archaeological record and the behavior that produced it." Alternatively, Bettinger (1987) refers to this as "theories of limited sets" which he describes as being "by design practical and intended for application in the real world." In other words, middle range theory seeks to explain specific human behavior by limiting its scope to directly testable implications focusing on small-scale phenomena.

Archaeologists employing middle range theory acknowledge the limitations of operationalizing general social theory. In confronting the problems in “fleshing out the linking arguments between archaeological data and theory” (Shackley 1990: 16), archaeologists have taken a more modest approach by developing more applicable middle range models. My goal is to build upon these studies by using technological organization as a middle-range theory to understand mobility in band-level societies.

Technological Organization

Technological organization is, as Nelson (1991: 57) states, “the selection and integration of strategies for making, using, transporting, and discarding tools and the materials needed for their manufacture and maintenance. Studies of the organization of technology consider economic and social variables that influence those strategies.” Studies of technological organization lend themselves well to Archaic Period lithic assemblages primarily because of the concern with raw material type and cycles of use (Andrefsky 1994). Furthermore, technological organization is often intrinsically linked to hunter-gatherer mobility patterns. As Carr (1994: 36) states, “by documenting strategies of technological organization inferences can be made concerning mobility strategy”.

As Andrefsky (1994, 1998, 2001) has pointed out, researchers have long been interested in the organization of lithic technology and the relationship to past human behavior. Notable examples include a model demonstrating the association of bifacial core technologies with mobile populations (Parry and Kelly 1987), the examination of use-wear analysis as reflecting differential site use (Odell 1980), and the “minimum analytical nodule” analysis developed by Larson (1994: 58) used to differentiate production, use, and discard behaviors. Recently, archaeologists have begun incorporating the quantitative information available through geochemical sourcing into questions about the availability of high-quality raw material sources. As Andrefsky (1994: 21) asserts, toolstone availability “may well be the primary factor in how a lithic assemblage is ultimately organized with regard to tool form, production effort, and prehistoric time budgeting.” Important for this study is the close correlation such aspects of behavior have with the degree of mobility practiced by Archaic peoples in Northern Arizona.

Discard Behavior and Reduction Strategies (Retooling)

One component of technological organization useful in inferring mobility is the relationship between tool discard behavior and tool manufacture strategies. According to Andrefsky (1994), in areas of high lithic abundance and of high quality raw material, hunter-gatherers produced a combination of formal and informal tools (Figure 45). Formal tools generally consist of those suitable for use in numerous divergent tasks. Such formal tools are manufactured in anticipation of future needs. Formal tools include the projectile points used in the present study. Informal tools include those manufactured expediently and lack broad applicability. Scrapers, flake tools, and spokeshaves constitute examples of informal tools. Informal and formal tools are also commonly referred to as expedient and curated tools, respectively. Because these tool classes represent different functions, activities, and technological strategies, archaeologists encounter these tool classes in different contexts. By identifying the contexts within which each tool class commonly occurs, archaeologists can begin to reconstruct the roles of sites and regions in the territorial or procurement ranges.

When situated in stone-rich areas, Archaic populations presumably did not need to manufacture versatile tools in anticipation of long distance (and long term) disconnection with lithic sources. Instead, hunter-gatherers foraging in the vicinity of toolstone sources relied on informal tools manufactured expediently for immediate use. However, when the groups planned on leaving source areas, the production of formal tools likely took over. Archaeological evidence in northern Arizona suggests peoples used source areas as “retooling” centers. As Daniel (1998: 137) points out, “curated tools should enter the archaeological record more often at locations where they are replaced, which is not necessarily where they were used”. Viewed this way, areas surrounding high quality lithic sources were areas where two related activities would have taken place. First, band members would “gear up” for an anticipated trip away from lithic material by alternating to formal tool manufacture. Second, upon return, well-worn formal tools would have been discarded in favor of newly manufactured forms.

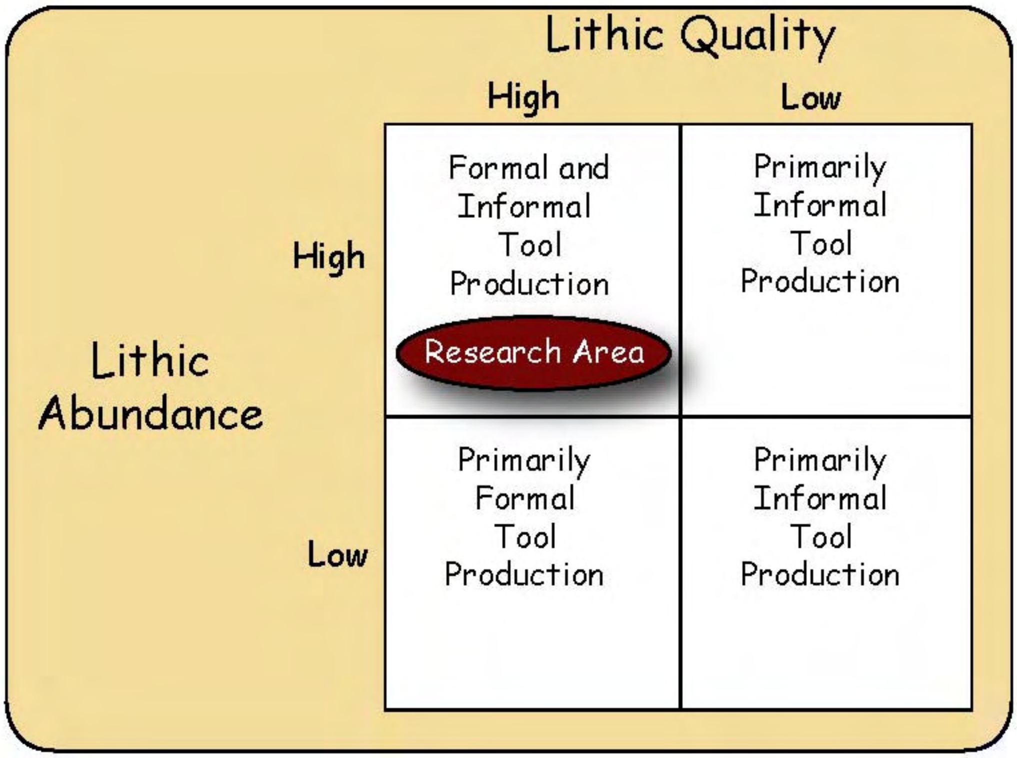


Figure 45. Diagram showing the relationship between lithic material quality and abundance and resulting technological adaptations. Redrawn from Andrefsky (1994: 30).

Archaeological evidence supports the idea of highly mobile groups often retooling in areas of high lithic availability. Viewed in this way, the San Francisco Peaks region represents an essential destination for Archaic peoples in their seasonal rounds. Although access to many resources, including game, plants, and water undoubtedly influenced Archaic mobility, the ethnographic record (Gould 1978, 1980, 1985) suggests that aboriginal groups traveled great distances to procure quality lithic raw materials. Furthermore, because Northern Arizona encompasses an area containing the majority of high-quality obsidian available for hundreds of miles, Archaic peoples may have established their annual ranges based upon seasonal obsidian availability of the San Francisco and Mount Floyd Volcanic Fields. Many of the thirteen sources, particularly those at higher elevation, are currently inaccessible due to snow cover during the winter months. These conditions alone cannot serve as a proxy measure for the seasonality of mobility patterns. However, inaccessible lithic sources coupled with subsistence resource availability likely conditioned hunter-gatherers occupation of northern Arizona when snow was absent.

Archaic Period hunter-gatherers most likely abandoned conservative tool use and reduction strategies in retooling areas because of the high abundance of available raw material. This would result in larger debitage surrounding retooling areas as well as discarded intensively-used tools. In fact, Newman (1994: 491) has found that average flake size and volume “appears to be a direct reflection of the ease of lithic procurement, with the greater the distance to the lithic source, the smaller the respective general flake size.” One way to measure the effects of retooling in the area is by looking at percentages of retouched and reused projectile points in the assemblage. Another way entails discerning local versus non-local sources. However, due to the difficulties in quantitatively making such determinations, the role of the region as a retooling center remains unknown. The extreme use-wear and fragmentation of the projectile points in this study support the contention, however.

Behavioral Ecology/Optimal Foraging Theory

Behavioral ecological approaches in anthropology “begin with a specific question about behavior; answers typically involve the use of formal optimality models” (Broughton and O’Connell 1999: 153). Optimal foraging theory provides a deductive approach to understanding specific cultural phenomena. While much of optimal foraging theory developed from principles of microeconomics, Darwinian evolutionary theory also influences optimization models. As Kelly (2000: 64) explains, “Behavioral ecology does rely on notions of ‘fitness’ because it assumes that humans possess an innate drive to reproduce.” Successful continuation (reproduction) relies on informed knowledge of the availability of all classes of resources. Optimal foraging theory predicts hunter-gatherer behavior selecting for high return subsistence practices relative to energy output. Thus, if all things are equal foragers will consistently choose high-energy foodstuffs over those foods providing limited caloric value.

Optimal foraging theory in archaeology is based on the assumption “rational decision-making of individuals” conditions choices “made to maximize net rate of energy return” (Bettinger 1987: 131). Within this behavioral ecology paradigm, forager food choices are conditioned by rational decisions concerning the range of available subsistence alternatives. Foraging behavior thus works in ways to ensure the greatest possible benefit for the group’s survival. As Broughton and O’Connell (1999: 154) point out, “optimization logic predicts only that selection will tend to favor the best strategy among ***a defined set of alternatives possible in the context of interest***”.

Virtually every optimal foraging model used by archaeologists is based on subsistence behaviors; that is, choices about food. The models “assume that foragers will be selected to behave so as to maximize the net rate of return (of energy or nutrients) per unit foraging time” (Smith 1983: 626). Increasingly, archaeologists interested in lithic technology have adapted optimization theory to explain stone tool use. For example, Kuhn (1994) views the relationship between portability, durability, and functionality of mobile toolkits as a “problem in optimization” (Kuhn 1994: 428).

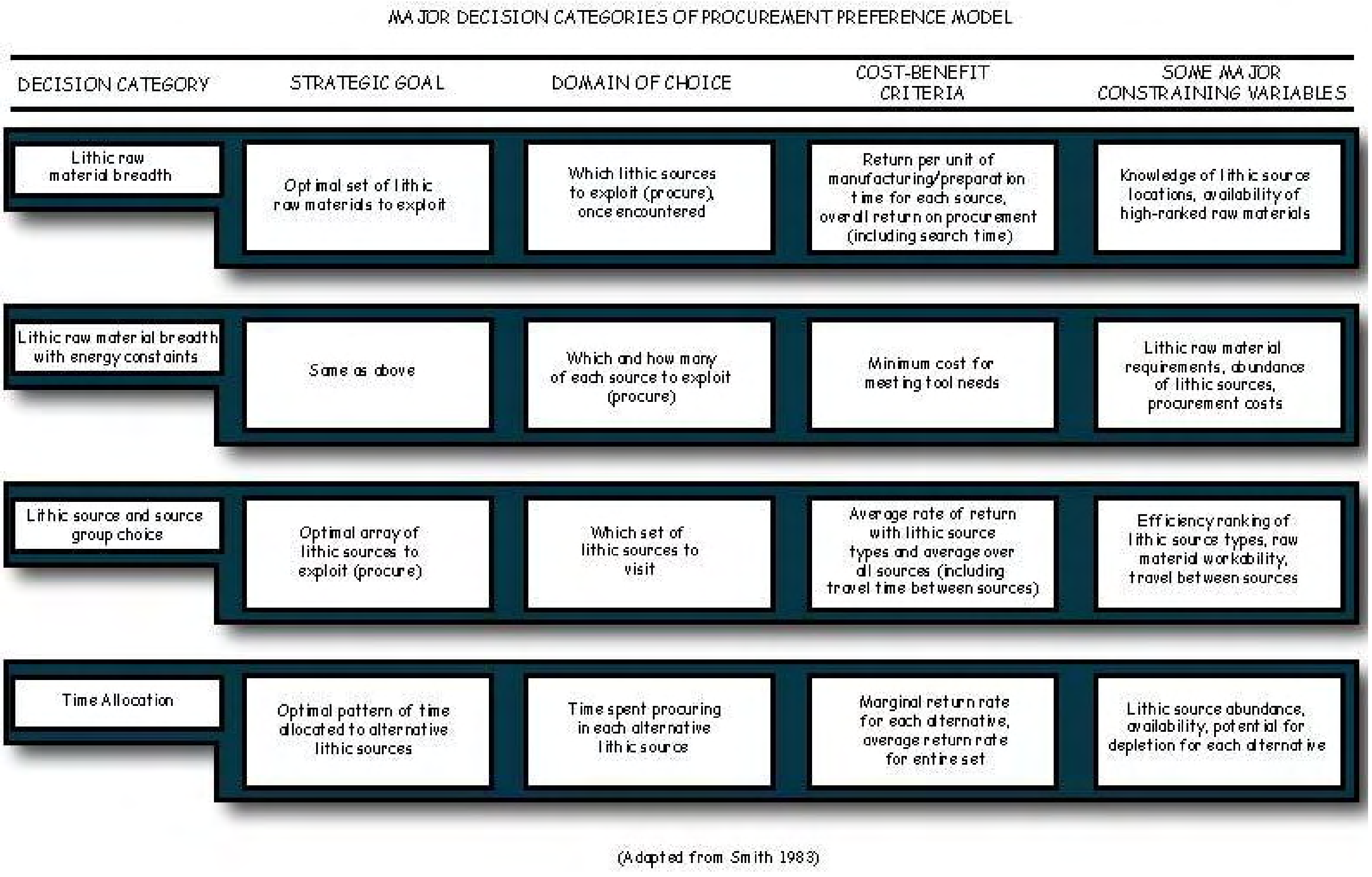
In addition, Jeske's (1992) look at the ways energy efficiency conditioned a less formal toolkit uses optimization theory to explain changes in tool industries. Furthermore, Kelly's (2000) study of the different return rates of bifacial, core-making, and bipolar technologies rests on the assumption that "people weigh their options and opt for those that provide the highest benefit" (Kelly 2000: 69). In fact, in the conclusion, Kelly (2000: 78) proclaims, "For hunter-gatherer archaeology…stone-tool production and use should be examined within the framework of optimal foraging models."

While very useful for approaching lithics-related optimization decisions archaeologically, the above studies concentrated on the choices made by prehistoric populations on which ***tool types*** to manufacture given efficiency and return rates. However, to my knowledge, no attempts have been made at developing optimization models focusing strictly on procurement of ***raw material types***. That is, archaeologists specializing in lithics have yet to incorporate diet breadth models in questions about lithic raw material source choices.

The Procurement Preference Model

Instead, I am proposing an optimal foraging model formulated to explain the differential procurement and use of northern Arizona obsidian sources spanning the 6,600 years of Archaic Period occupation. The model, termed the procurement preference model (PPM) attempts to answer the question of why hunter-gatherers exploited local obsidian sources differentially (Figure 46). First, the currency of the model must be specified. In this case, such currency is tool manufacturing time and energy output preparing bifaces. Manufacturing time and energy output are closely related. While time spent manufacturing tools necessarily decreases available time performing other tasks, energy output is used as a proxy measure of the training and experience of the knapper within a cultural context. As Geib (2000: 509) puts it, "the basic motor habits of artifact fabrication that are transmitted from generation to generation."

Knappers learn tool-making socially and thus would presumably display patterned behavior when choosing lithic sources. Unnecessary energy should not be expended manufacturing bifaces from inferior lithic raw material, no matter how satisfactory the material may be. Toolstone sources are only as valuable as those that surround it. That is, within a landscape yielding few toolstone sources, a lithic material considered high quality in certain regions would not be considered so in stone-rich areas containing superior source material.



MAJOR DECISION CATEGORIES OF PROCUREMENT PREFERENCE MODEL

DECISION CATEGORY	STRATEGIC GOAL	DOMAIN OF CHOICE	COST-BENEFIT CRITERIA	SOME MAJOR CONSTRAINING VARIABLES
Lithic raw material breadth	Optimal set of lithic raw materials to exploit	Which lithic sources to exploit (procure), once encountered	Return per unit of manufacturing/preparation time for each source, overall return on procurement (including search time)	Knowledge of lithic source locations, availability of high-ranked raw materials
Lithic raw material breadth with energy constaints	Same as above	Which and how many of each source to exploit (procure)	Minimum cost for meeting tool needs	Lithic raw material requirements, abundance of lithic sources, procurement costs
Lithic source and source group choice	Optimal array of lithic sources to exploit (procure)	Which set of lithic sources to visit	Average rate of return with lithic source types and average over all sources (including travel time between sources)	Efficiency ranking of lithic source types, raw material workability, travel between sources
Time Allocation	Optimal pattern of time allocated to alternative lithic sources	Time spent procuring in each alternative lithic source	Marginal return rate for each alternative, average return rate for entire set	Lithic source abundance, availability, potential for depletion for each alternative

(Adapted from Smith 1983)

Figure 46. PPM Decision Categories.

After determining the currency of the model (manufacturing time), the strategic goal of hunter-gatherers choosing optimal procurement practices must be made explicit. Thus, within the model, the goal is assumed to be to maximize procurement efficiency by choosing the optimal set of obsidian sources to use. Hunter-gatherer behavior, as viewed by the model, would opt for the greatest return in investment. Foragers should then select the optimal set of obsidian resources from among a larger suite of possible sources. Next, the set of options available to Archaic Period bands must be identified for the duration of the time period studied. In the PPM, the thirteen discrete (and quantitatively characterized) obsidian sources located within the Mount Floyd and San Francisco volcanic fields constitute the set of options. The set of options depends on the size of mobility range and could include distant sources. However, the local sources serve as the set of options within the study area (Figure 47). Finally, the factors limiting the range of options confronting hunter-gatherers exploiting the obsidian sources should be made apparent. In this study, the constraints include travel time, material abundance, and availability. Abundance and availability represent two closely related inhibiting factors. Abundance is simply the gross amount of obsidian present at the source while availability describes the difficulty of obtaining the lithic material. Obsidian availability refers to remoteness with respect to other resources including water and subsistence items. In addition, availability takes into account natural obstacles and nodule size.

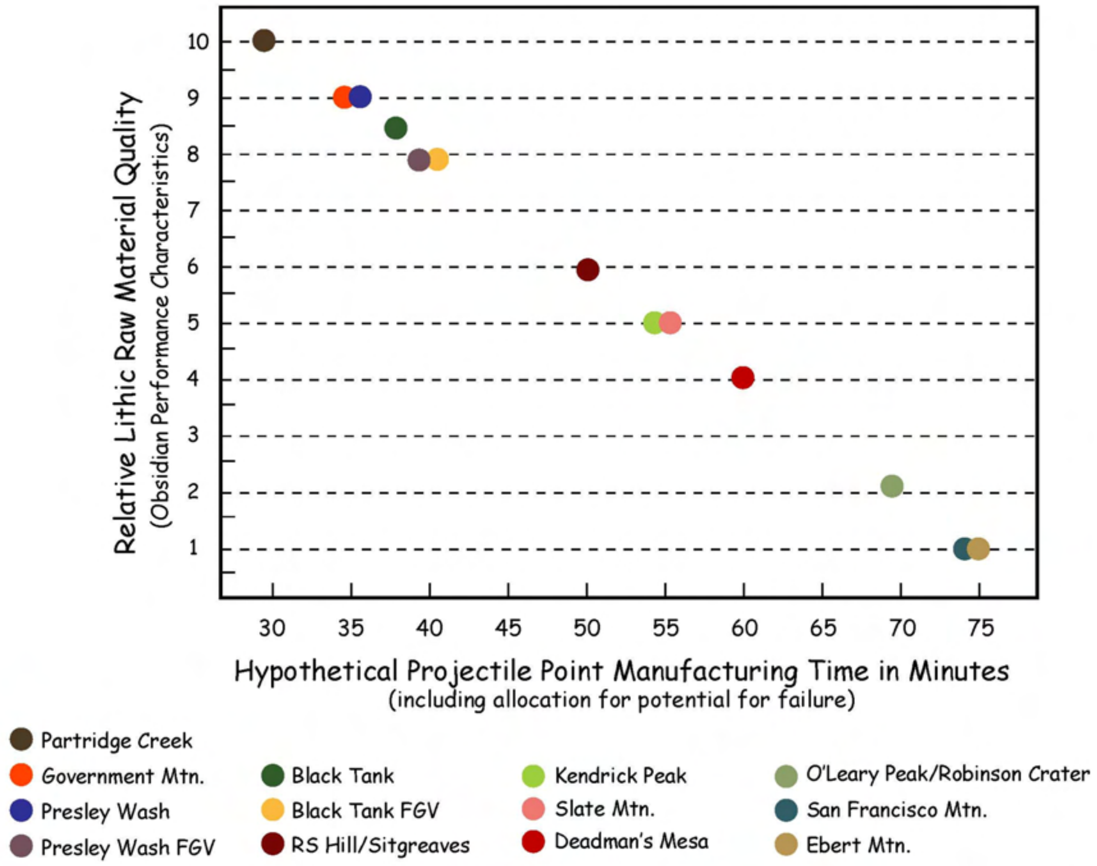


Figure 47. Graph depicting source ranking schema based on author's experimentation.

The analytical categories considered in the PPM include lithic raw material breadth (suite of obsidian sources used), lithic source patch choice, (adjacent source groups within the Mount Floyd and San Francisco volcanic fields), and time allocation. Because “optimal diet models predict the set of resource types harvested, not the tactics used in harvesting each” (Smith 1983: 626), quarrying behaviors are not accounted for in the model. Furthermore, because every source considered in the study occurs as eroded surface nodules, quarrying time is assumed to not play a significant role in obsidian source choices during the Archaic. Thus, the PPM serves as an attempt to state the specific set of decision rules regarding procurement choices.

As Smith (1983: 627) points out, “A key problem in foraging theory concerns prey choice and diet breadth: out of the array of available prey types, which ones should an efficient forager attempt to harvest?” This task is made easier in this study because the majority of obsidian sources in the region are believed to be known and geochemically characterized. Ascertaining every possible subsistence resource in a prehistoric diet presents a considerably bigger challenge to the archaeologist due to the vagaries of paleoethnobotanical and faunal preservation biases as well as the ambiguity of paleoenvironmental reconstructions. No such limitations exist here, because the sources locations and trace element characterizations are known as are the projectile point “fingerprints” and thus raw material origins. Moreover, the lithic landscape encountered by Archaic populations remains essentially unaltered to the present day.

The procurement preference model assumes a random encounter with obsidian sources. That is, Archaic Period hunter-gatherers encountered obsidian in the same relative proportions across northern Arizona. The model does not imply hunter-gatherers encountered the sources accidentally or fortuitously nor does the model assume band evagation. Indeed, the data suggest otherwise.

Germane to this study is the separation of travel times and manufacturing times. Because the model assumes hunter-gatherer populations rank obsidian types according to criteria of profitability, data suggest hunter-gatherers weighed options between search time and manufacturing time in order to create the optimal set of sources to procure. Thus, relying on Smith’s (1983) discussion, as an Archaic Period band widens its lithic raw material breadth by adding new sources of lower rank (i.e.

lower quality obsidian requiring more manufacturing time and more potential for tool failure), manufacturing times averaged over the entire source breadth increase. Therefore, the optimal set of obsidian sources is achieved by adding sources in descending rank (quality) until the expected return in manufacturing time and energy output is maximized (Figure 48).

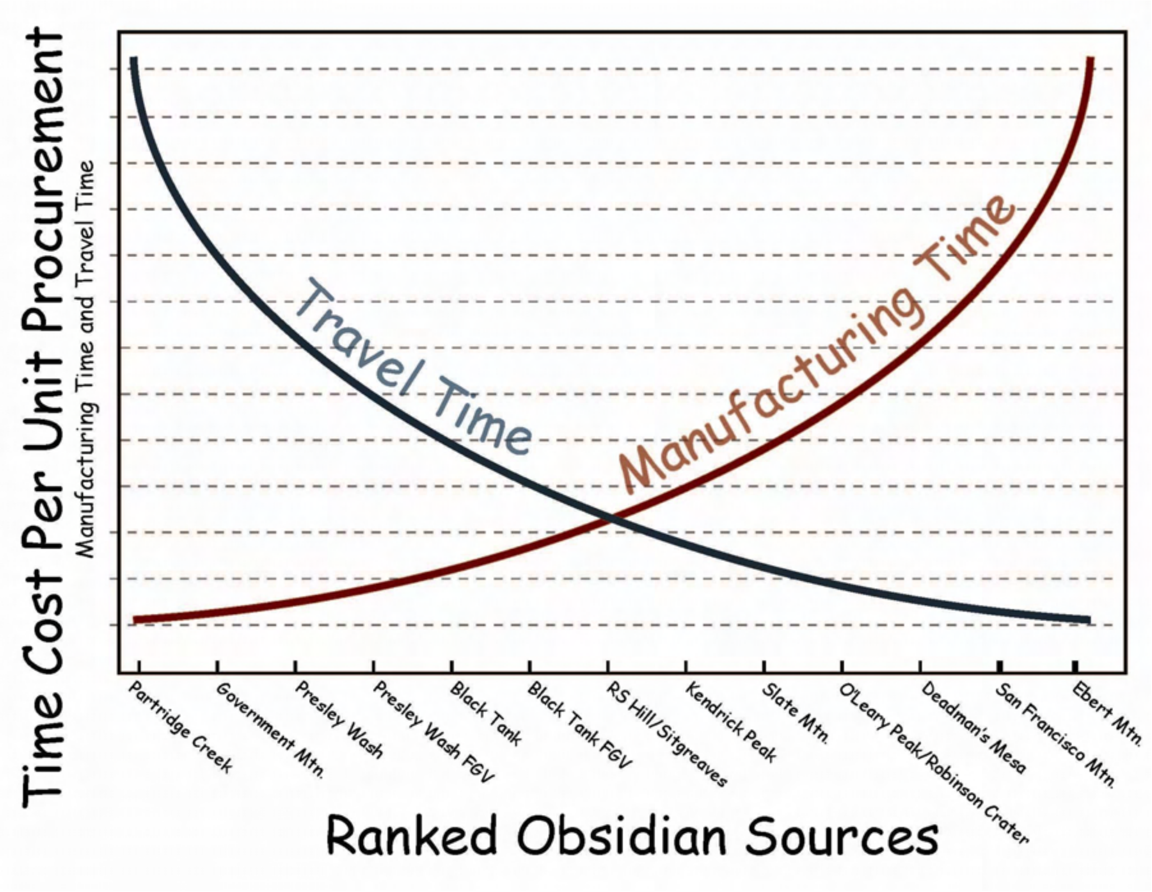


Figure 48. Diagram showing inverse relationship between travel and manufacturing time used by hunter-gatherers to decide the optimal set of lithic sources to exploit.

Smith (1983: 628) proposes a few predictions made possible by implementing a diet breadth optimal foraging model. I have adapted these to the procurement preference model. First, increased quality of obsidian sources should result in more specialized procurement behavior. That is, only the highest quality obsidians should be regularly exploited. Second, obsidian sources should be added or dropped from the optimal suite of utilized obsidians in rank order of manufacturing efficiency, with lower quality obsidians entering and leaving the hunter-gatherer’s optimal set of sources while the higher quality obsidians remain within the set invariably. Third, the presence of a certain source material in an assemblage should depend only on the availability of higher quality obsidian, not on its own availability. That is, to understand the procurement of each source, one must know all options available within the foraging territory. Therefore, no source type with a manufacturing efficiency lower than the average of the optimal set should be taken, regardless of how commonly the source material occurs. Moreover, the quality of the obsidian procured does not determine its *proportion* within the toolkit; rather the quality will simply determine whether or not the source will appear in the optimal set.

Because procurement and manufacturing time takes away from time spent accomplishing other tasks such as subsistence activities, populations during the Archaic presumably allocated their time economically. However, in what ways can we measure cultural conceptions of optimal time allocation? One way is through models such as the PPM. For example, the projectile point data suggests that minimization of manufacturing time (using high quality raw material) superceded travel time concerns. The idea is simple: the more obsidian sources an Archaic Period band chose to incorporate, the less travel time was expended between the sources because each would be procured as encountered (sources would not have been passed up in order to reach others). As argued by Jones and Madsen (1989: 529), “a resource’s abundance is not the principal factor influencing its value.”

Testing the Model

If lithic abundance and availability concerns were paramount in hunter-gatherer procurement decisions, all of the northern Arizona sources would have been exploited more-or-less equally. However, only certain sources appear in the archaeological record, as reflected in the current study. Of the 13 analyzed obsidian sources in northern Arizona, only seven were used. Two of the sources, Deadman's Mesa and San Francisco Mountain, appear once each in the sample (the first time these sources have been detected archaeologically). Because RS Hill and Sitgreaves Mountain sources are geochemically identical, I count the two sources as one. Of these, five sources comprised 89% of the points recovered through the Archaic Period (Figure 49). Thus, the projectile point data suggest travel time was less important than manufacturing time in determining procurement behaviors. Because manufacturing time is conditioned by the performance characteristics of obsidian toolstone, lithic quality appears most crucial in lithic procurement decisions throughout the Archaic Period. Of course, previous researchers have reached the same conclusion based on different hypotheses and models (Andrefsky 1994; Beck and Jones 1990; Brantingham 2003; Cotterell and Kamminga 1987; Jones and Madsen 1989; Kamp and Whittaker 1986; Newman 1994; etc.). However, simply observing the fact that hunter-gatherers preferred the highest quality lithic material within a foraging radius does little to explain the reasons for the behavior. The PPM offers one such possible explanation.

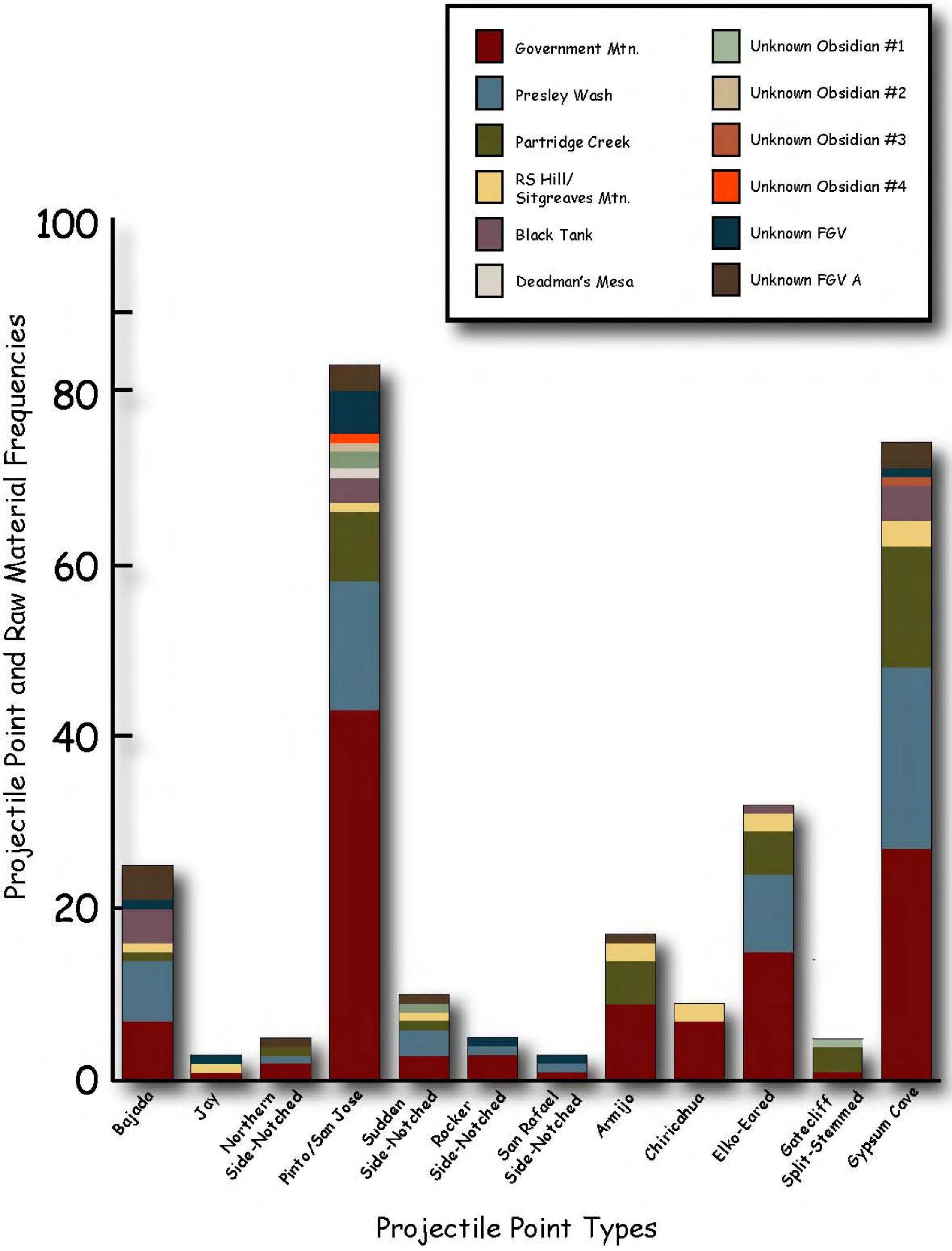
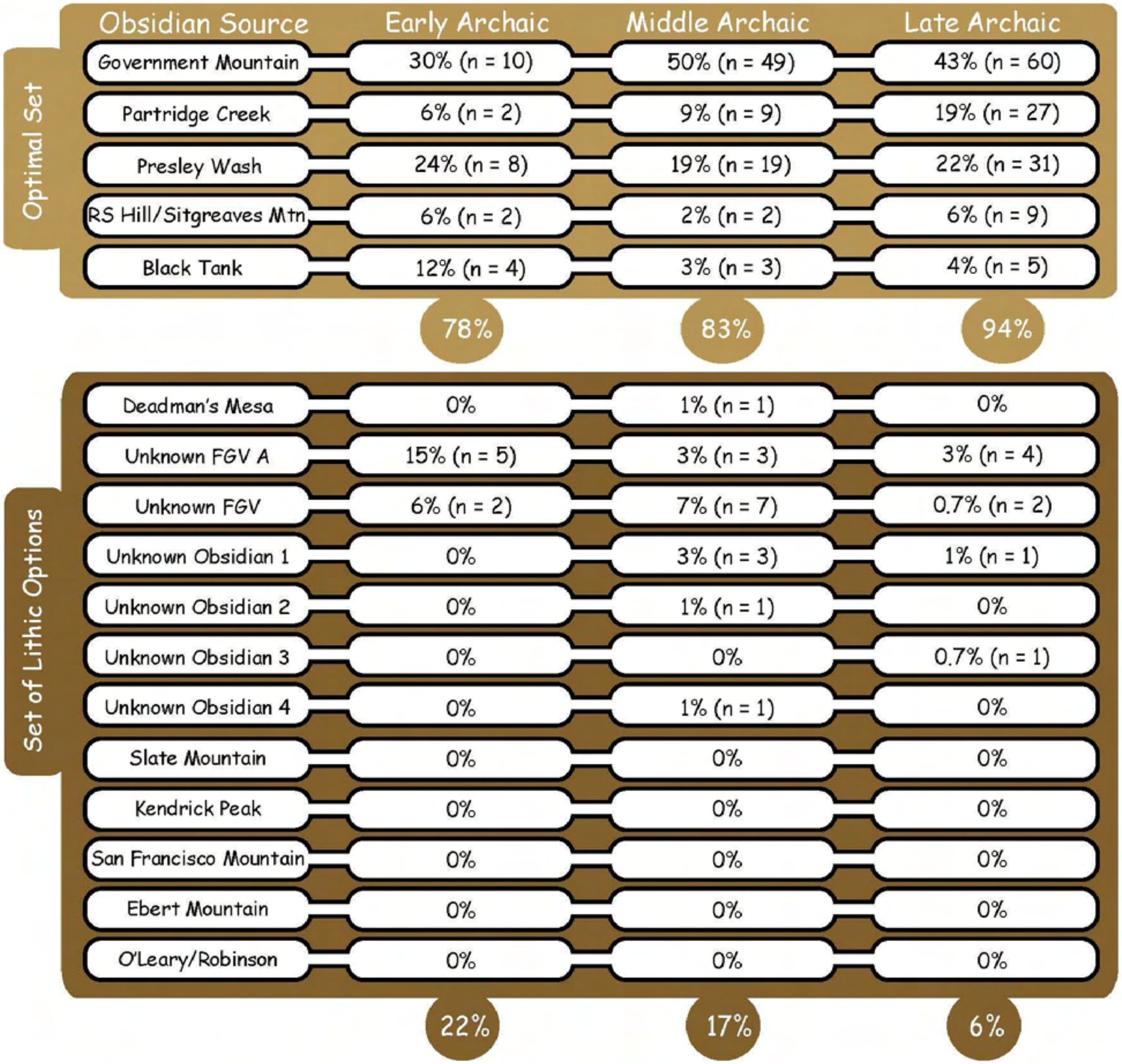


Figure 49. Bar graph showing source frequencies within each projectile point type.

In addition to the seven utilized sources noted above, results from geochemical projectile point analysis revealed the presence of six previously unknown sources. Twenty-eight points from the current assemblage exhibited chemical signatures indicative of these six sources. The unknowns include Unknown FGV A (n = 12), Unknown FGV (n = 11), Unknown Obsidian 1 (n = 4), Unknown Obsidian 2 (n = 1), Unknown Obsidian 3 (n = 1), and Unknown Obsidian 4 (n = 1). None of these chemical signatures have been published and the geologic sources remain undiscovered. Presumably, the unknown obsidians come from extremely distant or virtually unused sources (inferior production characteristics) due to their paucity in the current assemblage. Conversely, due to the relatively intensive use of the unknown FGV’s, however, these sources may be of local, as yet undetected, origin. In fact, due to the prevalence of the Unknown FGV’s in the assemblage, these sources may have been considered part of the optimal set. Unfortunately, lacking source material to rank, this remains speculative.



	Obsidian Source	Early Archaic	Middle Archaic	Late Archaic
Optimal Set	Government Mountain	30% (n = 10)	50% (n = 49)	43% (n = 60)
	Partridge Creek	6% (n = 2)	9% (n = 9)	19% (n = 27)
	Presley Wash	24% (n = 8)	19% (n = 19)	22% (n = 31)
	RS Hill/Sitgreaves Mtn	6% (n = 2)	2% (n = 2)	6% (n = 9)
	Black Tank	12% (n = 4)	3% (n = 3)	4% (n = 5)
		78%	83%	94%
Set of Lithic Options	Deadman's Mesa	0%	1% (n = 1)	0%
	Unknown FGV A	15% (n = 5)	3% (n = 3)	3% (n = 4)
	Unknown FGV	6% (n = 2)	7% (n = 7)	0.7% (n = 2)
	Unknown Obsidian 1	0%	3% (n = 3)	1% (n = 1)
	Unknown Obsidian 2	0%	1% (n = 1)	0%
	Unknown Obsidian 3	0%	0%	0.7% (n = 1)
	Unknown Obsidian 4	0%	1% (n = 1)	0%
	Slate Mountain	0%	0%	0%
	Kendrick Peak	0%	0%	0%
	San Francisco Mountain	0%	0%	0%
	Ebert Mountain	0%	0%	0%
	O'Leary/Robinson	0%	0%	0%
		22%	17%	6%

Figure 50. Table illustrating toolstone frequencies among the optimal set and set of options.

Diminishing Returns: Or, When to Move On

Traditional optimal foraging models must account for the effects of diminishing returns as the result of foraging behaviors. These models have met with varied success when approaching the question of which set of patches (adjacent sources) would be optimal to forage and for how long could each be foraged optimally. The common explanation holds that “foragers leave a patch when the last item in their diet is harvested and the expected or marginal harvest rate suddenly drops to zero” (Smith 1983: 631). Archaeologists have assumed that foragers would eventually deplete the subsistence resources in a patch, resulting in a decline in the net return rate. Therefore, archaeologists have developed marginal value theories dealing with the problem of diminishing returns.

Alternatively, the PPM suffers no such complications because the procurement process never depleted the obsidian at the sources. In fact, the thirteen sources considered in the present study currently boast ample quantities of obsidian. Hunter-gatherers during the Archaic Period likely enjoyed procurement choices unrestricted by abundance or availability concerns. Thus, constraints on obsidian procurement appear to be minimal. In short, the model makes clear that hunter-gatherers need not be facing the eminent disappearance of lithic raw materials in order to make procurement decisions based on optimization strategies.

The Optimal Set

The overwhelming majority of Archaic Period projectile points recovered from northern Arizona contexts were manufactured from Government Mountain, Presley Wash, and Partridge Creek obsidian sources. In addition, RS Hill/Sitgreaves and Black Tank obsidian sources were exploited less than the previous sources but still significantly. Thus, based on the projectile point data, these sources constitute the optimal set of lithic sources for Archaic populations. In fact, one could reasonably presume that the only reason other sources are present at all in the assemblage is due to periodic sampling of other sources in order to redetermine the source rank ordering. As Eric Alden Smith (1983: 631) contends, “any patch not yet in the utilized set should not be added unless it can yield a marginal rate of return equal to or greater than the average rate for the utilized set.”

Based on knappability, sharpness, durability, lack of inclusions, or internal flaws, and potential for biface manufacture, the obsidian materials making up the optimal set of sources exhibit the highest rank of all sources in the study. The sources not included in the optimal set, either absent entirely or very rare, are so because they exhibit inferior production characteristics. Optimization models predict that larger numbers of resources will be exploited in areas where high-ranked foodstuffs are less abundant. Therefore, in accordance with the prediction of such models, the optimal set in northern Arizona is relatively small due to the local occurrence of high-ranked obsidian sources.

An additional component of traditional optimal foraging theory is the “patch-choice model.” As Bettinger (1991: 84) writes, “the patch choice model is merely a special case of the same general model from which the diet breadth model is derived”. Although the model focuses on foraging behavior conditioned by the effects of diminishing returns, certain aspects are useful in understanding Archaic Period toolstone procurement. Smith (1983: 631) points out that in regards to “superabundant resources…the optimal strategy is simply to locate oneself in the patch with the highest rate of return and remain there until conditions change.” Certainly this explanation ignores general mobility theory, however, the model may help to elucidate hunter-gatherer source choice.

I grouped the sources in the study into patches as an exercise in exploratory data analysis and as a heuristic device. I selected the patches based on geographic proximity and geochemical similarity. Within the Spring Valley Patch are Government Mountain, Sitgreaves Mountain, and RS Hill. In addition, Black Tank, Presley Wash, and Partridge Creek sources comprise the Mt. Floyd Patch. The O’Leary Patch includes Deadman’s Mesa, Robinson Crater, and O’Leary Peak. The Kendrick Patch includes Slate Mountain, Kendrick Peak, and Ebert Mountain. Lastly, the Peaks Patch includes all material from the San Francisco stratovolcano.

Interestingly, two patches contain 242 (89%) of the projectile points included in this study. The Spring Valley Patch provided 133 (49%) of the projectile points while the Mt. Floyd Patch consisted of 109 (40%) of the points. Certainly hunter-gatherers did not “camp out” next to these sources until conditions changed. However, the patch-choice model may provide another way to view decision-making during the Archaic. Smith (1983: 631) writes, “optimal time allocation to any patch is a function of average yields for all utilized patches, as the overall productivity of a set of patches rises less time should be spent in any one patch.” Presumably, hunter-gatherers in the region never reevaluated the quality of the other patches favorably, because the optimal time allocation to the Spring Valley and Mt. Floyd Patches remained virtually unchanged throughout the period.

The procurement preference model provides a useful explanation for the highly patterned and selective obsidian exploitation practices apparent prehistorically on the Coconino Plateau. While the model fails to explain large-scale mobility during the Archaic, it does serve to answer the question of why certain obsidian sources bearing artifact-quality toolstone were all but ignored for roughly 6,600 years. Systematic source abnegation and predilection lasting for the entire Archaic Period is best understood within an optimization framework. If such long-term consistency in source procurement behavior resulted from simple information transmittal between and among hunter-gatherer bands, the archaeological record would exhibit more diversity in source choice. Accordingly, a generalized procurement strategy resulting in trial and error toolstone use would likewise produce a more variable archaeological record. In addition, large-scale mobility strategies certainly changed through time and such change should be apparent in the obsidian sources used. Thus, the limited scope of the model cannot account for hunter-gatherer mobility across large physiographic zones but can explain band movement within such zones.

In contrast to ideas of Archaic Period hunter-gatherers forced to use every possible resource due to their marginal existence, the archaeological evidence supports the notion of bands practicing highly rational decision making, designed to optimize technological potential. Hunter-gatherers, once inhabiting the region, consistently chose to focus procurement on a few sources, regularly bypassing inferior, yet usable, obsidian.

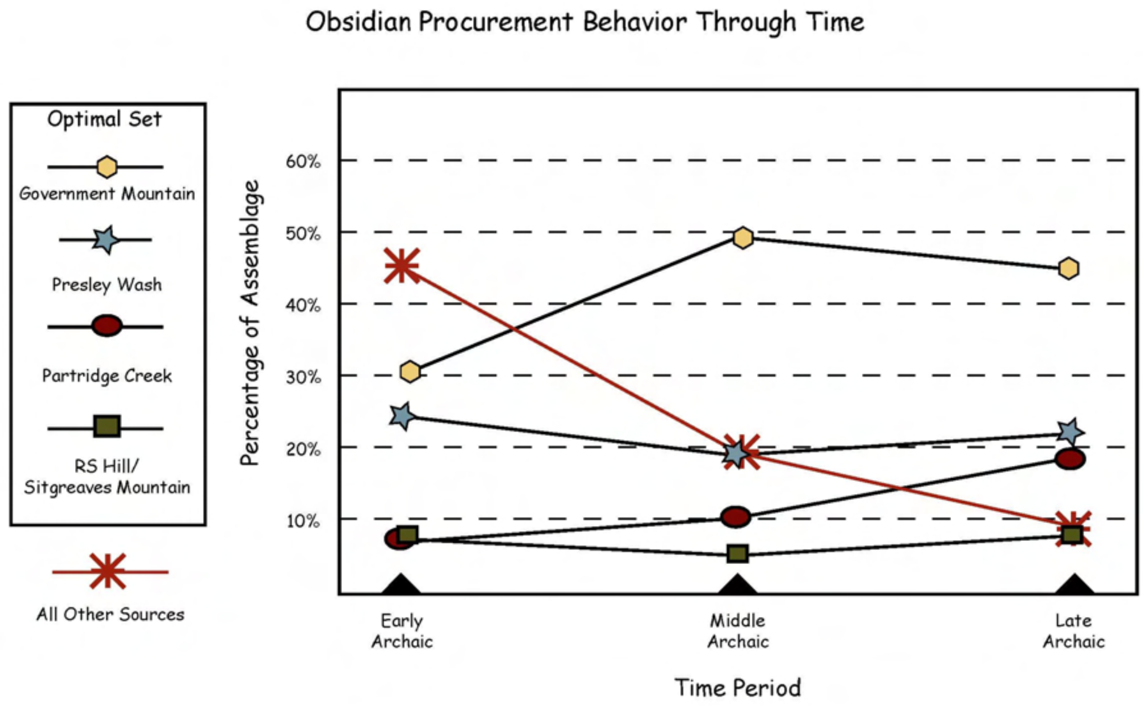


Figure 51. Graph showing changes in source material use through the Archaic Period.

Additional Optimization Considerations

As discussed above, optimal foraging models often take into account diet breadth, which considers optimal food sources and the most favorable combinations of such subsistence resources. Numerous models have been devised calculating optimal diet breadth proportions based on rate of return. In one application of an optimization model, Broughton and O'Connell (1999: 155) explain "return rates are generally scaled to prey body mass. Among Holocene North American vertebrates in particular, the larger the animal, the higher the post-encounter return rates." Therefore, prehistoric elk herds, deer, and antelope occupying the Coconino Plateau may serve as an example of an essential resource to Archaic Period hunter-gatherer populations. Disregarding the energy output necessary to track and kill such ungulates (which may have been less on the Coconino Plateau than in other regions), Archaic hunter-gatherers may have opted for relatively localized mobility strategies relying on elk, deer, and antelope as the most efficient subsistence resource. Within a basic model of diet breadth, “foragers confront an array of items…[and] select the combination of these items that maximizes net energy intake per unit of foraging time” (Bettinger 1987: 132).

Pinyon nuts may have served as another optimal resource within the possible diet breadth options drawing hunter-gatherer bands to the area during the Archaic Period. Some researchers (Betancourt:1982, Van Devender 1981-82) have suggested a major vegetal shift occurring in the early Holocene (11,000-8,000 B.P.) Southwest. Abundant Douglas Fir, Rocky Mountain Juniper, and Spruce gave way to Ponderosa Pine, Pinyon, and Juniper. Pinyon pine nuts contain exceptional nutritional value. In fact, the nuts compare favorably with “pecans, peanuts, and walnuts in protein, fat, and carbohydrate content” (Lanner 1981: 100). One can appreciate the importance of a food containing 14% protein, between 62 and 71% fat, and 18% carbohydrates occurring in dense concentrations at predictable locations. Would a diet including these subsistence resources, coupled with the abundant lithic raw material available locally provide enough of a draw to inhibit the enormous mobility ranges common in other areas of North America during the Archaic? If high mobility is conditioned by differential access to resources located at far distances, would not the local presence of a complete set of resources condition relatively small mobility ranges? As

Bettinger (1987: 132) points out, “no rational forager should pass over a more-rewarding to exploit a less-rewarding item.” Of course, the data of this study does not bear out this speculation.

In an application of optimal foraging theory to questions concerning lithic technology, Jeske (1992) developed an energetic efficiency model explaining the change from formal biface manufacture to more expedient technologies. Jeske cites the well-documented “degeneration” of stone tool manufacture that accompanied the change from highly mobile to more sedentary populations during the late prehistoric period (ca. A.D. 500-1670) in North America as evidence for a “reduction in energy input into lithic technology” (Jeske 1992: 469). While the model deals with an adaptive strategy nonsynchronous with this study, an applicable aspect of the model has the potential to frame an understanding of the Archaic period in northern Arizona through an optimization perspective. In fact, Jeske (1992: 468) points out that “Studies using optimal foraging models have indeed met with better results when examining humans in extreme environments” such as the northern Southwest. The assumption is that time and energy is significantly constrained in arid climates and thus monitoring adaptive behaviors, such as subsistence practices and lithic procurement, would be easier. Jeske (1992: 467) states, “The amount of time and energy available to a particular group exerts a strong influence on the makeup of lithic assemblages in terms of raw materials chosen.” Within this framework, the amount of energy invested in lithic procurement and manufacture reflects the amount of energy stress on the culture as a whole. I argue that because obsidian availability is not constrained in northern Arizona, and subsistence resources were plentiful and of high return, lithic assemblages serve as a good proxy measurement for low overall energy stress. In other words, the preponderance of bifacial technologies manufactured from high quality toolstone evidence a lifeway enjoying relatively ample amounts of “free-time”.

Chapter Six: Model Summary and Archaeological Implications

This chapter serves to summarize the procurement preference model. First, I discuss the degree to which projectile points can inform our understanding of prehistoric toolstone choices. In addition, I discuss the ancillary factors potentially affecting Archaic Period lithic procurement. Such factors include trade, tool depletion, and the concept of local and non-local toolstone sources. Furthermore, I provide several archaeological implications of the model and examine the research results. Lastly, I acknowledge the caveats of my study.

Projectile Points as Indicators of Source Variability

The question remains whether the projectile point procurement patterns evident in this study represent overall lithic source exploitation during the Archaic in northern Arizona. The inferences drawn from projectile point material distribution must be tested against patterns displayed by other components of the Archaic toolkit as well as debitage using future regional geochemical studies. As Kooyman (2000: 43) aptly points out,

> The information obtained on quarry sources is central to reconstructing patterns of trade, seasonal movement, and contact with other people…To fully exploit the potential of this information, it is useful to further subdivide material types by form. This might include the percentage of each material type (finished tools, unfinished tools, flakes with cortex) or each particular flake type or debitage category.

Indeed, how the toolstone sources were used for different tool types, either formal or informal, would inform our understanding of procurement behaviors significantly, as would evidence from debitage. In the Maya region, Braswell et al.

(2000: 269) observed that “certain obsidian sources may have been used preferentially for producing specific tool types.” Thus, the need for comprehensive geochemical assays of complete lithic assemblages appears necessary. A recent study by Eerkens, et al. (2007) used geochemical analysis to investigate patterns in source diversity used by residentially mobile groups for flaked stone assemblages, including small and large flakes, and formal tools. Because hunter-gatherers often performed the majority of flintknapping, including core preparation and removal or cortex, at source locations, Eerkens et al. (2007: 586) assert “waste flakes and cores at archaeological sites are composed primarily of local raw materials, while (discarded) tools at those same sites are disproportionately composed of exotic toolstone.”

The study recognized a general pattern based on three case studies from California and Oregon. Eerkens et al. (2007: 586) propose “the types of raw materials represented among large flakes should be more diverse, again representing mainly the closest raw materials, while smaller flakes and formal tools include a more diverse range of materials, representing local as well as more distant sources”. Currently, the applicability of the model to the northern Arizona Archaic remains unknown. However, the study serves as an example of the additional information possible through geochemical analysis when incorporating all components of a lithic assemblage.

As is the case with the current study, Eerkens et al. (2007) identified selective and highly patterned obsidian procurement behavior. One facet of the model not supported by this study, however, relates to formal tools representing a greater diversity of sources occurring farther from the source. The current study reflects the opposite pattern. The vast majority (86%) of projectile points recovered from the study area were manufactured from nearby sources. In addition the possible future discovery of location of the unknowns may boost the number.

Eerkens et al. (2007: 594) acknowledge a few shortcomings of the model, including the criticism that the model fails to take into account material quality. I believe the differences between the California and Oregon assemblages and the current assemblage from northern Arizona can best be understood in terms of lithic raw material quality. While the authors cite the presence of many local, low-quality sources as a reason for the existence of increased amounts of source material from afar, therein lies a problem of causality. As the current study demonstrates, the presence of many local, average-quality sources may also condition the optimization strategy discussed previously. Such behavior can result in procurement patterns focusing on a few local sources rather than reliance on more distant materials. Nevertheless, Eerkens et al. (2007: 593) make a valid point when writing, “to avoid biases…it is important to include all three categories (formal tools, large flakes, and small flakes) in any thorough geochemical provenance analysis.”

Implications of the PPM on “Embedded” Procurement

As mentioned earlier, most researchers believe lithic raw material procurement was incidental to food choices. As Binford (1979: 259) asserts, “procurement of raw materials is embedded in basic subsistence schedules.” Binford discounts the occurrence of toolstone material within an assemblage as evidence of disembedded lithic procurement, noting that “the cost of procurement was not referrable to the distance between the source location and the location of use, since this distance would have been traveled anyway" (Binford 1979: 260) within everyday subsistence activities. In addition, as Gould (1985: 118) points out, Binford also doubts the degree to which raw material quality affects procurement choices. In this vein, I pursued the research questions raised in chapter one. Gould (1985: 118) considers "a controlled examination of technological factors pertaining to lithic procurement and use as essential before any convincing archaeological perception of relationships to subsistence economy is possible." Thus, the material performance characteristics ranking order used as a foundation for the PPM serves as such an examination.

Stafford et al. (2000: 320) suggest that changes in food resource abundance condition shifts in settlement and mobility practices. During the roughly 6,600 years of Archaic occupation of the area, food resource abundance and patchiness undoubtedly oscillated. Thus, if lithic resource procurement in northern Arizona was indeed embedded, source variation should reflect the pattern, i.e. other sources should appear in the archaeological record. However, the optimal set never changed, although frequencies did. Particularly, if food abundance fluctuations determined changes in mobility, yet lithic source behavior remains unchanged, then Archaic obsidian procurement appears to reflect a "disembedded" strategy.

Procurement strategies favoring travel of long distances in order to obtain high-quality sources instead of relying on suitable sources of lower quality suggests Archaic lifeways accustomed to high mobility. Undoubtedly such lifeways developed from the differential placement of subsistence resources across the landscape. I believe the established social structure and underlying mental templates indicative of high mobility may have been adapted, however, to living in a relatively circumscribed area (by Archaic standards) due to the ecotonal environment and the presence of abundant, high-quality obsidian and FGV's. Within the circumscribed foraging territory evidenced by procurement activities, I believe Archaic Period hunter-gatherers did not practice an "embedded" strategy in the region. Rather, procurement behavior appears specialized, economical, and commensurate with subsistence behaviors. Moreover, based on the geochemical evidence, hunter-gatherers in the region appear to have practiced direct, disembedded procurement based largely on material quality.

Archaic Trade

Researchers have noted the implausibility of highly articulated trade networks during the Archaic Period (Jones 2003; Shackley 2005; Ward 1977), thus the assumption can be plausibly made that Archaic populations acquired obsidian by direct procurement. Archaeological evidence does not support the idea that "down-the-line" trade or other such organizational mechanisms ever existed during the Archaic. In addition, as Daniel argues, "it would be a highly disadvantageous adaptive strategy for a group to rely on exchange for a critical resource like stone" (Daniel 1998: 179). I propose bands practiced direct procurement of lithic materials and thus constitutes a more plausible explanation for Archaic Period behavior. Direct procurement, coupled with the Quaternary nature of the San Francisco volcanic domes, reduces the possibility of spurious conclusions concerning the spatial distribution of obsidian artifacts in northern Arizona and their indication of Archaic mobility.

Because I rely on the relationship between artifact and source, exact knowledge of the procurement location is necessary. In northern Arizona, this is made easier because the San Francisco and Mt. Floyd volcanic fields arose during the Quaternary. Quaternary-era volcanoes are relatively young geologically and thus have not eroded to the extent of older Tertiary-age volcanoes. The implication, of course, is the Quaternary-age igneous toolstone has not traveled far from the source in the region by natural channels. Thus, the arid region of northern Arizona is an ideal region to pursue questions concerning patterns of mobility and resource choice in band-level societies. Lacking the “noise” created by archaeological remnants of trade and natural processes, the spatial relationship between source and tool becomes clearer.

Tool Depletion

Another possible correlate of the behavior explained by the PPM regards toolstone depletion events (Figure 52). Such events occurred inevitably during regular subsistence activities and the rate and scope of toolstone depletion was undoubtedly predicted by hunter-gatherers anticipating a future disconnect with the lithic sources. As such, procurement behavior likely reflected this knowledge in terms of quantity exploited at the source.

It stands to reason that hunter-gatherers systematically choosing only the highest quality sources would also display highly patterned behavior with respect to amount of igneous toolstone collected during each procurement event. Because hunter-gatherers avoided several toolstone sources, the amount taken at the preferred sources presumably accounted for these choices. Particularly, Archaic Period groups likely safeguarded the mobile toolkit by exploiting larger quantities of toolstone at the source. In short, hunter-gatherers ensured “a gain in marginal returns from the use of a bulk extractive technique” (Stafford et al. 2000: 318). Moreover, because the distance between source patches is not so great as to preclude portability concerns, hunter-gatherers may have taken away ample (surplus?) amounts of obsidian and FGV materials. Indeed, Close (1996: 545) argues, “for prehistoric people the priority was not portability but anticipated activity and serviceability.”

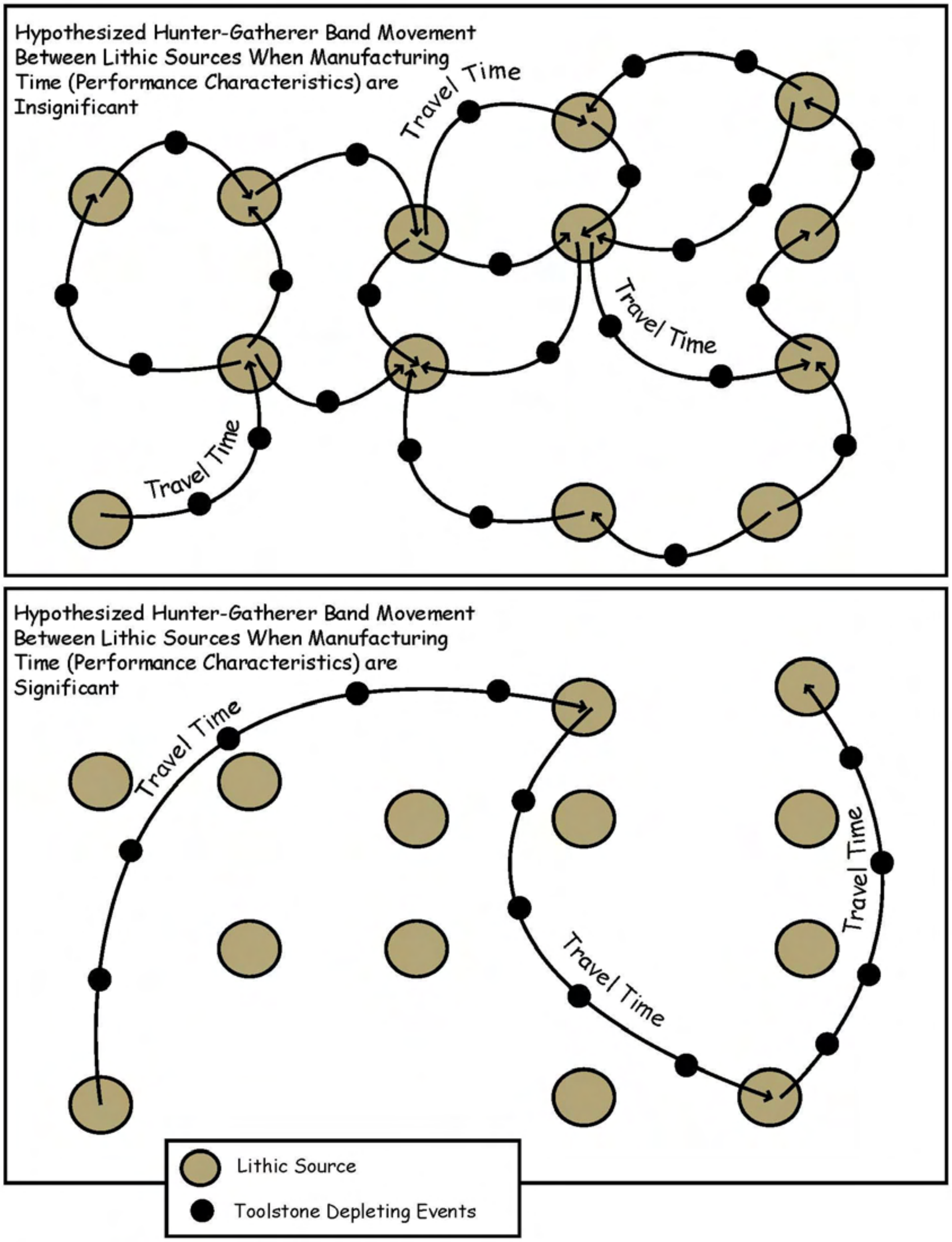


Figure 52. Diagram showing relationship between toolstone source, tool depletion events and mobility.

In the Neighborhood: A Note About “Local” vs. “Non-local” Sources

In efforts to draw inferences about mobility, trade, and settlement patterns, archaeologists have long differentiated between “local” and “non-local” lithic raw materials. Such distinctions have aided researchers in reconstructing foraging territories and lithic technological organization, among other questions. Indeed, within many studies, such categories are appropriate (Close 1996, Smith 1999, Anderson and Hanson 1988, Jones et al. 2003, Beck and Jones 1990, Newman 1994, Andrefsky 1994). Research with a large scale of inquiry or concentrated on sedentary populations, for example, could benefit from distinguishing between local and non-local raw materials. For the current study, however, an attempt at dividing local and non-local seemed capricious and arbitrary.

Alternatively named “supralocal,” “exotic,” or “extralocal,” these “non-local” raw materials presumably arrived at a given site from a considerable distance. While numerous studies have benefited from this classificatory scheme, I suspect the separation of “local” and non-local” lithic materials is more often fueled by fiscal concerns, rather than reality. For instance, how does one decide which category a raw material fits into? Do we draw an arbitrary 50 kilometer circle around an archaeological site and classify all raw material sources located within the circumference as local, while those lying outside as non-local? (see Munson and Munson 1984 for an explicit example). How do we account for topographic, physiographic, cultural, or geologic variables in the above scenario? Furthermore, how do we take into account the transportation mechanism by which the material arrived at the site? Raw material transportation through seasonal movements of populations certainly must be viewed differently than raw material movement via trade or exchange. Moreover, are the local vs. non-local categories emic or edic? Did prehistoric populations view a material as “non-local”? Lastly, are raw materials considered local during one mobility strategy and nonlocal in another? Do individual sources alternate between the two categories at a single multi-component site?

For the above stated reasons, I have chosen not to employ such a classification device. Due to the relatively limited geographic region of the study area as well as the high level of mobility practiced by Archaic Period hunter-gatherers, all toolstone sources available in northern Arizona could justifiably be considered more-or-less local. This is not meant to diminish the information potential of raw material nor limit inferences. In fact, the opposite is true. Unburdened by inappropriate designations, we can gain a more resolute understanding of procurement strategies in northern Arizona during the Archaic.

Caveats

I must offer a word on the ranking criteria used to formulate the PPM. I graded the various igneous materials relative to the entire suite of sources, and the criteria I used was based on perceived performance characteristics gained through experimental flintknapping. While I believe most contemporary flintknappers would agree with my assertions, I acknowledge the idiosyncratic nature of the system. Whether the Archaic Period flintknapper inhabiting the region would agree with the ranking scale remains unknown. Indeed, as Young and Bonnichsen (1984: 135) aptly point out, “the modern day flintknapper…interprets prehistoric artifacts in terms of his own production code, which does not encompass the total range of possible cross-cultural tool manufacturing procedures."

Constructing a statistically significant ranking device would have provided efficacy and validity to the rank ordering schema. Ideally, this would entail gathering a large group of archaeologists and flintknappers together for a workshop in order to reach consensus on the relative performance characteristics of the northern Arizona toolstone source materials. However, the result of such a process would nonetheless be based on modern flintknappers opinions, a problem often faced in replication studies. Unfortunately, the workshop was beyond the scope of the current study thus any weaknesses in the model remain solely the responsibility of the author. Hopefully I am not of the flintknappers who "behave as if the act of breaking rocks gives them the inside track to truth" (Thomas 1986: 623).

Because this study relies on the interrelationships between spatially disconnected resources and the role they play in driving mobility, the role of edible resources in conditioning hunter-gatherer movements remains unknown. Specifically, did the richness of ecotonal environments serve to circumscribe territorial ranges? While such transition zones certainly affected the scope of mobility, the archaeological application of the effects of ecotones must advance "from an unquestioned assumption to a testable hypothesis in archaeological research design" (Rhoades 1978: 612).

Another caveat of my research involves the geographic scale. Shackley (1990: 420) urges future researchers dealing with hunter-gatherer mobility to expand the scale of inquiry to incorporate uplands and lowlands so to acknowledge the potential enormity of Archaic territorial ranges. Shackley (1990: 420) laments the traditionally limited scopes of many research projects and provides the following as a cause for the small study areas: “overwhelming worldwide ethnographic evidence indicates that arid land hunter-gatherers occupied very large procurement ranges. Perhaps it is simply due to our own ethnocentric view of sedentary humankind, tempered by our concept of post-Archaic sedentary agricultural lifeways in the Southwest.” Without question, the geographic range covered by this thesis cannot account for the entire territory covered annually by hunter-gatherers in the region. However, as I mentioned previously, this study provides an explanation for band movement *within* a physiographic zone.

Chapter Seven: Conclusion

This thesis represents the most complete igneous toolstone geochemical study yet performed on the Coconino Plateau. Recent advancements in X-ray fluorescence analysis enables archaeologists to employ technology not available to past generations. The conclusions presented here will undoubtedly continue to be refined and updated as geochemical techniques become increasingly more sophisticated. Indeed, this thesis represents a basis from which further research may advance. A baseline study is meant to be elaborated and improved upon; hopefully the current research will stimulate such work.

The study contributes to the growing body of knowledge of lithic raw material procurement in the region and worldwide. Ideally, archaeologists bolstered by quantitative geochemical data will continue to question long held assumptions about hunter-gatherer mobility, settlement, and lithic procurement. I attempted to take a small step to this end. As Shackley (1990: 422) argues, “It is apparent that the study of early Southwestern hunter-gatherers requires rather substantial reorientation from approaches that focus on phase/time based theory.” This, of course, is the reason I neglected to propose different phases within the periods. Moreover, while trends in lithic procurement were evident, they lacked sufficient discriminate parameters to justify separation.

The elucidation of hunter-gatherer adaptive strategies requires employing a multidisciplinary approach and fine-grained analyses. XRF analysis provided one way to wring much from relatively little. Because of the ephemeral nature of temporary band campsites and procurement locales during the Archaic Period, archaeologists must rely on every available method to reconstruct hunter-gatherer settlement systems and mobility strategies. As Smiley (2002: 15) points out, "post-Pleistocene Archaic groups left, at best, only evanescent records across the greater region."

Although large-scale Archaic Period mobility in Southwest remains poorly understood, this study contributes to an understanding of regional mobility in northern Arizona. While researchers such as Jochim (1976), Kelly (1983, 1987, 2005), Carr (1994), and Anderson and Hanson (1988) have long understood hunter-gatherer bands throughout prehistory to practice a highly mobile way of life, the variability of mobility strategies differs significantly between regions. Northern Arizona is an area that exhibits evidence of long-term Archaic occupation, yet lacks a comprehensive reconstruction of mobility adaptations. Studies concerning hunter-gatherer mobility in comparable arid climates, containing high topographic relief and abundant toolstone-quality lithic sources, could test the conclusions found here. In addition, future systematic research focusing on this period in northern Arizona is greatly needed.

Included in the study is an up to date geochemical source characterization library useful for further research throughout the northern Southwest. While the presence of the unknown igneous toolstone materials indicate the source sampling survey remains incomplete, the chemical signature library presented here constitutes the most comprehensive source standard data in the region. Additional work is needed in this area. Until then, I trust archaeologists will refer to the appendices if not the conclusions.

Concluding Remarks

This study focused on the Archaic Period for two simple reasons. First, as noted previously, the era remains poorly understood. The farther one looks into prehistory, the less clear things become. Archaeological inference rests on the material remains of past societies. Archaeometric techniques used to glean information from cultural remains continue to become more and more sophisticated. However, such techniques become increasingly irresolute when applied to progressively older cultures. Confounding this methodological conundrum is the fact that the archaeological record has a preservation bias against perishable artifacts. Thus, the older a site is, the less likely the site will retain all of the material correlates of the occupation. It is no surprise then that archaeologists have focused more attention on the later prehistoric populations throughout North America (0 A.D.-1500 A.D.). Not only is there simply more to study, but also the techniques and methods used to analyze the artifacts are more accurate and developed. Therefore, we know considerably more about the periods leading up to European contact than we do about the Archaic and Paleoindian Periods.

These early periods of North American occupation are thus relatively unknown. As Cordell (1984: 154) asserts, “the archaeology of the Archaic suffers from the many of the same problems of Paleo-Indian archaeology: the remains are ephemeral because they are those of mobile hunters and gatherers; the artifactual remains at Archaic camps may include few, if any, temporally diagnostic tool types; and Archaic chronology and paleoenvironmental reconstructions are far less precise than is desirable.” Moreover, when studying the Archaic, archaeologists frequently concentrate on the Terminal Late Archaic (Early Agricultural), a time when cultivation of crops was first adopted. Undoubtedly paramount to an understanding of the development of sedentism and increased cultural complexity, the adoption of agriculture occurred at the terminus of the period. Although a major goal of archaeology is to understand change through time (and presumably not much change occurred during the Archaic), perhaps the focus solely on the origins of domestic crops undermines the importance of the preceding 7,000 years.

Second, and perhaps more important, this thesis may encourage future archaeologists to concentrate on the Archaic in the area. The Southwest United States contains North America’s most spectacular prehistoric standing architecture and extant archaeology. Preceding the agricultural tribes responsible for these structures were the small egalitarian hunter-gatherers that laid the groundwork. The Archaic Period deserves no lesser treatment than subsequent eras in the Southwest.

As is the case with many archaeological inquiries, this study provokes more questions than it provides answers. From the onset, I attempted to answer five questions about Archaic Period people occupying an arid region containing abundant sources of high-quality lithic raw material. The thesis met the primary research objective, which entailed determining whether the majority of diagnostic projectile points dating to the Archaic Period and recovered in the San Francisco and Mount Floyd volcanic fields were manufactured from local material. Geochemical analysis of the points provided an unequivocal answer to this baseline question. Indeed, the hunter-gatherers inhabiting the region prior to the adoption of agriculture relied overwhelmingly on nearby toolstone sources.

Second, I looked at the role of obsidian and other igneous toolstone in driving residential and logistic mobility. Although impressionistic ideas emerged, this question remains beyond the scope of my thesis. I simply needed more data. The geochemical analysis integral to this study serves as the foundation from which I made all behavioral inferences. However, because the sample size was rather small (n = 271), I looked at only one material class (igneous toolstone) and because I examined only one component of the Archaic toolkit (projectile points) such inferences are not without shortcomings. Furthermore, geochemical analysis must be supplemented with additional lines of evidence in order to confidently approach such complex questions. In fact, based on projectile point data alone, Archaic Period mobility appears to be neither far ranging nor dynamic, both contrasting sharply with the majority of previous research. However, by integrating mobility theory into the geochemical data, another picture emerges. Particularly, the masking effect created by "disembedded" procurement, coupled with the limited geographic range, may skew my interpretations. Nevertheless, I will not apologize for my conclusions because, like all archaeological investigations, the whole picture remains hidden.

Next, I questioned the extent to which the area served as a retooling center within a larger procurement range. Based on the extensive rejuvenation apparent on the majority of the projectile points used in this study (see appendix), the research area appears to have been used as a retooling center for Archaic populations. The majority of artifacts recovered from the Kaibab National Forest, as well as the areas yielding the points from the private collection, were manufactured from igneous toolstone, suggesting the importance of volcanic rock to Archaic lithic industries.

However, based on the evidence presented in this study, it is likely the Archaic groups were not disconnected from the northern Arizona toolstone sources for long. Whether this implies a circumscribed procurement territory or frequent and rapid movement remains unknown. As Shackley (1990: 422) puts it, “Obsidian to early hunter-gatherers in the Southwest formed a quantitatively small, but very important resource that could be procured two to three times a year in all the visited resource zones. This is probably partially why a large amount did not have to be transported- it would be again available in the next month or so.”

The last two questions became closely articulated throughout the research process and involved the factors influencing the discriminate use of obsidian and fine-grained volcanic toolstone in the region. At the onset of the study, I questioned whether equally high-quality igneous material occurred consistently across the research area. I also speculated on the reasons why prehistoric knappers made certain toolstone choices. I found that equally high-quality toolstone in fact does not occur uniformly over the area yet perfectly acceptable material most certainly did. I believe the procurement preference model addressed these questions fittingly.

This study is somewhat distinctive because of the combination of the geochemical analysis and the baseline source survey. Without these components working in concert, the suite of lithic options would be impossible to ascertain. Thus, the model is efficient as an explanatory device only after the lithic landscape becomes quantitatively established. Therefore, I recommend archaeologists understand the quality, location, and abundance of all possible toolstone sources before coming to any conclusions about the use of a few.

Specific Research Conclusions

I reached several conclusions regarding Archaic Period lithic procurement and mobility in this research.

1.) Once within the research area, hunter-gatherers practiced disembedded procurement practices. Based on projectile point data, prehistoric people systematically sought out, and then exploited, certain toolstone sources irrespective of small-scale spatial relationships with subsistence resources.

2.) Hunter-gatherers exhibited optimal procurement behavior based on toolstone quality and the specific igneous sources included within the optimal set remained unaltered throughout the period.

3.) While the specific sources within the optimal set continued unchanged, the intensity of specific source exploitation increased. In other words, Archaic procurement adaptations became more specialized (Figure 53).

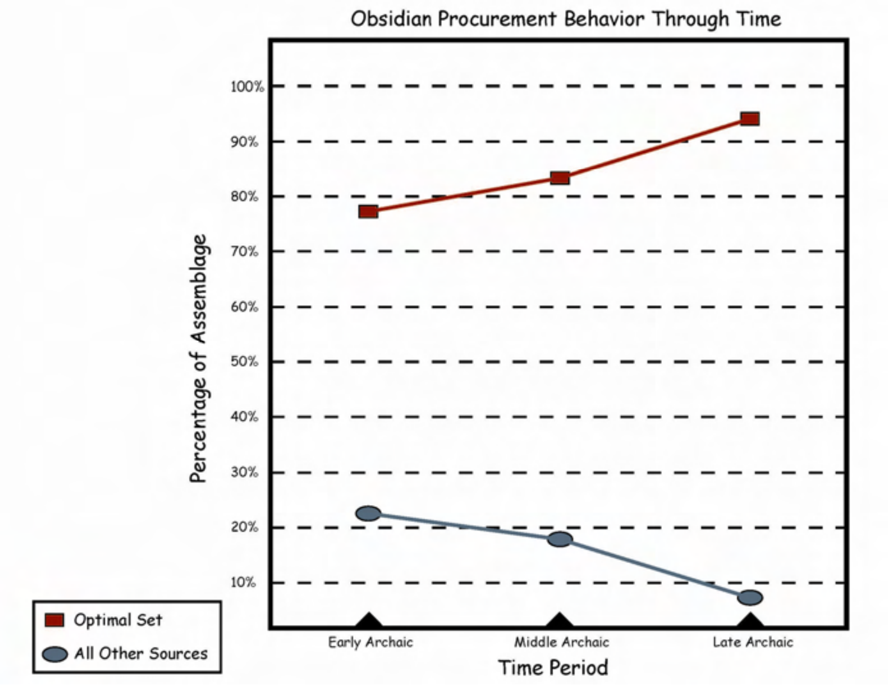


Figure 53. Obsidian procurement behavior through the Archaic period.

4.) Hunter-gatherers practiced lithic optimization strategies regardless of abundance and availability. A resource need not be disappearing before people act economically.
5.) The occurrence of many sources of high quality igneous toolstone sources resulted in highly specialized procurement behavior. Because many options were available, people opted for the lithic material least likely to present performance problems.
6.) Each geologic toolstone material is only as valuable as those varieties surrounding the source. Specifically, archaeologists should ascertain the quality of all lithic source options before making claims about the presence of one source.

Future Research Suggestions

Finally, I propose the presence of a disembedded lithic procurement strategy could mask the archaeological evidence for extensive mobility. In other words, the highly selective procurement strategy explained by the PPM, as evidenced by discard behavior, could appear very similar to the archaeological record of hunter-gatherers occupying a small geographic range. Archaeologists need a much larger sample size, including expedient tools, small and large flakes, and cores to test the conclusions offered here. Moreover, additional geochemical techniques performed on toolstone classes such as chert, chalcedony, jasper, and silicified wood should be incorporated into future studies of this kind. Integrating surface and subsurface assemblages would have improved this study tremendously, and I recommend researchers make use of such evidence. Lastly, the need to expand research areas beyond sites, landform features, and quarry clusters remains paramount. Apparently, troubles in archaeological inquiry continue to largely stem from the same problem today as in the beginning: sample size. As Brantingham (2003: 488) points out, “observed richness is frequently- if not universally- constrained by sample size.”

Sample size cannot, however, account for source distributions and frequencies as they reflect source material abundance. Brantingham (2003: 489) raises the question of whether assemblage variability (and thus procurement behavior) merely represents “the natural densities of raw material in the environment.” In northern Arizona, this is certainly not the case. The thirteen sources in the area each yield copious amounts of obsidian (except perhaps Ebert Mountain) and therefore none of the lithic sources would have a higher probability of being observed in an assemblage.

As discussed previously, one of the trademark cultural traits of Archaic populations is a high level of mobility, owing to the hunter-gatherer lifestyle. As I have shown, the study of lithic procurement as it relates to mobility is a convenient and practical line of inquiry when approaching the Archaic Period. Evidence of the Archaic presence throughout the Southwest is scant, and the bulk of that evidence consists of lithic artifacts. Therefore, analysis of lithic materials as markers of Archaic mobility is a useful tool to infer social organization, settlement patterns, and land-use.

I propose that the organization of Southwestern stone tool technologies is a powerful indicator of mobility and that lithic artifacts can be used in two relatively unused ways to infer Archaic mobility strategies and patterning. By combining debitage analysis and geochemical sourcing of stone, researchers can add significantly to the body of knowledge concerning the Archaic Period. Unfortunately, debitage analysis was beyond the scope of the current research so I relied on XRF analysis of projectile points to provide the basis for inference. However, debitage analysis and geochemical analysis of flaking debris, remain a fruitful avenue of study for future researchers.

Finally, I hope this study serves as a small impetus for further hunter-gatherer studies in the northern Southwest. Many questions remain about the nature and scope of territorial ranges in the region and how they changed through the Archaic. I also hope that this study serves to demonstrate the value of combining lithic source surveys with regional archaeological inquiry to future researchers working in other areas.

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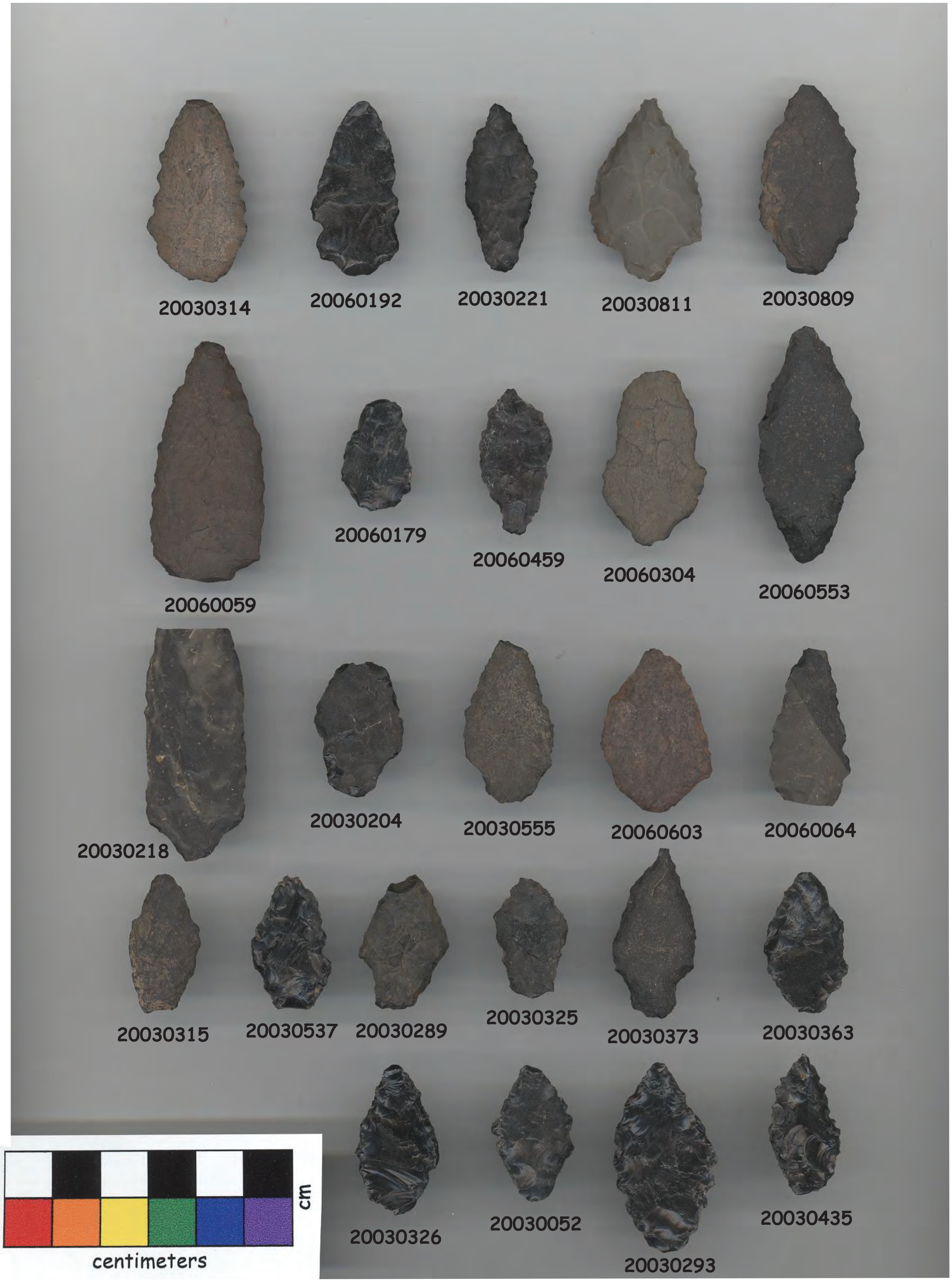
Appendix A:
Scanned Images of Northern Arizona Projectile Points Dating to the Archaic Period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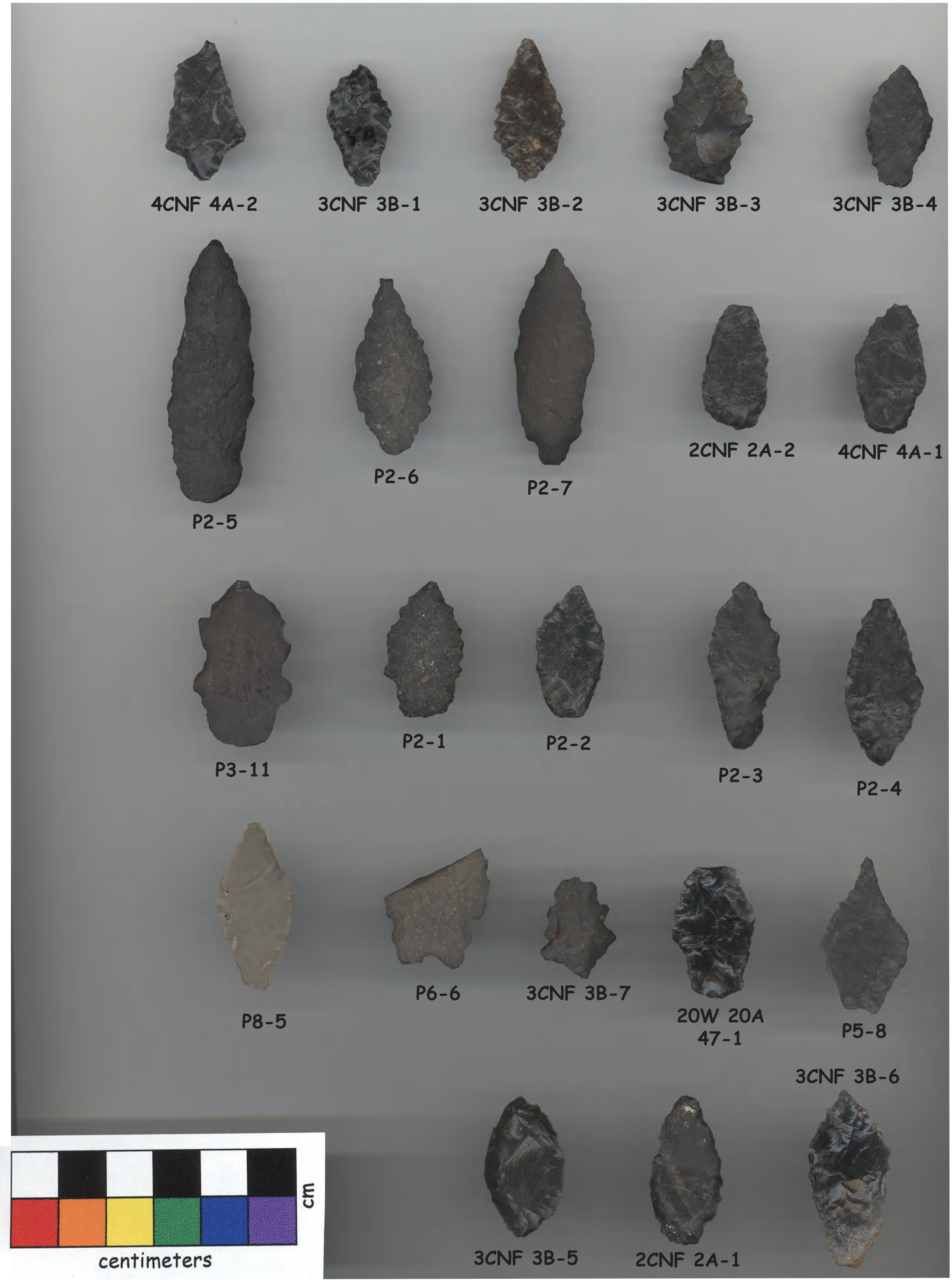
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P2-6
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2CNF 2A-2
4CNF 4A-1
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P2-1
P2-2
P2-3
P2-4
P8-5
P6-6
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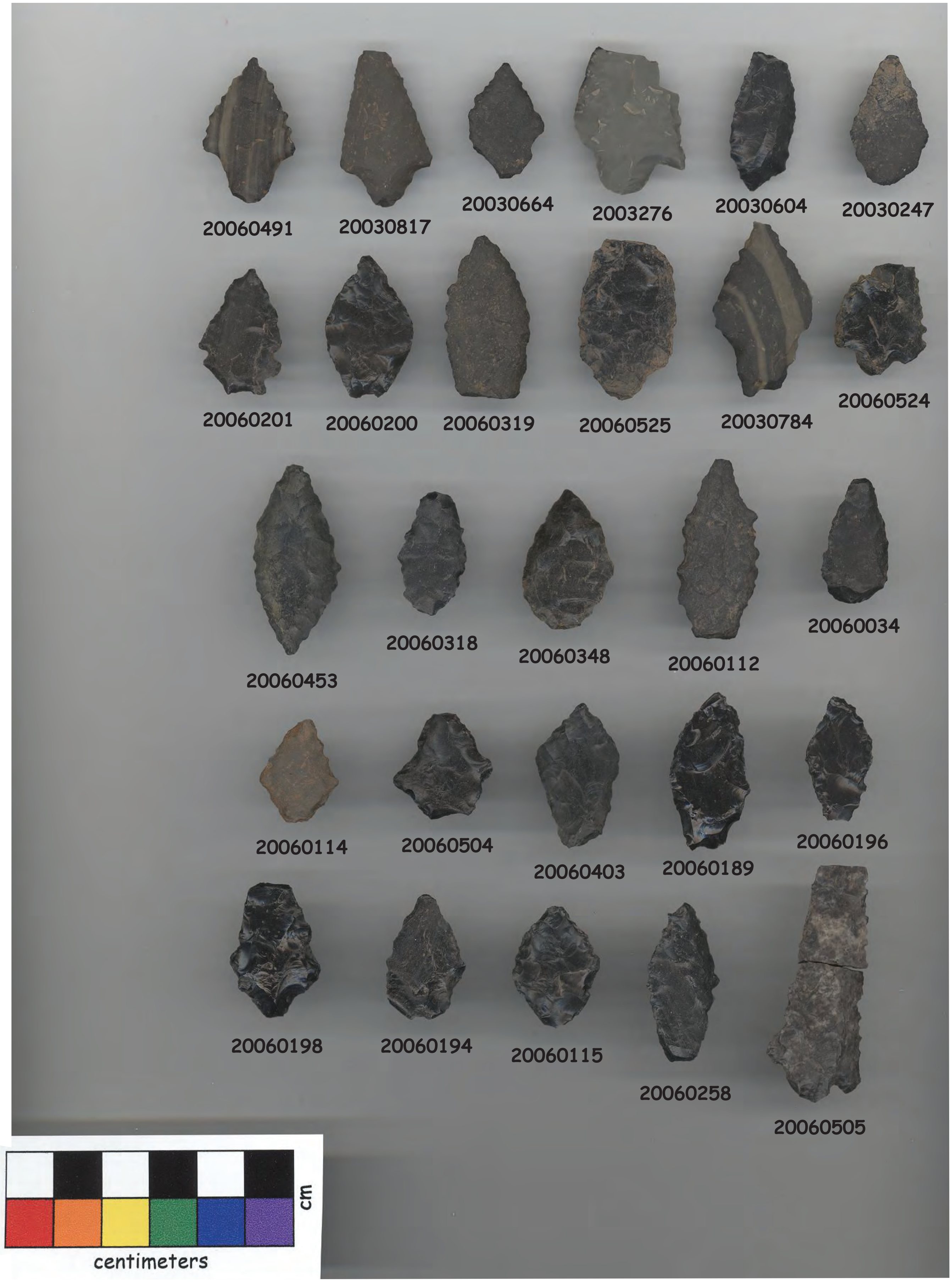
centimeters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P3-10
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66CNF 6A-10
6CNF 6A-9
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6CNF 6A-2
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cm
centimeters


8CNF
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7CNF
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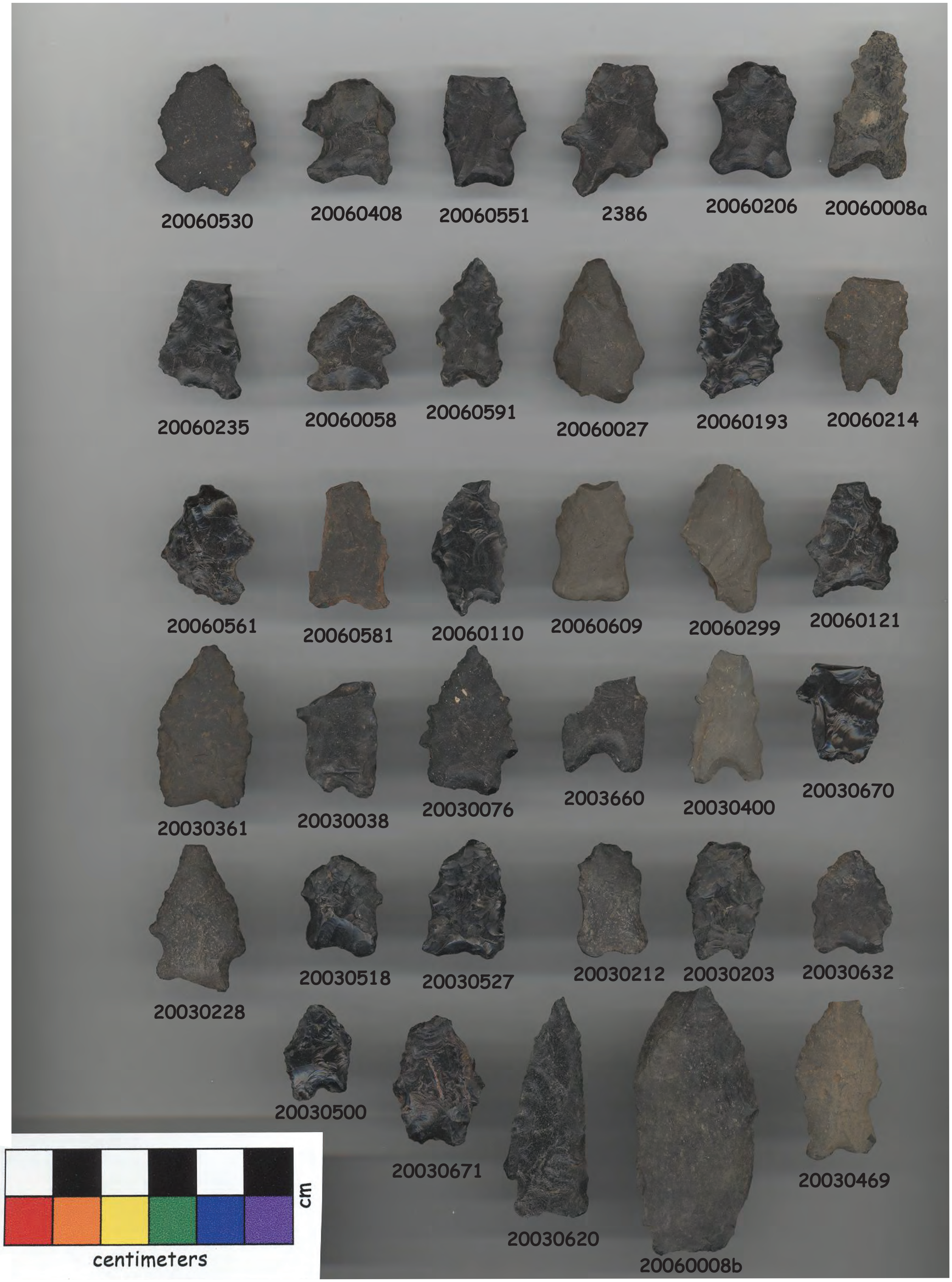
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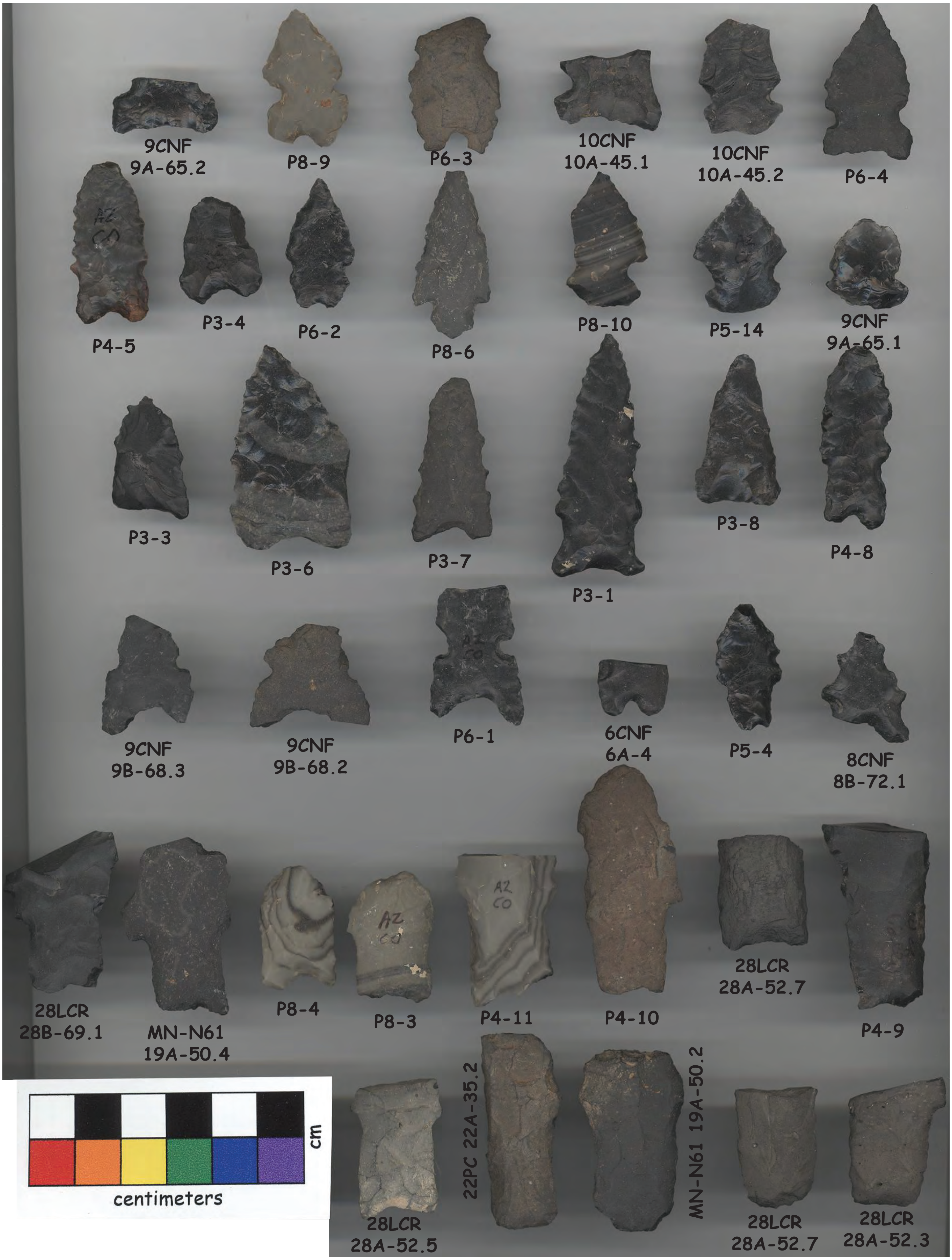
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cm
centimeters

Appendix B:
Database Coding Sheet

Projectile Point Designation	Projectile Point Type	Temporal Period Designation	Temporal Period
12	Jay	Early Archaic	1
1	Bajada	Early Archaic	1
2	Northern Side-notched	Early Archaic	1
3	Pinto/San Jose	Middle Archaic	2
4	Sudden Side-notched	Middle Archaic	2
5	Armijo	Late Archaic	3
6	Chiricahua	Late Archaic	3
7	Elko Eared	Late Archaic	3
8	Gatecliff Split-stemmed	Late Archaic	3
9	Gypsum Cave	Late Archaic	3
10	Rocker Side-notched	Late Archaic	3
11	San Rafael Side-notched	Late Archaic	3

Source Designation	Lithic Source Name
1	Black Tank
2	Deadman's Mesa
3	Ebert Mountain
4	Government Mountain
5	Kendrick Peak
6	O'Leary Peak/ Robinson Crater
7	Partridge Creek
8	Presley Wash
9	RS Hill/ Sitgreaves Mountain
10	San Francisco Peaks I
12	Slate Mountain
13	Unknown Obsidian I
14	Unknown Obsidian II
15	San Francisco Peaks II
16	Unknown Obsidian IIII
17	Unknown FGV
18	Unknown FGV A

General Provenience Designation	General Provenience
1	Kaibab National Forest
2	Coconino National Forest
3	Little Colorado River Watershed
4	Partridge Creek
5	Northwest of Coconino National Forest
6	West of Coconino National Forest

Appendix C:
Results of XRF Studies-
The Sources

Northwest Research Obsidian Studies Laboratory

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Collection Locale	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Government Mountain	1	1514-1	52	25	103	70	18	80	50	268	572	261	0.63	9.9	76.8	Government Mountain
			± 11	5	4	9	3	10	2	88	28	32	0.11			
Government Mountain	2	1514-2	37	33	109	77	19	83	48	372	523	288	0.89	14.9	78.7	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
Government Mountain	3	1514-3	73	35	141	82	20	83	51	228	591	286	0.79	11.8	109.5	Government Mountain
			± 9	4	4	9	3	10	2	88	28	32	0.11			
Government Mountain	4	1514-4	52	32	100	77	20	81	50	149	393	292	0.68	15.4	135.5	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
Government Mountain	5	1514-5	31	38	100	74	17	77	48	100	481	274	0.75	13.8	204.3	Government Mountain
			± 11	4	4	9	3	10	2	87	28	32	0.11			
Government Mountain	6	1514-6	46	33	128	80	20	84	49	96	378	286	0.59	14.1	168.6	Government Mountain
			± 10	5	4	9	3	10	2	87	27	32	0.11			
Government Mountain	7	1514-7	37	32	102	68	19	80	45	144	418	290	0.73	15.4	149.3	Government Mountain
			± 11	5	4	9	3	10	2	88	28	32	0.11			
Government Mountain	8	1514-8	48	29	105	77	19	78	47	127	636	270	0.72	10.1	164.7	Government Mountain
			± 10	5	4	9	3	10	2	87	28	32	0.11			
Government Mountain	9	1514-9	48	21	101	76	20	79	49	221	619	284	0.90	12.7	126.9	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
Government Mountain	10	1514-10	50	35	112	80	21	84	49	159	622	292	0.75	10.6	141.0	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
Government Mountain	11	1514-11	61	24	101	78	19	78	43	178	561	284	0.57	9.3	101.3	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
Government Mountain	12	1514-12	45	36	113	80	22	84	50	208	504	299	0.84	14.5	124.5	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
Government Mountain	13	1514-13	48	29	108	76	18	76	46	494	524	285	0.91	15.1	61.4	Government Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Government Mountain	14	1514-14	46	36	103	76	20	79	51	411	690	315	0.99	12.4	79.0	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
Government Mountain	15	1514-15	37	26	100	71	19	77	44	122	507	270	0.83	14.3	190.8	Government Mountain
			± 11	5	4	9	3	10	2	88	28	32	0.11			
Government Mountain	16	1514-16	52	35	106	79	21	78	48	151	509	261	0.81	14.0	158.8	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Collection Locale	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Government Mountain	17	1514-17	51	22	105	76	19	79	47	164	440	285	0.74	14.8	135.5	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
Government Mountain	18	1514-18	51	31	102	80	19	77	46	123	626	275	0.68	9.7	159.6	Government Mountain
			± 10	5	4	9	3	10	2	87	28	32	0.11			
Government Mountain	19	1514-19	40	27	100	72	18	78	49	430	690	267	0.79	10.1	61.5	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
Government Mountain	20	1514-20	40	30	103	78	22	80	50	229	654	285	0.84	11.3	115.3	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
Government Mountain	21	1514-21	45	32	105	73	20	78	49	343	468	311	0.83	15.5	78.9	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
Government Mountain	22	1514-22	40	34	111	78	20	81	51	170	496	306	0.77	13.7	137.7	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
RS Hill	23	1515-1	63	27	104	62	21	135	41	467	384	531	1.02	23.0	72.0	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
RS Hill	24	1515-2	52	29	91	84	18	83	44	271	654	519	0.85	11.4	100.2	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	25	1515-3	57	26	97	87	18	88	45	364	432	489	0.85	17.2	76.4	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	26	1515-4	59	30	99	88	21	93	48	156	559	567	0.92	14.3	174.2	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	27	1515-5	58	19	93	76	19	91	48	116	485	506	0.73	13.4	178.6	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	28	1515-6	50	33	100	78	17	91	47	262	381	531	0.83	19.1	100.4	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
RS Hill	29	1515-7	55	26	96	77	19	88	46	174	476	510	0.94	17.1	160.5	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	30	1515-8	40	28	106	79	21	94	51	135	365	467	0.72	17.5	155.5	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
RS Hill	31	1515-9	55	24	94	73	20	87	46	130	564	452	0.84	12.9	184.2	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	32	1515-10	66	26	97	77	19	90	47	192	355	542	0.65	16.5	106.5	Government Mountain
			± 10	5	4	9	3	10	2	88	27	32	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
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Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Collection Locale	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
RS Hill	33	1515-11	44	19	93	95	19	86	43	112	614	519	0.96	13.5	234.9	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	34	1515-12	48	36	96	78	18	90	44	130	461	488	0.89	16.8	194.6	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	35	1515-13	43	31	94	81	19	86	47	134	564	527	0.94	14.4	199.9	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	36	1515-14	53	24	94	87	21	89	47	72	589	513	0.97	14.2	325.6	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	37	1515-15	138	72	395	9	86	163	247	98	392	0	0.95	21.0	257.5	RS Hill
			± 10	5	5	10	3	10	2	87	28	31	0.11			
RS Hill	38	1515-16	145	76	413	8	88	166	250	125	380	0	0.85	19.6	192.7	RS Hill
			± 10	5	5	14	3	10	2	87	28	31	0.11			
RS Hill	39	1515-17	128	76	403	9	87	162	242	108	517	16	0.83	14.0	210.9	RS Hill
			± 10	5	5	10	3	10	2	87	28	31	0.11			
RS Hill	40	1515-18	124	69	373	10	82	157	238	93	326	16	0.75	20.4	215.6	RS Hill
			± 10	5	5	10	3	10	2	87	27	31	0.11			
RS Hill	41	1515-19	118	76	389	ND	90	158	247	110	395	26	0.98	21.5	242.4	RS Hill
			± 10	5	5	ND	3	10	2	87	28	53	0.11			
RS Hill	42	1515-20	140	69	389	ND	87	159	246	139	390	0	0.96	21.3	197.8	RS Hill
			± 10	5	5	ND	3	10	2	87	28	31	0.11			
RS Hill	43	1515-21	114	73	426	10	86	168	251	112	605	0	0.78	11.3	193.8	RS Hill
			± 10	5	5	10	3	10	2	87	28	31	0.11			
RS Hill	44	1515-22	138	74	409	9	88	164	252	133	375	0	0.83	19.4	179.2	RS Hill
			± 10	5	5	10	3	10	2	87	28	31	0.11			
RS Hill	45	1515-23	34	25	90	74	20	88	45	98	404	533	0.78	17.0	214.7	Government Mountain
			± 11	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	46	1515-24	53	21	103	83	18	86	48	161	622	562	0.82	11.5	150.9	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	47	1515-25	55	21	103	85	17	92	44	121	705	507	0.93	11.4	214.6	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	48	1515-26	41	28	98	84	18	90	46	173	698	518	0.80	10.0	139.1	Government Mountain
			± 11	5	4	9	3	10	2	88	28	32	0.11			

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Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Collection Locale	Specimen No.	Catalog No.		Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
RS Hill	49	1515-27		67	30	100	76	17	90	46	201	513	518	0.98	16.5	147.6	Government Mountain
			±	10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	50	1515-28		59	28	97	78	19	93	44	138	486	484	0.89	15.9	184.7	Government Mountain
			±	10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	51	1515-29		48	28	96	73	18	88	43	180	691	523	0.88	11.1	147.0	Government Mountain
			±	10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	52	1515-30		33	23	99	77	19	89	48	131	633	515	0.74	10.3	163.6	Government Mountain
			±	11	5	4	9	3	10	2	88	28	32	0.11			
Partridge Creek	53	1516-1		45	22	88	190	13	128	18	2155	453	1090	2.10	38.7	32.8	Presley Wash
			±	11	5	4	9	3	10	2	94	28	32	0.11			
Partridge Creek	54	1516-2		14	19	85	166	11	125	17	1569	296	1203	1.79	51.0	38.2	Presley Wash
			±	19	5	4	9	3	10	2	93	28	32	0.11			
Partridge Creek	55	1516-3		47	27	84	173	16	134	21	1616	414	1195	1.77	35.9	36.9	Presley Wash
			±	11	5	4	9	3	10	2	92	28	32	0.11			
Partridge Creek	56	1516-4		39	25	83	176	15	128	17	1523	298	1151	1.73	49.2	38.3	Presley Wash
			±	11	5	4	9	3	10	2	92	28	32	0.11			
Partridge Creek	57	1516-5		29	19	79	166	14	124	19	1807	297	1203	1.90	53.8	35.3	Presley Wash
			±	13	6	4	9	3	10	2	93	28	32	0.11			
Partridge Creek	58	1516-6		26	26	83	198	16	134	19	2285	356	1089	2.33	54.6	34.1	Presley Wash
			±	12	5	4	9	3	10	2	94	28	32	0.11			
Partridge Creek	59	1516-7		34	19	83	165	10	123	18	1800	323	1216	1.37	36.0	25.9	Presley Wash
			±	11	5	4	9	3	10	2	92	28	32	0.11			
Partridge Creek	60	1516-8		35	17	79	174	13	125	19	1271	233	1150	1.47	54.0	39.1	Presley Wash
			±	11	5	4	9	3	10	2	92	27	32	0.11			
Partridge Creek	61	1516-9		44	36	223	9	39	90	47	168	521	3	0.74	12.6	133.4	Partridge Creek (Round Mountain)
			±	10	5	5	10	3	10	2	87	28	31	0.11			
Partridge Creek	62	1516-10		38	45	245	12	38	91	48	863	324	5	0.58	16.2	23.9	Partridge Creek (Round Mountain)
			±	10	4	5	9	3	10	2	89	28	31	0.11			
Partridge Creek	63	1516-11		35	19	68	244	15	130	19	3017	315	1016	2.38	62.9	26.5	Presley Wash FGV
			±	12	5	4	10	3	10	2	95	28	32	0.11			
Partridge Creek	64	1516-12		53	37	262	8	42	91	54	152	339	13	0.62	16.5	122.6	Partridge Creek (Round Mountain)
			±	10	5	5	13	3	10	2	87	28	31	0.11			

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Northwest Research Obsidian Studies Laboratory

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Collection Locale	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Partridge Creek	65	1516-13	32	21	73	204	17	142	20	2615	369	1137	2.45	55.3	31.4	Presley Wash
			± 12	5	4	9	3	10	2	95	28	32	0.11			
Partridge Creek	66	1516-14	41	25	71	214	15	129	18	2723	333	1008	2.44	61.1	30.0	Presley Wash FGV
			± 11	5	4	10	3	10	2	94	28	32	0.11			
Partridge Creek	67	1516-15	34	17	79	172	13	122	18	1492	278	1157	1.73	52.5	38.9	Presley Wash
			± 11	5	4	9	3	10	2	92	28	32	0.11			
Partridge Creek	68	1516-16	49	29	78	215	16	135	21	2930	445	1090	2.77	51.4	31.6	Presley Wash FGV
			± 12	6	4	10	3	10	2	95	28	32	0.11			
Partridge Creek	69	1516-17	46	25	92	185	15	132	21	1410	264	1108	1.42	46.0	34.2	Presley Wash
			± 10	5	4	9	3	10	2	92	27	32	0.11			
Partridge Creek	70	1516-18	46	26	78	217	14	219	19	2650	473	1042	2.48	43.4	31.3	Partridge Creek Unknown
			± 11	5	4	10	3	10	2	95	28	32	0.11			
Partridge Creek	71	1516-19	54	23	88	201	15	142	19	1843	348	1109	1.82	44.0	33.2	Presley Wash
			± 10	5	4	9	3	10	2	93	28	32	0.11			
Partridge Creek	72	1516-20	11	25	86	177	13	127	21	1301	316	1123	1.50	40.4	38.9	Presley Wash
			± 25	5	4	9	3	10	2	92	28	32	0.11			
Partridge Creek	73	1516-21	39	45	242	ND	38	94	48	201	421	0	0.73	15.4	112.9	Partridge Creek (Round Mountain)
			± 10	5	5	ND	3	10	2	87	28	31	0.11			
Partridge Creek	74	1516-22	34	40	235	10	39	90	50	1007	410	0	0.58	12.8	20.6	Partridge Creek (Round Mountain)
			± 10	5	5	10	3	10	2	89	28	31	0.11			
Partridge Creek	75	1516-23	60	24	64	238	18	128	17	3106	435	983	2.18	41.8	23.7	Presley Wash FGV
			± 11	5	4	10	3	10	2	95	28	32	0.11			
Partridge Creek	76	1516-24	41	21	71	216	13	128	15	2969	535	1021	2.78	42.9	31.3	Presley Wash FGV
			± 11	5	4	10	3	10	2	95	28	32	0.11			
Partridge Creek	77	1516-25	42	25	85	173	14	131	17	1496	312	1142	1.76	47.6	39.5	Presley Wash
			± 11	5	4	9	3	10	2	92	28	32	0.11			
Partridge Creek	78	1516-26	42	36	248	9	40	93	52	195	449	18	0.82	16.0	128.7	Partridge Creek (Round Mountain)
			± 10	5	5	10	3	10	2	88	28	31	0.11			
Partridge Creek	79	1516-27	29	21	85	177	16	128	17	1757	299	1158	1.87	52.6	35.8	Presley Wash
			± 12	5	4	9	3	10	2	93	28	32	0.11			
Partridge Creek	80	1516-28	62	27	78	226	15	134	19	3299	314	993	2.68	71.0	27.2	Presley Wash FGV
			± 10	5	4	10	3	10	2	96	28	32	0.11			

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Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Collection Locale	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Partridge Creek	81	1516-29	45	33	75	238	17	147	17	3031	463	1027	2.65	47.4	29.3	Presley Wash FGV
			± 11	5	4	10	3	10	2	95	28	32	0.11			
Partridge Creek	82	1516-30	36	27	70	222	17	133	17	3078	358	1071	2.78	64.6	30.3	Presley Wash FGV
			± 12	5	4	10	3	10	2	96	28	32	0.11			
Partridge Creek	83	1516-31	41	21	80	206	15	143	20	2612	528	1027	2.43	38.1	31.1	Presley Wash
			± 12	6	4	10	3	10	2	94	28	32	0.11			
Robinson Crater	84	1517-1	78	24	65	227	31	262	47	703	696	1321	2.35	28.0	108.5	Robinson Crater 3
			± 11	5	4	10	3	10	2	91	28	32	0.11			
Robinson Crater	85	1517-2	80	26	68	145	31	227	48	622	775	1312	2.15	23.1	112.0	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Robinson Crater	86	1517-3	92	20	65	139	30	201	42	1077	490	1363	1.80	30.7	55.5	O'Leary Peak/Robinson Crater
			± 11	5	4	9	3	10	2	91	28	33	0.11			
Robinson Crater	87	1517-4	91	10	7	968	25	150	49	6827	1049	1203	6.83	52.8	33.2	Unknown FGV
			± 13	7	4	11	3	10	2	103	29	33	0.11			
Robinson Crater	88	1517-5	84	28	76	181	30	233	50	534	780	1367	1.94	20.7	116.8	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	90	28	32	0.11			
Robinson Crater	89	1517-6	93	23	69	136	30	205	45	1005	537	1342	1.35	21.4	45.3	O'Leary Peak/Robinson Crater
			± 11	5	4	9	3	10	2	91	28	33	0.11			
Robinson Crater	90	1517-7	74	28	72	144	28	204	43	1125	418	1323	1.28	26.2	38.6	O'Leary Peak/Robinson Crater
			± 10	4	4	9	3	10	2	91	28	33	0.11			
Robinson Crater	91	1517-8	94	24	64	142	28	221	48	1198	448	1356	1.61	30.3	45.1	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	33	0.11			
Robinson Crater	92	1517-9	67	27	65	150	30	229	47	777	640	1356	2.07	26.9	87.3	O'Leary Peak/Robinson Crater
			± 11	5	4	9	3	10	2	91	28	32	0.11			
Robinson Crater	93	1517-10	86	20	62	134	30	211	45	1451	505	1378	2.42	39.7	55.3	O'Leary Peak/Robinson Crater
			± 11	5	4	9	3	10	2	93	28	32	0.11			
Robinson Crater	94	1517-11	80	26	70	156	30	218	48	868	708	1305	1.90	22.4	72.3	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Robinson Crater	95	1517-12	89	21	78	189	31	237	50	1839	452	1411	2.26	41.6	41.1	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	94	28	32	0.11			
Robinson Crater	96	1517-13	88	33	66	174	29	242	46	905	603	1313	2.25	31.0	81.6	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	92	28	32	0.11			

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Northwest Research Obsidian Studies Laboratory

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Collection Locale	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Robinson Crater	97	1517-14	74	31	65	155	32	252	47	917	613	1385	2.36	32.0	84.5	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	92	28	32	0.11			
Robinson Crater	98	1517-15	88	29	70	145	32	217	48	707	721	1385	2.37	27.1	108.5	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Robinson Crater	99	1517-16	77	31	69	142	29	227	43	934	521	1339	2.17	34.7	76.6	O'Leary Peak/Robinson Crater
			± 11	5	4	9	3	10	2	92	28	32	0.11			
Robinson Crater	100	1517-17	81	24	59	124	31	213	48	922	527	1338	1.88	29.8	67.4	O'Leary Peak/Robinson Crater
			± 11	5	4	9	3	10	2	91	28	32	0.11			
Robinson Crater	101	1517-18	90	21	71	137	32	211	48	991	538	1353	1.86	29.0	62.4	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Robinson Crater	102	1517-19	90	23	65	146	34	209	48	631	621	1438	1.98	26.6	101.9	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Robinson Crater	103	1517-20	78	32	74	157	30	229	47	514	489	1323	1.76	30.1	110.1	O'Leary Peak/Robinson Crater
			± 10	4	4	9	3	10	2	90	28	33	0.11			
Robinson Crater	104	1517-21	69	21	73	157	30	220	46	1340	507	1416	1.88	31.1	46.9	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	92	28	32	0.11			
Robinson Crater	105	1517-22	86	22	64	151	31	218	46	704	636	1332	2.00	26.2	92.6	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Robinson Crater	106	1517-23	90	23	69	141	31	216	48	649	578	1319	2.14	30.8	106.9	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Robinson Crater	107	1517-24	79	18	66	136	29	204	42	1177	890	1345	2.14	19.9	60.3	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	92	28	32	0.11			
Robinson Crater	108	1517-25	81	31	69	146	31	223	47	854	579	1386	1.99	28.7	76.8	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Robinson Crater	109	1517-26	81	20	72	135	32	210	45	516	578	1322	2.11	30.3	130.8	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
O'Leary Peak	110	1518-1	80	23	50	527	31	318	43	2630	1075	1149	3.92	29.8	49.4	Deadman Mesa
			± 11	5	4	10	3	10	2	95	29	32	0.11			
O'Leary Peak	111	1518-2	103	20	40	917	29	353	49	4871	1096	1583	5.50	40.7	37.4	O'Leary Peak 3
			± 11	5	4	10	3	10	2	100	29	33	0.11			
O'Leary Peak	112	1518-3	78	13	47	514	29	315	41	3142	939	1262	4.23	36.7	44.6	Deadman Mesa
			± 11	5	4	10	3	10	2	96	29	32	0.11			

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NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

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Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Collection Locale	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
O'Leary Peak	113	1518-4	102	21	71	145	33	217	47	723	578	1431	2.17	31.2	97.7	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	33	0.11			
O'Leary Peak	114	1518-5	77	28	74	156	27	209	48	640	500	1294	1.90	31.8	96.8	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	90	28	32	0.11			
O'Leary Peak	115	1518-6	90	20	73	142	31	242	46	650	674	1430	2.36	28.9	117.2	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
O'Leary Peak	116	1518-7	94	26	72	147	31	220	46	708	678	1461	2.49	30.3	113.8	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
O'Leary Peak	117	1518-8	87	27	66	236	32	330	44	1138	856	1357	2.93	28.2	84.5	O'Leary Peak 1
			± 10	5	4	10	3	10	2	92	28	32	0.11			
O'Leary Peak	118	1518-9	83	27	72	142	33	214	46	652	772	1381	2.16	23.3	107.6	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	90	28	32	0.11			
O'Leary Peak	119	1518-10	62	19	68	143	31	215	44	637	589	1420	2.23	31.4	113.4	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
O'Leary Peak	120	1518-11	83	23	72	144	29	217	48	594	640	1390	2.35	30.4	127.1	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
O'Leary Peak	121	1518-12	93	14	44	535	28	316	41	2340	813	1202	3.72	37.4	52.6	Deadman Mesa
			± 10	5	4	10	3	10	2	94	28	32	0.11			
O'Leary Peak	122	1518-13	104	22	45	534	27	326	39	2959	918	1246	4.15	36.9	46.4	Deadman Mesa
			± 10	5	4	10	3	10	2	95	29	32	0.11			
O'Leary Peak	123	1518-14	100	22	47	541	28	322	39	2449	950	1225	3.87	33.3	52.4	Deadman Mesa
			± 10	5	4	10	3	10	2	95	29	32	0.11			
O'Leary Peak	124	1518-15	83	24	71	158	32	231	50	994	753	1394	2.56	28.1	84.5	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	92	28	32	0.11			
O'Leary Peak	125	1518-16	99	17	49	499	29	368	38	2506	813	1136	3.79	38.1	50.1	O'Leary Peak 1
			± 10	5	4	10	3	10	2	94	28	32	0.11			
O'Leary Peak	126	1518-17	75	36	63	174	31	237	47	1203	572	1392	2.42	35.0	66.4	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	92	28	32	0.11			
O'Leary Peak	127	1518-18	67	6	35	583	23	223	38	4755	539	917	3.62	55.1	25.4	O'Leary Peak 2
			± 11	8	4	10	3	10	2	97	28	33	0.11			
O'Leary Peak	128	1518-19	68	23	64	144	30	213	47	914	598	1423	2.20	30.6	79.1	O'Leary Peak/Robinson Crater
			± 11	5	4	9	3	10	2	91	28	32	0.11			

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Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Collection Locale	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Partridge Creek	129	1519-1	47	27	75	254	24	144	20	3766	368	1084	2.99	67.3	26.6	Presley Wash FGV
			± 10	5	4	10	3	10	2	96	28	32	0.11			
Partridge Creek	130	1519-2	38	23	74	240	17	137	18	3171	334	1117	2.73	67.8	28.8	Presley Wash FGV
			± 12	5	4	10	3	10	2	95	28	32	0.11			
Partridge Creek	131	1519-3	45	23	79	222	17	136	21	3117	426	1088	2.76	53.5	29.6	Presley Wash FGV
			± 10	5	4	10	3	10	2	95	28	33	0.11			
Partridge Creek	132	1519-4	41	27	73	252	16	147	19	4123	434	983	3.34	63.5	27.1	Presley Wash FGV
			± 11	5	4	10	3	10	2	97	28	32	0.11			
Partridge Creek	133	1519-5	43	28	82	221	17	140	20	3055	350	1068	2.81	66.5	30.7	Presley Wash FGV
			± 10	5	4	10	3	10	2	95	28	32	0.11			
Partridge Creek	134	1519-6	45	33	83	248	15	147	18	3860	395	1071	3.22	67.3	27.9	Presley Wash FGV
			± 10	5	4	10	3	10	2	97	28	32	0.11			
Partridge Creek	135	1519-7	54	27	73	243	15	137	23	3706	487	1080	3.36	56.8	30.2	Presley Wash FGV
			± 11	5	4	10	3	10	2	97	28	32	0.11			
Partridge Creek	136	1519-8	39	26	105	62	21	147	41	251	355	620	0.92	22.7	115.8	Slate Mountain?
			± 11	5	4	9	3	10	2	88	28	32	0.11			
Slate Mountain	137	1520-1	47	27	107	57	20	129	39	471	459	638	1.26	23.3	86.9	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	138	1520-2	52	19	102	58	21	125	36	347	451	579	1.09	20.8	100.9	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	139	1520-3	22	20	102	57	22	126	36	432	471	593	1.11	20.3	84.1	Slate Mountain
			± 12	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	140	1520-4	52	31	111	61	22	135	37	454	501	620	1.19	20.3	85.4	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	141	1520-5	58	27	108	64	21	137	39	469	528	638	1.22	19.7	84.8	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	142	1520-6	50	26	114	60	21	128	37	409	510	631	1.15	19.2	90.9	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	143	1520-7	34	35	108	63	20	132	39	409	428	628	1.17	23.5	92.9	Slate Mountain
			± 11	4	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	144	1520-8	47	20	115	65	19	129	39	415	325	639	0.90	24.2	71.5	Slate Mountain
			± 10	5	4	9	3	10	2	89	27	32	0.11			

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Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Collection Locale	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Slate Mountain	145	1520-9	58	24	109	59	19	171	38	417	512	632	1.22	20.3	94.5	Slate Mountain B
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	146	1520-10	48	23	107	61	25	170	38	432	461	576	1.16	21.5	87.1	Slate Mountain B
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	147	1520-11	53	25	110	60	21	129	38	382	299	641	0.85	24.9	73.0	Slate Mountain
			± 10	5	4	9	3	10	2	89	27	32	0.11			
Slate Mountain	148	1520-12	63	27	111	58	21	126	37	448	479	649	1.02	18.4	75.0	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	149	1520-13	59	27	111	61	20	123	38	449	452	600	1.23	23.2	89.2	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	150	1520-14	48	25	105	59	22	124	37	397	448	616	1.19	22.7	96.8	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	151	1520-15	29	34	105	62	19	126	38	423	443	625	1.17	22.7	90.0	Slate Mountain
			± 11	4	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	152	1520-16	52	29	102	59	22	124	36	408	481	619	1.19	21.2	94.7	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	153	1520-17	45	31	105	60	18	125	36	466	482	612	1.15	20.5	80.7	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	154	1520-18	58	23	100	74	20	125	34	477	499	630	1.20	20.5	82.4	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	155	1520-19	37	30	106	60	21	146	40	407	459	573	1.21	22.5	96.1	Slate Mountain
			± 11	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	156	1520-20	46	30	105	66	22	130	41	435	422	592	1.12	22.9	84.2	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	157	1520-21	62	24	105	58	21	132	40	425	471	625	1.31	23.6	99.5	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	158	1520-22	48	28	106	58	24	130	38	468	483	602	1.18	20.8	82.2	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	159	1520-23	50	21	105	59	25	131	40	273	291	636	0.78	23.7	91.4	Slate Mountain
			± 10	5	4	9	3	10	2	88	27	32	0.11			
Slate Mountain	160	1520-24	42	24	111	64	21	132	40	472	374	566	1.02	23.7	71.6	Slate Mountain
			± 10	4	4	9	3	10	2	89	28	32	0.11			

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Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Collection Locale	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Slate Mountain	161	1520-25	54	22	101	54	20	128	36	1138	477	657	1.39	24.7	41.2	Slate Mountain
			± 10	5	4	9	3	10	2	90	28	32	0.11			
Slate Mountain	162	1520-26	41	28	104	61	22	127	40	374	424	626	1.12	22.7	96.5	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	163	1520-27	50	30	110	60	20	134	38	373	383	618	1.02	23.0	88.5	Slate Mountain
			± 10	4	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	164	1520-28	41	22	104	56	21	128	37	416	409	610	1.05	22.1	82.2	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	165	1520-29	28	29	103	62	20	134	39	407	525	650	1.20	19.6	95.6	Slate Mountain
			± 11	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	166	1520-30	46	24	106	55	20	127	35	440	437	624	1.21	23.7	89.6	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	167	1520-31	35	23	100	57	20	121	37	442	413	595	1.11	23.1	82.0	Slate Mountain
			± 11	5	4	9	3	10	2	89	28	32	0.11			
Slate Mountain	168	1520-32	37	24	105	59	20	130	37	448	496	614	1.21	20.8	87.8	Slate Mountain
			± 11	5	4	9	3	10	2	89	28	32	0.11			
San Francisco Peaks	169	1521-1	96	13	35	701	26	245	34	5217	833	992	4.52	44.2	28.8	San Francisco Peaks
			± 11	6	4	10	3	10	2	99	29	32	0.11			
San Francisco Peaks	170	1521-2	90	20	36	709	31	263	43	4804	625	914	3.84	50.3	26.6	San Francisco Peaks B
			± 11	5	4	10	3	10	2	98	28	32	0.11			
San Francisco Peaks	171	1521-3	91	16	33	738	26	241	38	5457	828	954	4.85	47.6	29.5	San Francisco Peaks B
			± 11	6	4	10	3	10	2	100	29	32	0.11			
San Francisco Peaks	172	1521-4	65	17	22	1114	20	161	28	4442	698	927	4.02	47.1	30.1	San Francisco Peaks B
			± 11	5	4	11	3	10	2	98	28	32	0.11			
San Francisco Peaks	173	1521-5	77	23	31	758	24	232	38	5350	717	973	4.65	52.9	28.9	San Francisco Peaks B
			± 11	5	4	10	3	10	2	99	28	32	0.11			
San Francisco Peaks	174	1521-6	52	6	28	825	26	230	39	5100	652	1038	4.22	52.9	27.6	San Francisco Peaks B
			± 12	7	4	10	3	10	2	99	28	32	0.11			
San Francisco Peaks	175	1521-7	86	16	31	771	27	226	34	5884	809	1010	4.72	47.6	26.7	San Francisco Peaks B
			± 11	5	4	10	3	10	2	100	29	32	0.11			
San Francisco Peaks	176	1521-8	69	15	36	735	25	238	39	5239	728	960	4.36	48.9	27.7	San Francisco Peaks B
			± 11	5	4	10	3	10	2	99	28	32	0.11			

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	Specimen		Trace Element Concentrations											Ratios		
Collection Locale	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
San Francisco Peaks	177	1521-9	84	23	36	781	29	224	33	5166	677	1000	4.49	54.1	28.9	San Francisco Peaks B
			± 11	5	4	10	3	10	2	99	28	32	0.11			
San Francisco Peaks	178	1521-10	94	22	33	695	26	238	39	4692	718	940	4.11	46.8	29.2	San Francisco Peaks B
			± 11	5	4	10	3	10	2	98	28	32	0.11			
San Francisco Peaks	179	1521-11	80	18	34	742	27	230	38	5466	688	950	4.62	54.7	28.1	San Francisco Peaks B
			± 11	5	4	10	3	10	2	100	28	32	0.11			
San Francisco Peaks	180	1521-12	62	16	33	726	23	245	38	5389	718	968	4.86	55.1	30.0	San Francisco Peaks B
			± 11	5	4	10	3	10	2	100	28	32	0.11			
San Francisco Peaks	181	1521-13	57	14	34	922	23	195	33	5471	702	993	4.66	54.1	28.3	San Francisco Peaks B
			± 11	5	4	10	3	10	2	99	28	32	0.11			
San Francisco Peaks	182	1521-14	76	16	30	841	27	216	39	5852	748	1002	4.80	52.3	27.3	San Francisco Peaks B
			± 11	5	4	10	3	10	2	100	28	32	0.11			
San Francisco Peaks	183	1521-15	95	18	28	778	27	216	35	5423	809	978	4.67	47.1	28.7	San Francisco Peaks B
			± 11	5	4	10	3	10	2	99	29	32	0.11			
San Francisco Peaks	184	1521-16	70	13	31	677	28	242	39	5930	852	979	4.98	47.6	27.9	San Francisco Peaks B
			± 12	6	4	10	3	10	2	101	29	32	0.11			
San Francisco Peaks	185	1521-17	97	15	31	722	33	260	37	5794	785	870	5.21	54.0	29.9	San Francisco Peaks B
			± 11	6	4	10	3	10	2	101	28	32	0.11			
San Francisco Peaks	186	1521-18	68	17	37	883	25	230	37	4829	596	941	4.18	57.3	28.8	San Francisco Peaks B
			± 11	5	4	10	3	10	2	98	28	32	0.11			
San Francisco Peaks	187	1521-19	90	20	35	780	23	245	36	5068	678	932	4.37	52.7	28.7	San Francisco Peaks B
			± 11	5	4	10	3	10	2	99	28	32	0.11			
San Francisco Peaks	188	1521-20	75	22	33	734	25	179	22	7012	564	968	5.87	84.8	27.8	San Francisco Peaks B
			± 11	5	4	10	3	10	2	102	28	32	0.11			
San Francisco Peaks	189	1521-21	71	8	30	869	26	239	36	5066	692	892	4.55	53.6	29.9	San Francisco Peaks B
			± 11	6	4	10	3	10	2	98	28	32	0.11			
Deadman Mesa	190	1522-1	91	25	48	505	29	367	41	2368	869	1315	3.83	36.0	53.6	Deadman Mesa
			± 11	5	4	10	3	10	2	94	29	33	0.11			
Deadman Mesa	191	1522-2	115	23	93	498	30	378	42	3693	934	1380	4.98	43.4	44.7	Deadman Mesa
			± 10	5	4	10	3	10	2	97	29	33	0.11			
Deadman Mesa	192	1522-3	79	22	44	521	28	349	42	2696	849	1319	4.08	39.3	50.2	Deadman Mesa
			± 11	5	4	10	3	10	2	95	29	32	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Collection Locale	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Deadman Mesa	193	1522-4	102	21	50	507	28	343	34	2337	832	1273	3.91	38.4	55.3	Deadman Mesa
			± 10	5	4	10	3	10	2	94	29	32	0.11			
Deadman Mesa	194	1522-5	83	21	46	486	31	333	41	2210	771	1207	3.52	37.4	52.8	Deadman Mesa
			± 11	5	4	10	3	10	2	94	28	33	0.11			
Deadman Mesa	195	1522-6	87	10	50	507	28	358	41	2454	914	1258	4.00	35.7	54.0	Deadman Mesa
			± 11	6	4	10	3	10	2	94	29	32	0.11			
Deadman Mesa	196	1522-7	89	16	52	514	32	355	41	2598	888	1329	4.12	37.9	52.5	Deadman Mesa
			± 11	5	4	10	3	10	2	95	29	33	0.11			
Deadman Mesa	197	1522-8	86	23	48	510	28	346	39	2498	889	1301	4.06	37.3	53.8	Deadman Mesa
			± 11	5	4	10	3	10	2	94	29	33	0.11			
Deadman Mesa	198	1522-9	97	18	45	510	25	348	41	2602	952	1281	4.19	35.9	53.3	Deadman Mesa
			± 11	5	4	10	3	10	2	95	29	33	0.11			
Deadman Mesa	199	1522-10	70	23	45	490	27	347	38	2550	849	1322	3.90	37.6	50.7	Deadman Mesa
			± 11	5	4	10	3	10	2	94	29	33	0.11			
Deadman Mesa	200	1522-11	85	22	47	479	31	363	36	2182	983	1270	3.90	32.4	59.1	Deadman Mesa
			± 11	5	4	10	3	10	2	94	29	32	0.11			
Deadman Mesa	201	1522-12	83	19	45	500	26	348	40	2141	1061	1285	3.71	28.6	57.3	Deadman Mesa
			± 11	5	4	10	3	10	2	94	29	33	0.11			
Deadman Mesa	202	1522-13	102	24	45	515	27	360	37	2169	900	1268	3.74	33.9	57.0	Deadman Mesa
			± 10	5	4	10	3	10	2	95	29	32	0.11			
Deadman Mesa	203	1522-14	90	22	54	474	29	369	42	2168	834	1346	3.72	36.5	56.8	Deadman Mesa
			± 10	5	4	10	3	10	2	94	28	33	0.11			
Deadman Mesa	204	1522-15	79	19	44	501	28	351	38	2408	827	1274	3.93	38.9	54.1	Deadman Mesa
			± 11	5	4	10	3	10	2	94	28	32	0.11			
Deadman Mesa	205	1522-16	98	12	47	507	29	355	35	2627	985	1276	4.30	35.6	54.2	Deadman Mesa
			± 11	5	4	10	3	10	2	95	29	32	0.11			
Deadman Mesa	206	1522-17	109	21	50	504	27	360	38	2199	954	1300	3.86	33.0	58.0	Deadman Mesa
			± 10	5	4	10	3	10	2	94	29	33	0.11			
Deadman Mesa	207	1522-18	95	18	48	518	28	354	38	2041	838	1268	3.69	36.0	59.7	Deadman Mesa
			± 10	5	4	10	3	10	2	94	28	33	0.11			
Deadman Mesa	208	1522-19	93	22	48	492	31	345	42	2326	1033	1291	4.00	31.6	56.9	Deadman Mesa
			± 11	5	4	10	3	10	2	94	29	33	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Collection Locale	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Deadman Mesa	209	1522-20	65	17	45	492	28	344	37	1962	778	1216	3.30	34.8	55.8	Deadman Mesa
			± 11	5	4	10	3	10	2	93	28	33	0.11			
Deadman Mesa	210	1522-21	86	19	47	556	31	326	39	2280	820	1235	3.63	36.2	52.7	Deadman Mesa
			± 11	5	4	10	3	10	2	94	28	33	0.11			
Deadman Mesa	211	1522-22	79	18	47	486	30	332	38	2568	894	1279	4.15	37.8	53.5	Deadman Mesa
			± 11	5	4	10	3	10	2	95	29	32	0.11			
Deadman Mesa	212	1522-23	86	21	45	492	27	345	41	2160	961	1315	3.60	30.6	55.2	Deadman Mesa
			± 11	5	4	10	3	10	2	94	29	33	0.11			
Ebert Mountain	213	1523-1	96	27	70	145	32	227	48	507	733	1275	2.02	22.9	127.7	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	90	28	33	0.11			
Ebert Mountain	214	1523-2	78	26	68	144	32	231	47	438	559	1355	1.63	24.4	118.7	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	90	28	33	0.11			
Ebert Mountain	215	1523-3	74	27	75	140	30	228	46	897	518	1378	1.75	28.4	64.7	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	33	0.11			
Ebert Mountain	216	1523-4	83	24	71	141	32	222	49	487	478	1389	1.74	30.5	114.9	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	90	28	32	0.11			
Ebert Mountain	217	1523-5	72	26	73	139	31	229	49	550	626	1352	2.26	29.9	131.6	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	33	0.11			
Ebert Mountain	218	1523-6	85	22	71	154	29	215	49	513	600	1340	2.18	30.2	136.1	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Ebert Mountain	219	1523-7	68	23	74	160	32	218	47	525	574	1282	2.02	29.3	123.6	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	90	28	33	0.11			
Ebert Mountain	220	1523-8	84	21	69	150	29	227	50	575	591	1341	2.17	30.5	121.5	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	33	0.11			
Ebert Mountain	221	1523-9	90	22	67	159	31	218	48	507	740	1309	2.01	22.6	126.9	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	90	28	33	0.11			
Ebert Mountain	222	1523-10	95	28	66	177	28	242	46	587	648	1338	2.29	29.2	125.5	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Ebert Mountain	223	1523-11	51	27	69	148	32	229	45	573	751	1364	2.24	24.7	125.9	O'Leary Peak/Robinson Crater
			± 11	5	4	9	3	10	2	91	28	32	0.11			
Ebert Mountain	224	1523-12	61	21	67	148	30	215	50	528	668	1386	2.23	27.7	135.2	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			

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Northwest Research Obsidian Studies Laboratory

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Collection Locale	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Ebert Mountain	225	1523-13	74	29	74	142	30	240	47	611	739	1351	2.30	25.8	121.4	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Ebert Mountain	226	1523-14	59	25	67	164	30	204	47	522	705	1347	2.16	25.4	132.5	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Ebert Mountain	227	1523-15	86	18	71	148	32	234	49	481	520	1294	1.83	29.5	122.3	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	90	28	33	0.11			
Ebert Mountain	228	1523-16	94	23	68	175	32	228	46	570	353	1304	1.34	32.4	77.4	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	89	28	33	0.11			
Ebert Mountain	229	1523-17	84	21	66	136	30	220	43	559	496	1353	1.81	30.5	104.7	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	90	28	33	0.11			
Ebert Mountain	230	1523-18	76	29	69	171	28	223	46	640	586	1422	2.16	30.7	109.3	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Ebert Mountain	231	1523-19	77	20	64	157	33	231	51	666	511	1393	1.85	30.3	90.7	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	90	28	33	0.11			
Ebert Mountain	232	1523-20	78	29	67	152	28	308	48	636	708	1410	2.08	24.4	105.9	Robinson Crater 2
			± 10	5	4	9	3	10	2	90	28	33	0.11			
Kendrick Peak	233	1524-1	43	28	105	59	20	130	40	512	462	623	1.14	21.2	73.5	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	234	1524-2	39	26	105	55	19	124	41	368	338	650	0.95	24.5	84.2	Slate Mountain
			± 11	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	235	1524-3	39	27	109	58	21	137	37	383	440	618	1.18	22.9	98.8	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	236	1524-4	43	24	100	96	19	117	36	429	428	613	1.16	23.2	87.9	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	237	1524-5	51	18	107	60	19	124	38	410	433	615	1.13	22.5	89.6	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	238	1524-6	57	25	107	60	25	137	44	331	574	612	1.08	16.1	104.1	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	239	1524-7	62	29	107	57	20	133	41	383	501	618	1.20	20.4	100.6	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	240	1524-8	43	21	97	57	22	126	39	390	437	624	1.15	22.7	95.6	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			

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Northwest Research Obsidian Studies Laboratory

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Collection Locale	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Kendrick Peak	241	1524-9	41	32	105	59	23	145	40	413	396	600	1.06	23.1	83.8	Slate Mountain
			± 10	4	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	242	1524-10	57	39	116	63	25	133	42	396	371	611	1.01	23.5	83.0	Slate Mountain
			± 9	4	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	243	1524-11	38	27	101	57	20	128	40	417	529	576	1.15	18.5	89.1	Slate Mountain
			± 11	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	244	1524-12	62	28	116	63	23	135	39	430	577	594	1.06	15.8	80.8	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	245	1524-13	51	25	110	63	21	124	39	478	424	588	1.06	21.6	73.1	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	246	1524-14	63	28	115	81	22	146	41	504	396	632	1.13	24.4	73.6	Slate Mountain
			± 9	4	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	247	1524-15	47	23	98	59	18	122	38	361	346	560	0.85	21.5	76.9	Slate Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
Kendrick Peak	248	1524-16	49	26	108	60	22	122	37	408	389	568	1.04	23.1	83.2	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	249	1524-17	39	24	102	56	20	138	35	393	362	613	0.98	23.5	81.5	Slate Mountain
			± 11	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	250	1524-18	74	29	114	66	22	132	36	323	294	529	0.72	21.9	73.4	Slate Mountain
			± 11	5	5	9	3	10	2	88	27	32	0.11			
Kendrick Peak	251	1524-19	39	23	106	61	20	122	39	380	558	568	1.07	16.4	90.7	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	252	1524-20	60	24	117	61	23	136	37	437	413	633	1.08	22.4	80.5	Slate Mountain
			± 9	4	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	253	1524-21	26	31	106	59	21	128	37	354	456	564	1.01	19.1	92.1	Slate Mountain
			± 11	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	254	1524-22	51	22	105	62	22	122	40	419	526	576	1.19	19.3	92.0	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	255	1524-23	41	25	99	57	22	123	39	333	485	614	1.01	17.9	97.3	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	256	1524-24	46	17	105	60	23	123	41	389	544	575	1.13	17.9	94.3	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			

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Northwest Research Obsidian Studies Laboratory

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Collection Locale	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Kendrick Peak	257	1524-25	44	29	108	57	19	128	37	395	392	602	1.06	23.3	87.0	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	258	1524-26	67	29	111	58	22	144	37	404	509	588	1.19	20.0	95.0	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	259	1524-27	37	28	110	59	22	129	41	461	512	582	1.25	20.8	88.3	Slate Mountain
			± 11	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	260	1524-28	59	17	95	80	18	121	35	420	407	605	1.12	23.7	87.0	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	261	1524-29	44	23	103	61	23	124	38	364	402	593	1.05	22.6	93.3	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	262	1524-30	50	24	108	60	22	127	39	400	535	608	1.15	18.4	93.0	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	263	1524-31	42	22	96	57	21	122	39	325	392	585	1.08	23.7	105.8	Slate Mountain
			± 11	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	264	1524-32	42	29	108	58	19	130	38	376	395	578	1.02	22.4	88.4	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	265	1524-33	50	22	101	65	19	131	37	425	415	581	1.16	24.0	89.0	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	266	1524-34	49	20	105	60	22	131	38	407	443	608	1.16	22.5	92.4	Slate Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	267	1524-35	41	24	102	56	23	126	37	415	423	615	1.15	23.4	90.2	Slate Mountain
			± 11	5	4	9	3	10	2	89	28	32	0.11			
Kendrick Peak	268	1524-36	47	27	110	59	20	127	39	438	459	603	1.14	21.2	84.6	Slate Mountain
			± 10	4	4	9	3	10	2	89	28	32	0.11			
Sitgreaves Mountain	269	1525-1	137	70	386	11	79	150	235	100	440	0	0.97	19.1	258.4	RS Hill
			± 10	5	5	9	3	10	2	87	28	31	0.11			
Sitgreaves Mountain	270	1525-2	118	66	375	9	84	158	231	320	356	15	0.87	21.5	88.5	RS Hill
			± 10	5	5	10	3	10	2	88	28	31	0.11			
Sitgreaves Mountain	271	1525-3	113	80	391	11	87	160	243	118	405	0	1.02	21.7	237.9	RS Hill
			± 10	5	5	10	3	10	2	87	28	31	0.11			
Sitgreaves Mountain	272	1525-4	145	61	403	ND	88	160	243	134	409	0	1.03	21.9	218.4	RS Hill
			± 10	5	5	ND	3	10	2	87	28	31	0.11			

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NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Collection Locale	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Sitgreaves Mountain	273	1525-5	117	70	393	10	87	161	246	133	536	0	1.05	16.8	222.2	RS Hill
			± 10	5	5	10	3	10	2	87	28	31	0.11			
Sitgreaves Mountain	274	1525-6	112	74	391	ND	84	160	243	98	492	0	0.97	17.1	262.5	RS Hill
			± 10	5	5	ND	3	10	2	87	28	31	0.11			
Sitgreaves Mountain	275	1525-7	113	73	406	8	86	160	244	370	409	15	1.03	21.8	90.4	RS Hill
			± 10	5	5	12	3	10	2	88	28	31	0.11			
Sitgreaves Mountain	276	1525-8	136	72	392	9	82	159	237	127	407	0	0.99	21.1	219.3	RS Hill
			± 10	5	5	10	3	10	2	87	28	31	0.11			
Sitgreaves Mountain	277	1525-9	105	60	380	9	83	152	236	130	343	0	0.79	20.4	175.7	RS Hill
			± 11	5	5	10	3	10	2	87	27	31	0.11			
Sitgreaves Mountain	278	1525-10	124	67	403	9	85	166	248	167	404	2	0.97	20.8	171.7	RS Hill
			± 10	5	5	10	3	10	2	87	28	31	0.11			
Sitgreaves Mountain	279	1525-11	128	80	402	9	84	158	240	134	408	0	0.98	20.8	207.7	RS Hill
			± 10	5	5	10	3	10	2	87	28	31	0.11			
Sitgreaves Mountain	280	1525-12	137	74	405	10	88	161	246	123	382	0	0.91	20.9	209.1	RS Hill
			± 10	5	5	10	3	10	2	87	28	31	0.11			
Sitgreaves Mountain	281	1525-13	130	76	396	10	87	169	240	101	517	0	1.00	16.7	264.0	RS Hill
			± 10	5	5	10	3	10	2	87	28	31	0.11			
Sitgreaves Mountain	282	1525-14	131	70	392	10	86	165	238	122	402	0	1.04	22.4	238.0	RS Hill
			± 10	5	5	10	3	10	2	87	28	31	0.11			
Sitgreaves Mountain	283	1525-15	140	68	399	10	86	158	233	730	422	7	0.81	16.9	38.3	RS Hill
			± 10	5	5	10	3	10	2	89	28	31	0.11			
Sitgreaves Mountain	284	1525-16	140	72	399	ND	86	160	239	94	532	6	1.02	16.5	283.6	RS Hill
			± 10	5	5	ND	3	10	2	87	28	31	0.11			
Sitgreaves Mountain	285	1525-17	118	76	402	10	83	173	249	128	471	0	0.96	17.8	211.8	RS Hill
			± 10	5	5	10	3	10	2	87	28	31	0.11			
Sitgreaves Mountain	286	1525-18	103	76	381	11	85	163	237	460	448	0	0.90	17.4	64.7	RS Hill
			± 10	5	5	9	3	10	2	88	28	31	0.11			
Sitgreaves Mountain	287	1525-19	140	70	398	10	84	158	240	116	414	6	1.03	21.6	245.5	RS Hill
			± 10	5	5	10	3	10	2	87	28	31	0.11			
Sitgreaves Mountain	288	1525-20	127	73	422	9	88	166	241	166	470	2	1.13	20.6	199.8	RS Hill
			± 10	5	5	10	3	10	2	88	28	31	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Collection Locale	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
RS Hill	289	1526-1	40	28	94	83	18	81	44	88	568	495	0.83	12.7	245.7	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
RS Hill	290	1526-2	54	26	99	77	18	90	46	138	506	502	0.97	16.6	201.7	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	291	1526-3	53	24	101	81	18	86	51	132	492	535	0.98	17.3	210.3	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	292	1526-4	61	26	97	78	18	89	46	80	620	502	0.92	12.8	287.6	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
RS Hill	293	1526-5	55	32	108	83	19	92	47	118	466	535	0.96	17.8	224.8	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
RS Hill	294	1526-6	30	28	99	80	18	88	46	129	454	568	0.90	17.2	198.1	Government Mountain
			± 11	4	4	9	3	10	2	88	28	32	0.11			
Government Mountain	295	1527-1	41	30	101	75	19	78	47	523	477	287	0.79	14.6	51.3	Government Mountain
			± 10	4	4	9	3	10	2	89	28	32	0.11			
Government Mountain	296	1527-2	46	29	102	76	22	78	49	108	535	303	0.90	14.6	227.2	Government Mountain
			± 10	4	4	9	3	10	2	87	28	32	0.11			
Government Mountain	297	1527-3	46	27	103	76	18	76	48	110	452	276	0.75	14.7	190.0	Government Mountain
			± 10	5	4	9	3	10	2	87	28	32	0.11			
Government Mountain	298	1527-4	57	23	101	72	20	76	47	98	574	309	0.87	13.2	237.8	Government Mountain
			± 10	5	4	9	3	10	2	87	28	32	0.11			
Government Mountain	299	1527-5	52	23	101	70	17	78	48	100	525	277	0.84	14.0	227.9	Government Mountain
			± 10	5	4	9	3	10	2	87	28	32	0.11			
Government Mountain	300	1527-6	40	30	110	75	17	79	51	305	453	282	0.78	15.1	82.9	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
Government Mountain	301	1527-7	55	36	118	80	19	84	49	461	461	299	0.78	14.9	56.7	Government Mountain
			± 9	4	4	9	3	10	2	88	28	32	0.11			
Government Mountain	302	1527-8	44	24	96	75	21	76	45	132	475	286	0.80	14.9	175.0	Government Mountain
			± 10	5	4	9	3	10	2	87	28	32	0.11			
Government Mountain	303	1527-9	43	31	104	74	20	81	52	112	612	283	0.86	12.3	211.7	Government Mountain
			± 11	5	4	9	3	10	2	88	28	32	0.11			
Government Mountain	304	1527-10	59	29	110	75	20	83	50	103	638	287	0.90	12.2	236.7	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			

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NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Collection Locale	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Government Mountain	305	1527-11	58	37	117	83	23	87	48	361	475	255	0.76	14.1	69.9	Government Mountain
			± 9	4	4	9	3	10	2	88	28	32	0.11			
Government Mountain	306	1527-12	40	27	107	73	19	82	47	109	480	281	0.80	14.7	202.9	Government Mountain
			± 10	5	4	9	3	10	2	87	28	32	0.11			
Black Tank	307	1528-1	70	28	113	191	18	106	27	2386	516	782	2.64	42.4	37.0	Black Tank FGV
			± 10	5	4	9	3	10	2	93	28	35	0.11			
Black Tank	308	1528-2	45	38	102	190	23	103	30	2633	515	744	3.17	50.7	40.0	Black Tank FGV
			± 11	5	4	9	3	10	2	94	28	35	0.11			
Black Tank	309	1528-3	42	29	97	196	22	97	26	2404	533	725	2.63	40.8	36.6	Black Tank FGV
			± 12	5	4	10	3	10	2	93	28	37	0.11			
Black Tank	310	1528-4	44	34	111	156	20	97	26	1765	430	755	2.05	39.8	38.9	Black Tank FGV
			± 10	5	4	9	3	10	2	92	28	36	0.11			
Black Tank	311	1528-5	35	23	107	163	20	96	27	1590	510	748	1.97	32.3	41.5	Black Tank FGV
			± 11	5	4	9	3	10	2	92	28	36	0.11			
Black Tank	312	1528-6	45	28	113	200	22	105	25	2661	506	779	2.87	46.9	36.0	Black Tank FGV
			± 11	5	4	9	3	10	2	94	28	35	0.11			
Black Tank	313	1528-7	44	26	123	112	21	100	26	1092	529	792	1.61	25.5	49.2	Black Tank
			± 10	5	4	9	3	10	2	91	28	35	0.11			
Black Tank	314	1528-8	52	33	123	114	18	93	26	1098	456	745	1.56	28.8	47.5	Black Tank
			± 10	5	4	9	3	10	2	91	28	36	0.11			
Black Tank	315	1528-9	47	34	118	129	22	95	26	1256	453	794	1.67	30.9	44.4	Black Tank
			± 10	5	4	9	3	10	2	91	28	35	0.11			
Black Tank	316	1528-10	58	24	97	192	20	104	31	2424	481	780	2.64	45.5	36.4	Black Tank FGV
			± 10	5	4	9	3	10	2	93	28	36	0.11			
Black Tank	317	1528-11	45	27	101	177	19	100	28	2168	467	806	2.50	44.5	38.6	Black Tank FGV
			± 11	5	4	9	3	10	2	93	28	36	0.11			
Black Tank	318	1528-12	42	31	110	175	22	105	29	1953	450	741	2.34	43.2	40.0	Black Tank FGV
			± 10	5	4	9	3	10	2	92	28	37	0.11			
Black Tank	319	1528-13	34	30	102	214	24	104	28	2695	512	703	2.76	44.6	34.2	Black Tank FGV
			± 11	5	4	10	3	10	2	94	28	36	0.11			
Black Tank	320	1528-14	58	21	102	150	18	95	24	1405	348	851	1.74	42.2	41.6	Black Tank
			± 11	5	4	9	3	10	2	91	28	36	0.11			

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NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Northwest Research Obsidian Studies Laboratory

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

	Specimen		Trace Element Concentrations										Ratios		
Collection Locale	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Black Tank	321	1528-15	46	30	100	195	23	102	23	2624	525	775	2.92	45.9	37.1	Black Tank FGV
			± 11	5	4	9	3	10	2	94	28	36	0.11			
Black Tank	322	1528-16	54	31	105	197	21	103	30	2643	622	712	2.61	34.7	33.1	Black Tank FGV
			± 10	5	4	9	3	10	2	94	28	32	0.11			
Black Tank	323	1528-17	59	34	103	192	20	102	23	2255	514	754	2.64	42.6	39.1	Black Tank FGV
			± 10	5	4	9	3	10	2	93	28	32	0.11			
Black Tank	324	1528-18	57	25	103	187	19	104	30	2258	484	796	2.54	43.4	37.5	Black Tank FGV
			± 10	5	4	9	3	10	2	93	28	32	0.11			
Black Tank	325	1528-19	50	20	108	195	21	105	28	2659	497	772	2.87	47.7	36.0	Black Tank FGV
			± 11	5	4	9	3	10	2	94	28	32	0.11			
Black Tank	326	1528-20	35	41	102	187	27	103	27	2350	545	779	2.70	41.0	38.4	Black Tank FGV
			± 11	5	4	9	3	10	2	93	28	32	0.11			
Black Tank	327	1528-21	44	27	99	196	21	104	28	2356	482	727	2.51	43.3	35.7	Black Tank FGV
			± 11	5	4	10	3	10	2	93	28	32	0.11			
Black Tank	328	1528-22	82	31	101	188	22	105	28	2629	524	750	2.69	42.5	34.2	Black Tank FGV
			± 10	5	4	9	3	10	2	94	28	32	0.11			
Black Tank	329	1528-23	44	28	93	214	21	103	27	2915	686	757	3.12	37.5	35.7	Black Tank FGV
			± 11	5	4	10	3	10	2	94	28	32	0.11			
Black Tank	330	1528-24	32	25	98	156	22	94	29	1960	601	798	2.46	33.9	41.9	Black Tank FGV
			± 12	5	4	9	3	10	2	92	28	32	0.11			
Black Tank	331	1528-25	49	34	111	190	22	106	29	2296	505	794	2.56	42.0	37.2	Black Tank FGV
			± 10	5	4	9	3	10	2	93	28	32	0.11			
Black Tank	332	1528-26	53	20	122	140	19	96	27	1760	612	789	2.13	28.9	40.5	Black Tank
			± 10	5	4	9	3	10	2	92	28	32	0.11			
Black Tank	333	1528-27	48	28	102	188	21	100	29	2781	567	803	2.92	42.4	35.0	Black Tank FGV
			± 11	5	4	9	3	10	2	94	28	32	0.11			
Black Tank	334	1528-28	53	28	111	181	21	105	29	2596	481	788	2.64	45.4	34.0	Black Tank FGV
			± 10	5	4	9	3	10	2	94	28	32	0.11			
Black Tank	335	1528-29	47	31	111	168	25	104	30	1991	534	783	2.36	36.6	39.6	Black Tank FGV
			± 10	5	4	9	3	10	2	92	28	32	0.11			
Black Tank	336	1528-30	31	29	113	134	18	92	30	1586	435	785	1.89	36.3	39.9	Black Tank
			± 11	5	4	9	3	10	2	92	28	32	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Collection Locale	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Black Tank	337	1528-31	28	28	114	116	18	97	25	899	649	735	1.28	16.8	47.9	Black Tank
			± 12	5	4	9	3	10	2	90	28	32	0.11			
Black Tank	338	1528-33	34	24	105	171	22	98	28	2267	481	738	2.35	40.5	34.7	Black Tank FGV
			± 12	5	4	9	3	10	2	93	28	32	0.11			
Black Tank	339	1528-34	49	37	119	179	22	104	29	2321	645	749	2.29	29.4	33.1	Black Tank FGV
			± 10	4	4	9	3	10	2	93	28	32	0.11			
Black Tank	340	1528-35	55	26	128	146	20	98	26	1490	402	702	1.76	36.7	39.5	Black Tank
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Black Tank	341	1528-36	45	28	110	171	21	95	25	1752	667	711	2.03	25.3	38.8	Black Tank FGV
			± 10	5	4	9	3	10	2	92	28	32	0.11			
San Francisco Peaks	342	1582-1	175	52	133	8	78	709	137	335	274	12	1.66	49.0	157.8	San Francisco Peaks
			± 12	5	4	11	3	9	2	85	23	23	0.12			(Fremont-Agassiz Saddle)
San Francisco Peaks	343	1582-2	188	51	136	11	73	688	139	522	422	0	2.09	40.2	128.4	San Francisco Peaks
			± 11	5	4	11	3	9	2	85	23	23	0.12			(Fremont-Agassiz Saddle)
San Francisco Peaks	344	1582-3	165	59	140	8	79	709	140	458	417	0	1.96	38.2	136.9	San Francisco Peaks
			± 11	5	4	11	3	9	2	85	23	23	0.12			(Fremont-Agassiz Saddle)
San Francisco Peaks	345	1582-4	185	45	149	10	80	723	147	487	732	0	2.12	23.8	139.6	San Francisco Peaks
			± 12	5	4	11	3	9	2	85	24	23	0.12			(Fremont-Agassiz Saddle)
San Francisco Peaks	346	1582-5	160	57	144	9	85	698	139	584	442	0	2.18	40.0	119.9	San Francisco Peaks
			± 11	5	4	11	3	9	2	85	23	23	0.12			(Fremont-Agassiz Saddle)
San Francisco Peaks	347	1582-6	172	46	138	8	83	744	133	529	340	3	1.75	41.9	107.2	San Francisco Peaks
			± 11	5	4	11	3	9	2	85	23	23	0.12			(Fremont-Agassiz Saddle)
San Francisco Peaks	348	1582-7	200	44	142	8	78	692	138	571	389	0	2.11	43.9	118.9	San Francisco Peaks
			± 11	5	4	11	3	9	2	85	23	23	0.12			(Fremont-Agassiz Saddle)
San Francisco Peaks	349	1582-8	181	44	139	9	78	691	131	514	712	4	1.98	22.9	123.9	San Francisco Peaks
			± 11	5	4	11	3	9	2	85	24	23	0.12			(Fremont-Agassiz Saddle)
San Francisco Peaks	350	1582-9	156	41	129	9	75	707	127	490	734	0	2.16	24.1	141.0	San Francisco Peaks
			± 11	5	4	11	3	9	2	85	24	23	0.12			(Fremont-Agassiz Saddle)
San Francisco Peaks	351	1582-10	179	49	140	10	82	730	140	452	371	0	2.04	44.5	144.5	San Francisco Peaks
			± 12	5	4	11	3	9	2	85	23	23	0.12			(Fremont-Agassiz Saddle)
San Francisco Peaks	352	1582-11	199	45	155	9	85	793	150	422	519	0	1.65	26.3	126.1	San Francisco Peaks
			± 11	5	4	11	3	9	2	85	23	23	0.12			(Fremont-Agassiz Saddle)

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table C-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanics (FGV) Sources, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Collection Locale	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
San Francisco Peaks	353	1582-12	172	54	138	9	81	712	142	828	418	0	2.39	46.2	93.4	San Francisco Peaks
			± 12	5	4	11	3	9	2	86	23	23	0.12			(Fremont-Agassiz Saddle)
Spring Valley Road 1	354	1630-1	148	72	417	10	88	173	256	157	425	0	1.12	22.2	219.5	RS Hill
			± 11	5	5	11	3	8	2	84	23	23	0.12			
Spring Valley Road 2	355	1631-1	158	73	408	8	85	165	237	165	472	20	1.02	18.5	193.7	RS Hill
			± 10	5	5	11	3	8	2	84	23	23	0.12			
Spring Valley Road 2	356	1631-2	153	82	440	11	89	174	260	145	432	0	1.06	20.8	225.1	RS Hill
			± 10	5	5	11	3	8	2	84	23	23	0.12			
Spring Valley Road 2	357	1631-3	153	71	419	10	91	167	253	148	419	3	1.06	21.5	221.1	RS Hill
			± 10	5	5	11	3	8	2	84	23	23	0.12			
Spring Valley Road 2	358	1631-4	130	77	439	9	85	169	249	483	394	9	1.00	21.6	69.7	RS Hill
			± 11	5	5	11	3	8	2	85	23	23	0.12			

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NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Appendix D:
Results of XRF Studies-
The Artifacts

Northwest Research Obsidian Studies Laboratory

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Site	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe^{2}O^{3\,T}$	Fe:Mn	Fe:Ti	Geochemical Source
Panel 2 - 1	1	Panel 2 - 1	48	24	78	235	15	136	16	3217	515	964	2.46	39.6	25.7	Presley Wash FGV
			± 11	5	4	10	3	10	2	95	28	32	0.11			
Panel 2 - 2	2	Panel 2 - 2	52	34	107	77	21	87	50	659	428	288	0.77	15.9	40.2	Government Mountain
			± 10	4	4	9	3	10	2	89	28	32	0.11			
Panel 2 - 3	3	Panel 2 - 3	50	34	114	79	20	83	47	1226	385	276	0.67	15.6	19.5	Government Mountain
			± 10	4	4	9	3	10	2	90	28	32	0.11			
Panel 2 - 4	4	Panel 2 - 4	34	42	250	8	39	98	50	788	416	0	0.79	16.7	34.5	Partridge Creek (Round Mountain)
			± 10	4	5	14	3	10	2	89	28	31	0.11			
Panel 2 - 5	5	Panel 2 - 5	68	30	73	233	17	138	19	3362	455	1084	2.98	54.2	29.7	Presley Wash FGV
			± 11	5	4	10	3	10	2	96	28	32	0.11			
Panel 2 - 6	6	Panel 2 - 6	60	25	59	449	21	125	36	3870	587	1071	3.36	47.0	29.0	Unknown FGV
			± 11	5	4	10	3	10	2	97	28	33	0.11			
Panel 2 - 7	7	Panel 2 - 7	58	28	52	533	15	199	36	3176	760	1309	3.16	34.1	33.1	Unknown FGV A
			± 10	5	4	10	3	10	2	95	28	33	0.11			
Panel 3 - 1	8	Panel 3 - 1	63	35	118	81	22	84	50	240	469	311	0.78	14.7	103.4	Government Mountain
			± 9	4	4	9	3	10	2	88	28	32	0.11			
Panel 3 - 2	9	Panel 3 - 2	52	30	106	76	20	78	47	1037	508	276	0.75	13.1	25.4	Government Mountain
			± 9	4	4	9	3	10	2	89	28	32	0.11			
Panel 3 - 3	10	Panel 3 - 3	62	37	105	75	20	83	48	317	520	275	0.93	15.5	94.2	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
Panel 3 - 4	11	Panel 3 - 4	82	26	117	81	20	87	51	1305	661	286	1.14	14.8	29.9	Government Mountain
			± 9	4	4	9	3	10	2	90	28	32	0.11			
Panel 3 - 5	12	Panel 3 - 5	57	37	111	80	22	80	53	NM	NM	289	NM	15.5	34.8	Government Mountain *
			± 9	4	4	9	3	10	2	NM	NM	32	NM			
Panel 3 - 6	13	Panel 3 - 6	48	30	115	78	19	80	51	285	616	303	1.02	14.3	113.5	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
Panel 3 - 7	14	Panel 3 - 7	40	15	43	554	17	210	37	3413	611	1272	3.51	47.1	34.3	Unknown FGV A
			± 11	5	4	10	3	10	2	96	28	33	0.11			
Panel 3 - 8	15	Panel 3 - 8	58	29	107	77	19	81	48	355	523	307	0.88	14.7	81.0	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
Panel 3 - 9	16	Panel 3 - 9	136	34	49	533	30	352	39	3098	1058	1285	4.31	33.2	46.1	Deadman Mesa
			± 11	5	4	10	3	10	2	96	29	33	0.11			

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Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Site	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Panel 3 - 10	17	Panel 3 - 10	52	20	49	523	16	199	35	3014	512	1277	3.09	49.7	34.2	Unknown FGV A
			± 11	5	4	10	3	10	2	95	28	33	0.11			
Panel 3 - 11	18	Panel 3 - 11	112	29	49	523	15	203	37	3122	1050	1309	3.31	25.8	35.3	Unknown FGV A
			± 10	5	4	10	3	10	2	96	29	33	0.11			
Panel 3 - 13	19	Panel 3 - 13	56	27	75	228	16	143	17	3477	409	1107	3.23	65.1	31.0	Presley Wash FGV
			± 11	5	4	10	3	10	2	96	28	32	0.11			
Panel 3 - 14	20	Panel 3 - 14	50	33	109	77	21	84	52	396	627	303	1.02	14.0	84.0	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
Panel 4 - 1	21	Panel 4 - 1	48	38	107	77	19	87	52	172	497	256	0.84	14.7	146.1	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
Panel 4 - 2	22	Panel 4 - 2	48	32	107	78	19	79	48	806	629	326	0.86	12.0	36.8	Government Mountain
			± 10	4	4	9	3	10	2	89	28	32	0.11			
Panel 4 - 3	23	Panel 4 - 3	35	30	101	74	19	79	47	289	514	295	0.97	16.4	107.2	Government Mountain
			± 11	5	4	9	3	10	2	88	28	32	0.11			
Panel 4 - 4	24	Panel 4 - 4	59	27	100	73	20	82	51	737	455	289	0.74	14.5	35.0	Government Mountain
			± 10	4	4	9	3	10	2	89	28	32	0.11			
Panel 4 - 5	25	Panel 4 - 5	18	13	ND	16	2	19	ND	97	347	125	0.06	3.0	32.5	Not Obsidian
			± 11	4	ND	9	17	11	ND	87	28	32	0.11			
Panel 4 - 6	26	Panel 4 - 6	46	37	126	121	21	96	29	1651	378	793	1.53	34.3	31.4	Black Tank
			± 10	5	4	9	3	10	2	92	28	32	0.11			
Panel 4 - 7	27	Panel 4 - 7	63	31	108	78	19	81	49	325	545	292	1.01	16.0	99.9	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
Panel 4 - 8	28	Panel 4 - 8	58	28	107	79	22	83	53	190	517	311	0.81	13.7	130.1	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
Panel 4 - 9	29	Panel 4 - 9	60	33	106	79	21	83	55	180	592	303	0.91	13.3	152.0	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
Panel 4 - 10	30	Panel 4 - 10	63	33	53	521	22	136	31	5664	1184	1135	4.77	32.8	28.0	Unknown FGV
			± 11	5	4	10	3	10	2	100	29	33	0.11			
Panel 4 - 11	31	Panel 4 - 11	59	30	84	179	16	134	18	1919	483	1114	1.69	29.4	29.7	Presley Wash
			± 10	5	4	9	3	10	2	93	28	32	0.11			
Panel 4 - 12	32	Panel 4 - 12	51	31	107	77	20	81	52	630	470	274	0.83	15.5	44.9	Government Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			

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NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Site	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Panel 4 - 13	33	Panel 4 - 13	36	26	88	176	14	145	18	2216	225	1141	1.47	55.8	22.6	Presley Wash
			± 10	5	4	9	3	10	2	93	27	32	0.11			
Panel 5 - 1	34	Panel 5 - 1	46	33	111	76	20	81	54	NM	NM	303	NM	17.1	28.5	Government Mountain *
			± 10	4	4	9	3	10	2	NM	NM	32	NM			
Panel 5 - 2	35	Panel 5 - 2	57	24	106	72	21	81	52	669	622	264	0.85	11.9	43.2	Government Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Panel 5 - 3	36	Panel 5 - 3	36	33	105	78	20	85	48	NM	NM	276	NM	14.8	173.5	Government Mountain *
			± 10	4	4	9	3	10	2	88	28	32	0.11			
Panel 5 - 4	37	Panel 5 - 4	19	29	191	24	32	78	26	882	431	45	0.56	11.9	22.8	Unknown Obsidian 1
			± 12	5	5	9	3	10	2	89	28	34	0.11			
Panel 5 - 5	38	Panel 5 - 5	56	18	44	509	14	205	36	3359	526	1273	3.47	54.2	34.5	Unknown FGV A
			± 11	5	4	10	3	10	2	96	28	33	0.11			
Panel 5 - 6	39	Panel 5 - 6	98	22	81	202	24	143	33	4647	568	543	3.74	54.0	26.8	Unknown FGV
			± 11	5	4	10	3	10	2	97	28	32	0.11			
Panel 5 - 7	40	Panel 5 - 7	47	29	107	72	15	80	47	267	474	321	0.84	15.4	99.7	Government Mountain
			± 11	5	4	9	3	10	2	88	28	32	0.11			
Panel 5 - 8	41	Panel 5 - 8	51	28	107	77	21	81	47	721	636	271	0.90	12.3	42.4	Government Mountain
			± 10	4	4	9	3	10	2	89	28	32	0.11			
Panel 5 - 9	42	Panel 5 - 9	33	22	84	176	14	131	20	2092	513	1155	1.75	28.6	28.3	Presley Wash
			± 11	5	4	9	3	10	2	93	28	32	0.11			
Panel 5 - 11	43	Panel 5 - 11	ND	10	ND	23	ND	ND	ND	0	303	121	0.00	1.5	70.3	Not Obsidian
			±ND	4	ND	9	ND	ND	ND	87	28	32	0.11			
Panel 5 - 12	44	Panel 5 - 12	67	24	106	75	21	83	49	297	621	283	1.01	14.0	107.9	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
Panel 5 - 13	45	Panel 5 - 13	48	32	104	74	18	79	50	191	535	299	0.95	15.4	150.4	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
Panel 5 - 14	46	Panel 5 - 14	52	32	112	78	21	85	52	623	671	301	0.82	10.7	45.0	Government Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
Panel 5 - 16	47	Panel 5 - 16	48	29	104	79	19	80	48	NM	NM	299	NM	13.9	32.0	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	32	NM			
Panel 5 - 17	48	Panel 5 - 17	68	39	53	482	24	226	27	3350	713	930	3.27	37.7	32.6	Unknown FGV
			± 12	6	4	10	3	10	2	95	28	33	0.11			

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Northwest Research Obsidian Studies Laboratory

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Site	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Panel 5 - 18	49	Panel 5 - 18	64	17	73	209	17	140	18	2719	293	1090	2.20	62.9	27.2	Presley Wash FGV
			± 11	5	4	10	3	10	2	94	28	32	0.11			
Panel 5 - 12	50	Panel 5 - 12	64	33	112	82	21	84	51	698	570	295	0.69	10.8	34.4	Government Mountain
			± 10	4	4	9	3	10	2	89	28	32	0.11			
IF-04-13	51	20060243	36	33	86	193	16	138	19	2591	413	1064	2.68	53.7	34.5	Presley Wash
			± 12	5	4	9	3	10	2	94	28	32	0.11			
IF-01-234	52	20060555	48	29	106	78	19	84	51	360	618	NM	1.00	13.9	89.9	Government Mountain *
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
IF-01-237	53	20060560	52	18	71	253	19	140	20	4992	442	1044	4.02	74.5	26.8	Presley Wash FGV
			± 11	5	4	10	3	10	2	99	28	32	0.11			
IF-02-29	54	20060044	41	38	241	12	39	98	52	913	461	NM	1.03	19.3	38.5	Partridge Creek (Round Mountain) *
			± 10	5	5	9	3	10	2	89	28	NM	0.11			
IF-01-19	55	20060143	44	41	243	9	42	94	52	686	442	NM	1.04	20.3	51.0	Partridge Creek (Round Mountain)
			± 10	5	5	10	3	10	2	89	28	NM	0.11			
IF-04-40	56	20060279	210	84	399	10	88	175	248	478	514	0	1.19	19.8	81.7	RS Hill *
			± 10	5	5	10	3	10	2	88	28	31	0.11			
IF-04-155	57	20060427	121	82	385	10	84	164	248	355	446	0	1.10	21.2	99.8	RS Hill
			± 10	5	5	10	3	10	2	88	28	31	0.11			
IF-01-195	58	20060207	47	27	102	76	18	80	50	396	540	NM	1.09	17.3	89.0	Government Mountain
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
IF-04-153	59	20060444	58	35	254	10	42	94	52	280	463	NM	0.83	15.8	95.4	Partridge Creek (Round Mountain)
			± 10	5	5	10	3	10	2	88	28	NM	0.11			
IF-01-107	60	20060080	48	21	78	236	15	136	23	3894	555	1081	3.27	48.5	28.0	Presley Wash FGV
			± 11	5	4	10	3	10	2	97	28	33	0.11			
IF-01-224	61	20030777	43	38	76	223	17	137	22	3248	569	1103	3.01	43.6	31.0	Presley Wash FGV
			± 11	5	4	10	3	10	2	96	28	32	0.11			
IF-02-114	62	20060377	75	30	107	74	20	85	49	881	581	NM	1.38	20.1	52.3	Government Mountain
			± 9	4	4	9	3	10	2	89	28	NM	0.11			
IF-04-206	63	20060515	32	34	100	181	20	102	30	2415	409	712	2.39	48.6	33.2	Black Tank FGV
			± 12	5	4	10	3	10	2	93	28	32	0.11			
IF-01-42	64	20060116	54	19	101	77	19	82	49	905	530	NM	1.25	20.0	46.4	Government Mountain *
			± 10	5	4	9	3	10	2	89	28	NM	0.11			

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Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Site	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
IF-02-69	65	20060548	44	20	84	184	15	132	15	2346	298	1161	2.22	62.3	31.7	Presley Wash
			± 10	5	4	9	3	10	2	94	28	32	0.11			
IF-04-189	66	20060494	60	35	104	74	23	81	48	428	510	NM	1.08	18.2	82.4	Government Mountain
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
IF-04-160	67	20060432	68	31	112	81	23	85	50	393	475	NM	0.90	16.4	75.1	Government Mountain *
			± 10	4	4	9	3	10	2	88	28	NM	0.11			
IF-04-170	68	20060325	132	77	401	9	84	166	247	610	454	0	1.36	25.5	73.6	RS Hill
			± 10	5	5	10	3	10	2	88	28	31	0.11			
IF-01-09	69	20060152	62	30	124	89	21	90	53	558	550	NM	0.80	12.8	48.6	Government Mountain *
			± 10	5	4	9	3	10	2	89	28	NM	0.11			
IF-01-232	70	20060532	57	31	117	84	22	83	54	452	468	NM	0.96	17.7	69.9	Government Mountain
			± 10	4	4	9	3	10	2	88	28	NM	0.11			
IF-04-119	71	20060327	71	40	108	80	19	83	49	252	570	NM	0.81	12.5	102.5	Government Mountain
			± 10	4	4	9	3	10	2	88	28	NM	0.11			
IF-01-167	72	20060184	39	25	77	226	17	134	19	3853	467	1094	3.39	59.9	29.4	Presley Wash FGV
			± 11	5	4	10	3	10	2	97	28	33	0.11			
IF-01-123	73	20060063	46	42	238	9	40	92	48	696	575	NM	1.11	16.5	53.4	Partridge Creek (Round Mountain) *
			± 10	5	5	10	3	10	2	89	28	NM	0.11			
IF-01-295	74	20060524	56	30	120	82	21	89	49	491	637	NM	0.98	13.2	66.0	Government Mountain
			± 10	4	4	9	3	10	2	88	28	NM	0.11			
IF-01-52	75	20060112	35	24	80	236	17	140	21	2717	284	1106	2.37	69.8	29.3	Presley Wash FGV
			± 11	5	4	10	3	10	2	94	28	33	0.11			
IF-04-209	76	20060505	17	8	-2	25	ND	20	ND	47	62	NM	0.02	12.2	36.5	Not Obsidian
			± 12	5	31	9	ND	11	ND	87	27	NM	0.11			
IF-04-202	77	20060491	48	27	122	144	23	100	28	1575	393	776	1.80	38.5	38.4	Black Tank
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Artifact 20030784	78	20030784	24	22	81	205	15	135	19	2661	364	1215	2.63	60.0	33.0	Presley Wash
			± 13	5	4	10	3	10	2	94	28	33	0.11			
IF-01-223	79	20060525	56	27	107	77	19	81	47	414	554	NM	1.05	16.3	82.8	Government Mountain
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
IF-04-89	80	20060319	53	25	77	250	17	137	19	2929	350	1081	2.59	61.6	29.6	Presley Wash FGV
			± 10	5	4	10	3	10	2	94	28	33	0.11			

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Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

Site	Specimen No.	Catalog No.	Trace Element Concentrations											Ratios		Geochemical Source
			Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	
IF-01-185	81	20060201	52	40	102	74	20	81	51	485	537	NM	1.15	18.4	78.0	Government Mountain *
			± 11	5	4	9	3	10	2	88	28	NM	0.11			
IF-02-18	82	20060034	134	72	377	10	83	157	245	997	310	2	0.89	25.2	30.8	RS Hill *
			± 11	5	5	10	3	10	2	89	27	31	0.11			
IF-02-120	83	20060348	48	32	108	77	22	83	49	396	439	NM	0.89	17.7	74.0	Government Mountain
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
IF-04-88	84	20060318	40	28	108	79	18	81	50	336	514	NM	0.85	14.4	82.3	Government Mountain *
			± 11	5	4	9	3	10	2	88	28	NM	0.11			
IF-02-85	85	20060453	68	38	125	86	22	89	55	1316	418	NM	1.20	24.5	31.0	Government Mountain
			± 9	4	4	9	3	10	2	90	28	NM	0.11			
IF-01-186	86	20060200	83	40	272	10	40	99	51	536	469	NM	0.85	15.8	53.4	Partridge Creek (Round Mountain)
			± 10	4	5	10	3	10	2	88	28	NM	0.11			
IF-01-180	87	20060196	57	46	246	10	44	93	50	385	510	NM	0.87	14.9	74.4	Partridge Creek (Round Mountain) *
			± 10	4	5	10	3	10	2	88	28	NM	0.11			
IF-1-170	88	20060189	44	37	249	9	40	93	53	297	355	NM	0.69	17.3	75.8	Partridge Creek (Round Mountain)
			± 10	5	5	10	3	10	2	88	28	NM	0.11			
IF-04-173	89	20060403	35	43	236	10	38	95	50	268	418	NM	0.85	17.9	101.6	Partridge Creek (Round Mountain)
			± 11	5	5	10	3	10	2	88	28	NM	0.11			
IF-04-212	90	20060504	53	31	107	78	20	78	47	176	405	NM	0.73	16.0	126.8	Government Mountain
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
IF-01-56	91	20060114	43	23	78	202	14	133	18	3526	320	1127	2.83	73.4	26.8	Presley Wash *
			± 11	5	4	9	3	10	2	96	28	33	0.11			
IF-04-30	92	20060258	40	30	114	79	18	86	49	198	369	NM	0.63	15.4	100.2	Government Mountain
			± 11	5	4	9	3	10	2	88	28	NM	0.11			
IF-01-43	93	20060115	48	37	243	10	38	96	48	628	429	NM	0.94	19.0	50.5	Partridge Creek (Round Mountain) *
			± 10	5	5	10	3	10	2	88	28	NM	0.11			
IF-01-174	94	20060194	45	28	100	77	20	82	49	613	560	NM	1.20	18.3	64.9	Government Mountain *
			± 10	5	4	9	3	10	2	89	28	NM	0.11			
IF-01-178	95	20060198	35	46	275	10	42	96	55	405	390	NM	0.75	17.0	61.5	Partridge Creek (Round Mountain)
			± 10	4	5	10	3	10	2	88	28	NM	0.11			
IF-01-177	96	20060192	49	31	105	74	18	81	45	363	525	NM	1.04	17.0	92.2	Government Mountain
			± 10	5	4	9	3	10	2	88	28	NM	0.11			

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Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Site	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
IF-02-87	97	20060459	53	34	105	74	19	79	48	263	587	NM	0.85	12.7	103.1	Government Mountain *
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
IF-01-163	98	20060179	56	25	101	74	18	79	47	346	439	NM	0.84	16.7	79.3	Government Mountain *
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
IF-01-126	99	20060059	62	27	81	228	18	137	19	2982	333	1104	2.51	62.8	28.3	Presley Wash FGV
			± 10	5	4	9	3	10	2	95	28	32	0.11			
IF-01-122	100	20060064	45	27	84	199	18	131	18	3020	320	1118	2.53	65.8	28.1	Presley Wash
			± 11	5	4	9	3	10	2	95	28	33	0.11			
IF-01-282	101	20060603	65	24	82	239	16	142	20	5239	397	1101	3.17	66.0	20.3	Presley Wash FGV
			± 10	5	4	10	3	10	2	99	28	32	0.11			
IF-01-227	102	20060553	65	26	74	246	17	132	23	3159	418	1149	2.58	51.3	27.4	Presley Wash FGV
			± 10	5	4	10	3	10	2	95	28	33	0.11			
IF-04-123	103	20060304	53	31	108	209	21	104	27	3204	526	778	3.31	51.8	34.5	Black Tank FGV
			± 10	5	4	9	3	10	2	95	28	32	0.11			
IF-04-105	104	20060301	31	36	109	77	20	84	51	282	516	NM	0.91	15.3	102.8	Government Mountain *
			± 11	4	4	9	3	10	2	88	28	NM	0.11			
IF-01-228	105	20060554	129	78	415	8	91	177	245	239	296	3	0.78	23.5	103.5	RS Hill *
			± 10	5	5	12	3	10	2	88	27	31	0.11			
IF-04-04	106	20060234	55	33	117	205	22	106	32	2477	356	788	2.43	56.8	32.9	Black Tank FGV
			± 10	5	4	9	3	10	2	93	28	32	0.11			
IF-02-62	107	20060544	47	20	47	523	14	184	35	5327	472	1290	4.03	70.0	25.2	Unknown FGV A
			± 11	5	4	10	3	10	2	100	28	33	0.11			
IF-01-207	108	20060540	58	29	117	85	20	87	53	309	482	NM	0.85	15.4	89.2	Government Mountain
			± 10	4	4	9	3	10	2	88	28	NM	0.11			
IF-04-151	109	20060438	35	33	109	75	17	80	50	334	456	NM	0.89	16.9	86.2	Government Mountain *
			± 11	4	4	9	3	10	2	88	28	NM	0.11			
IF-01-263	110	20060597	25	35	237	9	39	100	50	595	438	NM	0.85	16.9	48.2	Partridge Creek (Round Mountain)
			± 12	5	5	10	3	10	2	88	28	NM	0.11			
IF-02-154	111	20060581	52	21	91	247	17	148	18	2653	248	1112	2.08	70.7	26.4	Presley Wash FGV *
			± 11	5	4	10	3	10	2	94	27	33	0.11			
IF-01-46	112	20060110	45	38	250	7	38	91	52	331	490	NM	0.70	12.7	70.1	Partridge Creek (Round Mountain) *
			± 10	5	5	9	3	10	2	88	28	NM	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Northwest Research Obsidian Studies Laboratory

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Site	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
IF-01-266	113	20060609	45	29	97	199	17	150	19	1362	226	1196	1.49	56.2	36.8	Presley Wash
			± 10	5	4	9	3	10	2	91	27	32	0.11			
IF-04-103	114	20060299	58	41	133	203	24	107	30	1893	381	810	1.94	42.6	34.4	Unknown Obsidian 2
			± 10	4	4	9	3	10	2	92	28	32	0.11			
IF-01-38	115	20060121	51	33	111	80	21	85	50	701	577	NM	1.16	17.1	55.2	Government Mountain
			± 10	4	4	9	3	10	2	89	28	NM	0.11			
IF-04-03	116	20060235	81	38	118	86	23	86	51	268	430	NM	0.78	16.0	93.3	Government Mountain *
			± 9	4	4	9	3	10	2	88	28	NM	0.11			
IF-01-131	117	20060058	52	32	136	78	22	82	50	396	454	NM	0.91	17.5	75.7	Government Mountain
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
IF-01-257	118	20060591	58	41	249	10	41	91	48	731	420	NM	1.11	22.7	50.9	Partridge Creek (Round Mountain) *
			± 10	5	5	10	3	10	2	89	28	NM	0.11			
IF-02-08	119	20060027	40	34	54	437	21	131	61	3176	574	959	2.90	41.6	30.5	Unknown FGV
			± 11	5	4	10	3	10	2	96	28	32	0.11			
IF-01-175	120	20060193	51	50	252	10	40	94	55	664	603	NM	1.00	14.3	50.9	Partridge Creek (Round Mountain)
			± 10	4	5	10	3	10	2	89	28	NM	0.11			
IF-01-199	121	20060214	52	22	86	218	15	136	22	3095	346	1155	2.53	60.9	27.4	Presley Wash FGV *
			± 11	5	4	10	3	10	2	95	28	33	0.11			
IF-04-133	122	20060530	32	27	105	191	20	104	28	2849	520	770	3.03	48.0	35.5	Black Tank FGV
			± 12	5	4	9	3	10	2	94	28	32	0.11			
IF-04-65	123	20060408	40	28	107	77	20	84	52	399	438	NM	0.93	18.4	76.2	Government Mountain *
			± 11	5	4	9	3	10	2	88	28	NM	0.11			
IF-01-244	124	20060551	60	30	105	75	18	80	48	467	620	NM	1.13	15.6	79.4	Government Mountain *
			± 10	5	4	9	3	10	2	89	28	NM	0.11			
IF-01-238	125	20060561	65	32	120	90	23	86	53	395	499	NM	0.76	13.4	63.8	Government Mountain *
			± 10	4	4	9	3	10	2	88	28	NM	0.11			
IF-01-192	126	20060206	64	26	117	81	21	85	50	1072	478	NM	1.04	18.7	33.1	Government Mountain
			± 9	4	4	9	3	10	2	90	28	NM	0.11			
IF-02-43	127	20060008a	61	31	96	77	21	79	49	1367	557	NM	1.26	19.2	31.3	Government Mountain
			± 10	5	4	9	3	10	2	90	28	NM	0.11			
IF-02-43	128	20060008b	64	32	109	80	23	84	53	1113	698	NM	1.14	14.0	35.0	Government Mountain
			± 9	4	4	9	3	10	2	90	28	NM	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Site	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Site 04-529	129	20030323	128	65	407	11	88	167	250	441	424	27	1.11	22.4	82.1	RS Hill
			± 10	5	5	9	3	10	2	88	28	52	0.11			
Site 01-452	130	20030397	67	42	244	10	39	92	53	633	361	NM	0.71	17.6	38.8	Partridge Creek (Round Mountain)
			± 9	4	5	10	3	10	2	89	28	NM	0.11			
Site 04-354	131	20030577	37	25	99	76	21	77	48	216	597	NM	0.93	13.5	132.8	Government Mountain
			± 11	5	4	9	3	10	2	88	28	NM	0.11			
Site 04-399	132	20030266	41	22	85	182	14	132	19	1706	392	1227	1.81	38.8	35.6	Presley Wash
			± 10	5	4	9	3	10	2	92	28	33	0.11			
Site 01-314	133	20030740	39	26	81	174	18	151	19	1940	282	1223	2.02	60.1	34.9	Presley Wash
			± 11	5	4	9	3	10	2	93	28	32	0.11			
Site 01-513	134	20030250	21	46	257	9	38	96	52	341	420	NM	0.84	17.6	80.8	Partridge Creek (Round Mountain)
			± 12	4	5	10	3	10	2	88	28	NM	0.11			
Site 01-832	135	20030066	61	28	75	223	17	132	19	4090	429	1121	3.56	68.2	29.0	Presley Wash FGV
			± 10	5	4	10	3	10	2	97	28	32	0.11			
Site 01-130	136	20030688	45	44	249	9	44	99	52	530	392	NM	0.86	19.2	54.5	Partridge Creek (Round Mountain)
			± 10	5	5	10	3	10	2	88	28	NM	0.11			
Site 01-577	137	20030216	38	43	247	9	40	98	52	491	338	NM	0.81	21.0	55.3	Partridge Creek (Round Mountain) *
			± 10	4	5	10	3	10	2	88	27	NM	0.11			
Site 01-726	138	20030202	41	38	231	12	37	92	50	290	288	NM	0.65	20.3	73.7	Partridge Creek (Round Mountain) *
			± 10	5	5	9	3	10	2	88	27	NM	0.11			
Site 02-685	139	20030553	57	29	105	80	21	82	52	1281	424	NM	1.24	25.0	32.9	Government Mountain *
			± 10	5	4	9	3	10	2	90	28	NM	0.11			
Site 04-69	140	20030079	55	27	101	74	21	80	49	155	425	NM	0.69	14.5	134.2	Government Mountain *
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
Site 04-745	141	20030813	74	34	107	77	23	80	47	821	439	NM	0.83	16.7	35.0	Government Mountain *
			± 10	5	4	9	3	10	2	89	28	NM	0.11			
Site 01-277	142	20030675	38	42	241	9	37	93	50	706	557	NM	1.10	17.0	52.3	Partridge Creek (Round Mountain)
			± 11	5	5	10	3	10	2	89	28	NM	0.11			
Site 01-507	143	20030614	43	47	249	11	41	94	51	718	382	NM	0.86	19.7	41.0	Partridge Creek (Round Mountain)
			± 10	4	5	9	3	10	2	89	28	NM	0.11			
Site 01-507	144	20030615	57	25	107	77	19	81	49	398	619	NM	1.08	15.0	88.2	Government Mountain
			± 10	5	4	9	3	10	2	88	28	NM	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Site	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Site 01-518	145	20030225	55	50	247	9	40	96	50	922	436	NM	0.76	15.4	28.7	Partridge Creek (Round Mountain)
			± 9	4	5	10	3	10	2	89	28	NM	0.11			
Site 01-806	146	20030541	48	34	78	248	17	135	17	3341	287	1099	2.36	68.9	23.8	Presley Wash FGV *
			± 10	4	4	9	3	10	2	95	28	33	0.11			
Site 01-815	147	20030550	48	24	77	188	18	131	20	2997	415	1163	2.65	52.9	29.6	Presley Wash
			± 11	5	4	9	3	10	2	95	28	32	0.11			
Site 01-985	148	20030372	41	26	105	73	22	82	50	905	461	NM	0.97	18.3	36.8	Government Mountain
			± 10	4	4	9	3	10	2	89	28	NM	0.11			
Site 01-994	149	20030374	55	40	244	10	40	90	47	949	364	NM	0.74	18.0	27.3	Partridge Creek (Round Mountain) *
			± 9	4	5	10	3	10	2	89	28	NM	0.11			
Site 02-570	150	20030556	53	30	105	76	18	81	48	519	664	NM	1.01	13.1	64.7	Government Mountain
			± 10	5	4	9	3	10	2	89	28	NM	0.11			
Site 04-337	151	20030588	130	78	406	12	91	171	242	334	448	2	1.14	21.8	108.7	RS Hill
			± 10	5	5	9	3	10	2	88	28	31	0.11			
Site 01-277	152	20030676	53	42	266	11	40	95	52	202	331	NM	0.64	17.4	99.9	Partridge Creek (Round Mountain) *
			± 9	4	5	9	3	10	2	88	28	NM	0.11			
Site 01-518	153	20030244	44	40	235	10	38	91	52	265	348	NM	0.70	18.0	85.6	Partridge Creek (Round Mountain) *
			± 10	5	5	10	3	10	2	88	27	NM	0.11			
Site 01-496	154	20030604	62	30	103	76	20	78	47	682	524	NM	0.80	13.4	40.3	Government Mountain *
			± 9	4	4	9	3	10	2	89	28	NM	0.11			
Site 01-515	155	20030247	37	24	79	222	16	145	17	3098	354	1110	2.20	51.9	23.9	Presley Wash FGV *
			± 11	5	4	9	3	10	2	95	28	33	0.11			
Site 01-574	156	20030218	44	27	87	192	14	132	17	2047	286	1135	1.88	55.5	30.9	Presley Wash
			± 11	5	4	9	3	10	2	93	28	32	0.11			
Site 01-711	157	20030221	131	71	403	11	89	167	252	272	444	0	0.97	19.0	112.7	RS Hill
			± 10	5	5	10	3	10	2	88	28	31	0.11			
Site 01-726	158	20030204	132	76	407	8	89	167	250	721	715	0	1.32	15.7	60.9	RS Hill
			± 10	5	5	11	3	10	2	89	28	31	0.11			
Site 01-743	159	20030555	86	20	69	258	15	136	17	6013	492	1046	4.21	70.0	23.3	Presley Wash FGV
			± 11	5	4	10	3	10	2	100	28	33	0.11			
Site 01-771	160	20030314	61	29	72	241	18	135	20	4818	763	1077	3.81	40.8	26.3	Presley Wash FGV
			± 11	5	4	10	3	10	2	98	28	32	0.11			

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NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Site	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Site 01-771	161	20030315	50	29	78	234	16	135	19	3838	560	1147	3.36	49.3	29.2	Presley Wash FGV
			± 10	5	4	10	3	10	2	97	28	33	0.11			
Site 01-796	162	20030435	54	39	249	9	39	93	50	953	466	NM	0.77	14.6	28.1	Partridge Creek (Round Mountain)
			± 10	4	5	10	3	10	2	89	28	NM	0.11			
Site 01-805	163	20030537	30	37	231	11	38	91	48	750	396	NM	0.76	16.9	34.9	Partridge Creek (Round Mountain)
			± 11	5	5	10	3	10	2	89	28	NM	0.11			
Site 01-851	164	20030289	70	34	111	81	21	82	51	734	513	NM	1.07	18.0	49.2	Government Mountain
			± 10	4	4	9	3	10	2	89	28	NM	0.11			
Site 01-892	165	20030293	55	39	233	8	40	104	50	305	434	0	0.83	16.7	87.7	Partridge Creek (Round Mountain)
			± 10	5	5	17	3	10	2	88	28	31	0.11			
Site 01-916	166	20030052	58	30	109	76	19	82	50	483	472	NM	0.93	17.1	64.0	Government Mountain
			± 10	4	4	9	3	10	2	89	28	NM	0.11			
Site 01-949	167	20030326	45	43	246	9	37	93	51	270	412	0	0.78	16.7	92.5	Partridge Creek (Round Mountain)
			± 10	5	5	10	3	10	2	88	28	31	0.11			
Site 01-952	168	20030325	80	35	98	78	19	83	51	878	515	NM	1.27	21.0	48.7	Government Mountain *
			± 10	5	4	9	3	10	2	89	28	NM	0.11			
Site 01-994	169	20030373	45	22	71	217	15	134	20	3610	336	1054	2.93	72.3	27.1	Presley Wash FGV
			± 12	5	4	10	3	10	2	96	28	33	0.11			
Site 01-1015	170	20030363	46	33	106	78	22	80	50	237	531	NM	0.94	15.3	123.4	Government Mountain
			± 10	4	4	9	3	10	2	88	28	NM	0.11			
Site 01-1058	171	20030809	54	17	71	216	15	131	17	3923	325	1035	2.95	75.3	25.2	Presley Wash FGV
			± 11	6	4	10	3	10	2	96	28	32	0.11			
Site 01-1058	172	20030811	26	28	91	178	16	127	19	2793	404	1231	2.37	48.9	28.5	Presley Wash
			± 12	5	4	9	3	10	2	95	28	32	0.11			
Site 04-76	173	20030664	60	34	121	167	22	100	28	2173	416	816	2.24	44.8	34.5	Black Tank FGV *
			± 10	5	4	9	3	10	2	93	28	33	0.11			
Site 04-740	174	20030817	54	20	81	197	15	135	16	2329	404	1186	2.39	49.1	34.3	Presley Wash
			± 11	5	4	9	3	10	2	94	28	33	0.11			
Site 04-368	175	20030276	36	35	124	110	22	93	26	1070	522	819	1.56	25.2	48.9	Black Tank
			± 11	5	4	9	3	10	2	91	28	32	0.11			
Site 01-490	176	20030609	55	27	98	71	16	76	47	1238	397	NM	0.69	15.6	19.9	Government Mountain *
			± 9	4	4	9	3	10	2	90	28	NM	0.11			

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NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Northwest Research Obsidian Studies Laboratory

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Site	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe^{2}O^{3\,T}$	Fe:Mn	Fe:Ti	Geochemical Source
Site 01-813	177	20030548	112	69	384	9	87	160	243	518	321	0	0.80	22.1	52.5	RS Hill
			± 10	5	5	10	3	10	2	88	27	31	0.11			
Site 01-921	178	20030061	46	21	101	79	18	77	49	1006	359	NM	0.85	20.7	29.1	Government Mountain *
			± 10	5	4	9	3	10	2	90	28	NM	0.11			
Site 02-841	179	20030360	36	29	97	76	22	75	47	884	421	NM	0.77	16.2	30.4	Government Mountain
			± 10	4	4	9	3	10	2	89	28	NM	0.11			
Site 01-760	180	20030308	72	27	76	215	15	132	18	3465	503	1176	2.89	47.5	27.9	Presley Wash FGV
			± 11	5	4	10	3	10	2	95	28	33	0.11			
Site 01-809	181	20030544	62	40	244	10	41	96	51	857	453	NM	0.98	18.7	38.9	Partridge Creek (Round Mountain)
			± 9	5	5	10	3	10	2	89	28	NM	0.11			
Site 01-939	182	20030344	63	22	103	74	18	81	47	842	482	NM	0.87	15.7	35.4	Government Mountain *
			± 10	5	4	9	3	10	2	89	28	NM	0.11			
Site 02-454	183	20030485	58	30	102	76	19	78	49	513	569	NM	1.05	15.9	67.9	Government Mountain
			± 10	5	4	9	3	10	2	89	28	NM	0.11			
Site 02-727	184	20030399	49	27	109	77	19	83	48	1205	480	NM	1.01	18.1	28.7	Government Mountain *
			± 10	4	4	9	3	10	2	90	28	NM	0.11			
Site 04-69	185	20030080	108	68	382	10	81	158	236	817	296	4	0.76	22.9	32.5	RS Hill
			± 10	5	5	10	3	10	2	89	27	31	0.11			
Site 04-347	186	20030592	53	33	98	194	16	139	23	1603	212	1210	1.22	49.8	26.1	Presley Wash *
			± 11	5	4	9	3	10	2	92	27	33	0.11			
Site 01-282	187	20030670	40	40	240	10	42	95	54	309	415	NM	0.82	17.4	86.2	Partridge Creek (Round Mountain)
			± 11	5	5	10	3	10	2	88	28	NM	0.11			
Site 01-282	188	20030671	58	36	114	85	21	84	51	360	644	NM	0.76	10.3	69.4	Government Mountain
			± 9	4	4	9	3	10	2	88	28	NM	0.11			
Site 01-310	189	20030500	59	34	245	10	41	93	51	284	295	NM	0.64	19.6	74.3	Partridge Creek (Round Mountain) *
			± 10	5	5	10	3	10	2	88	27	NM	0.11			
Site 01-388	190	20030469	52	23	76	228	14	141	18	3985	429	1139	3.09	59.5	26.0	Presley Wash FGV
			± 11	5	4	10	3	10	2	97	28	33	0.11			
Site 01-516	191	20030228	57	31	83	246	16	144	20	3164	436	1124	2.64	50.1	27.9	Presley Wash FGV
			± 10	5	4	10	3	10	2	95	28	33	0.11			
Site 01-552	192	20030518	30	33	209	25	32	82	29	265	315	81	0.59	17.1	73.5	Unknown Obsidian 1
			± 11	5	5	9	3	10	2	88	27	32	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

Site	Specimen No.	Catalog No.	Trace Element Concentrations											Ratios		Geochemical Source
			Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	
Site 01-554	193	20030527	32	40	209	25	36	77	31	414	439	111	0.81	16.3	65.4	Unknown Obsidian 1
			± 10	4	5	9	3	10	2	88	28	32	0.11			
Site 01-712	194	20030212	35	17	82	218	14	139	18	3418	374	1018	3.06	67.7	29.9	Presley Wash FGV *
			± 11	5	4	10	3	10	2	96	28	32	0.11			
Site 01-726	195	20030203	49	36	251	11	40	92	52	307	410	NM	0.81	17.4	85.5	Partridge Creek (Round Mountain) *
			± 10	5	5	10	3	10	2	88	28	NM	0.11			
Site 01-739	196	20030632	31	44	240	8	40	92	51	815	366	NM	0.95	22.6	39.7	Partridge Creek (Round Mountain)
			± 11	5	5	11	3	10	2	89	28	NM	0.11			
Site 01-837	197	20030038	51	33	108	78	18	85	50	821	385	NM	0.96	21.7	40.0	Government Mountain
			± 10	4	4	9	3	10	2	89	28	NM	0.11			
Site 01-1047	198	20030361	50	32	81	211	17	140	22	4288	329	1125	2.90	73.1	22.7	Presley Wash FGV
			± 10	5	4	9	3	10	2	97	28	33	0.11			
Site 02-594	199	20030620	57	37	112	81	22	83	52	1032	450	NM	1.01	19.4	33.5	Government Mountain
			± 10	4	4	9	3	10	2	90	28	NM	0.11			
Site 02-727	200	20030400	48	33	133	152	22	101	28	1688	339	788	1.69	42.0	33.7	Black Tank
			± 10	5	4	9	3	10	2	91	28	32	0.11			
Site 04-66	201	20030660	51	31	106	77	20	84	54	570	419	NM	0.77	16.3	46.3	Government Mountain *
			± 10	5	4	9	3	10	2	89	28	NM	0.11			
Site 04-452	202	20030076	122	74	397	10	90	167	244	355	588	0	0.87	12.9	80.3	RS Hill
			± 10	5	5	10	3	10	2	88	28	31	0.11			
Artifact P8-10	203	P8-10	91	22	88	182	15	128	15	NM	NM	NM	NM	53.9	30.7	Presley Wash *
			± 11	5	4	9	3	10	2	NM	NM	NM	NM			
Artifact P6-1	204	P6-1	72	30	108	78	20	83	52	211	763	NM	0.90	10.3	131.8	Government Mountain
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
Artifact P6-3	205	P6-3	60	18	42	599	20	157	33	4046	593	NM	4.15	57.3	34.1	Unknown FGV
			± 11	5	4	10	3	10	2	97	28	NM	0.11			
Artifact P8-9	206	P8-9	56	24	82	178	16	137	19	NM	NM	NM	NM	46.0	35.8	Presley Wash *
			± 10	5	4	9	3	10	2	NM	NM	NM	NM			
Artifact P6-4	207	P6-4	54	19	52	497	18	185	36	3318	504	NM	3.35	54.7	33.7	Unknown FGV A
			± 11	5	4	10	3	10	2	96	28	NM	0.11			
Artifact P8-2	208	P8-2	34	28	110	172	21	98	27	NM	NM	NM	NM	36.4	36.8	Black Tank FGV *
			± 12	5	4	9	3	10	2	NM	NM	NM	NM			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Northwest Research Obsidian Studies Laboratory

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

Site	Specimen No.	Catalog No.	Trace Element Concentrations											Ratios		Geochemical Source
			Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	Fe^{2}O$^{3\,T}$	Fe:Mn	Fe:Ti	
Coconino NF	209	6 CNF-6A-4	49	29	112	79	20	83	53	NM	NM	NM	NM	17.1	100.0	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	NM	NM			
Artifact P8-5	210	P8-5	38	23	85	174	16	135	22	1797	296	NM	1.80	51.2	33.7	Presley Wash
			± 11	5	4	9	3	10	2	93	28	NM	0.11			
Coconino NF	211	2CNF-2A-1	42	28	110	78	21	82	51	NM	NM	NM	NM	16.1	69.4	Government Mountain *
			± 10	4	4	9	3	10	2	NM	NM	NM	NM			
Coconino NF	212	2CNF-2A-2	51	35	107	73	19	80	50	NM	NM	NM	NM	15.4	98.5	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	NM	NM			
Coconino NF	213	4CNF-4A-1	67	35	102	75	17	81	49	NM	NM	NM	NM	11.9	133.0	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	NM	NM			
Coconino NF	214	4CNF-4A-2	66	35	104	73	21	80	53	304	493	NM	0.89	15.7	94.0	Government Mountain
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
Coconino NF	215	3CNF-3B-1	62	44	228	9	40	87	51	NM	NM	NM	NM	14.2	71.0	Partridge Creek (Round Mountain) *
			± 10	5	5	10	3	10	2	NM	NM	NM	NM			
Coconino NF	216	3CNF-3B-2	163	63	136	8	78	709	139	NM	NM	NM	NM	35.9	104.1	San Francisco Peaks (Fremont-Agassiz
			± 11	5	5	12	3	11	2	NM	NM	NM	NM			
Coconino NF	217	3CNF-3B-3	45	23	92	68	18	79	49	816	604	NM	1.38	19.4	56.5	Government Mountain
			± 11	5	4	9	3	10	2	89	28	NM	0.11			
Coconino NF	218	3CNF-3B-4	51	33	106	79	23	87	51	NM	NM	NM	NM	13.8	109.4	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	NM	NM			
Coconino NF	219	3CNF-3B-5	58	33	111	80	19	85	52	193	548	NM	1.00	15.8	156.6	Government Mountain
			± 10	4	4	9	3	10	2	88	28	NM	0.11			
Coconino NF	220	3CNF-3B-6	46	37	243	8	38	90	55	228	614	NM	0.89	12.6	122.0	Partridge Creek (Round Mountain)
			± 10	5	5	11	3	10	2	88	28	NM	0.11			
Coconino NF	221	3CNF-3B-7	37	22	80	207	17	136	19	NM	NM	NM	NM	72.3	30.0	Presley Wash *
			± 11	5	4	9	3	10	2	NM	NM	NM	NM			
Artifact P8-3	222	P8-3	39	22	88	193	16	137	21	2705	440	NM	2.55	48.2	31.6	Presley Wash
			± 11	5	4	9	3	10	2	94	28	NM	0.11			
Artifact P8-4	223	P8-4	47	29	122	130	22	97	31	1431	552	NM	1.85	28.0	43.2	Black Tank
			± 10	5	4	9	3	10	2	91	28	NM	0.11			
Artifact P8-1	224	P8-1	56	25	84	179	15	134	18	NM	NM	NM	NM	55.3	30.7	Presley Wash *
			± 10	5	4	9	3	10	2	NM	NM	NM	NM			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Northwest Research Obsidian Studies Laboratory

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Site	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$\mathrm{Fe}^{2}\mathrm{O}^{3\,T}$	Fe:Mn	Fe:Ti	Geochemical Source
Artifact P8-2	225	P8-2	35	32	85	175	14	129	20	NM	NM	NM	NM	52.7	35.0	Presley Wash *
			± 11	5	4	9	3	10	2	NM	NM	NM	NM			
Coconino NF	226	6CNF-6A-1	67	25	99	76	20	83	47	233	632	NM	1.02	13.9	135.6	Government Mountain
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
Coconino NF	227	6CNF-6A-2	40	28	107	76	19	83	49	343	559	NM	1.06	16.4	99.6	Government Mountain
			± 11	5	4	9	3	10	2	88	28	NM	0.11			
Coconino NF	228	6CNF-6A-3	60	31	99	73	19	78	48	252	519	NM	0.93	15.6	116.4	Government Mountain
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
Coconino NF	229	6CNF-6A-5	53	21	101	76	20	81	49	727	566	NM	1.24	18.7	57.1	Government Mountain
			± 10	5	4	9	3	10	2	89	28	NM	0.11			
Coconino NF	230	6CNF-6A-6	62	45	109	51	35	126	81	NM	NM	NM	NM	23.8	99.8	Unknown Obsidian 3 *
			± 10	5	4	9	3	10	2	NM	NM	NM	NM			
Coconino NF	231	6CNF-6A-7	48	29	105	77	21	82	54	251	534	NM	0.97	15.7	120.9	Government Mountain
			± 10	5	4	9	3	10	2	88	28	NM	0.11			
Coconino NF	232	6CNF-6A-8	34	32	100	73	19	79	47	238	488	NM	0.89	15.9	117.4	Government Mountain
			± 11	5	4	9	3	10	2	88	28	NM	0.11			
Coconino NF	233	6CNF-6A-9	37	31	110	77	20	82	52	NM	NM	NM	NM	16.7	116.1	Government Mountain *
			± 11	5	4	9	3	10	2	NM	NM	NM	NM			
Coconino NF	234	6CNF-6A-10	59	38	113	79	21	83	53	NM	NM	NM	NM	16.0	81.6	Government Mountain *
			± 10	4	4	9	3	10	2	NM	NM	NM	NM			
Artifact P6-2	235	P6-2	60	30	113	77	17	85	52	NM	NM	NM	NM	14.8	105.7	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	NM	NM			
Artifact P6-5	236	P6-5	19	11	ND	14	6	19	ND	86	153	NM	0.68	40.4	208.2	Not Obsidian
			± 12	5	ND	9	3	11	ND	87	27	NM	0.11			
Artifact P6-6	237	P6-6	68	19	52	521	13	203	34	3149	518	NM	3.21	50.9	34.0	Unknown FGV A
			± 10	5	4	10	3	10	2	96	28	NM	0.11			
Artifact P8-6	238	P8-6	60	32	59	461	18	135	59	2218	599	NM	2.29	31.8	34.7	Unknown FGV
			± 10	5	4	10	3	10	2	93	28	NM	0.11			
Artifact P8-7	239	P8-7	53	27	123	114	21	97	28	1386	628	NM	1.84	24.4	44.3	Black Tank
			± 10	5	4	9	3	10	2	91	28	NM	0.11			
Site 01-120	240	20030643	40	24	108	75	19	81	51	416	530	NM	0.98	15.9	77.0	Government Mountain
			± 11	5	4	9	3	10	2	88	28	NM	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Northwest Research Obsidian Studies Laboratory

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Site	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Site 02-54	241	2321	45	30	143	124	22	104	28	NM	NM	NM	NM	51.5	25.7	Black Tank
			± 10	5	4	9	3	10	2	NM	NM	NM	NM			
Site 02-914	242	2113	136	70	410	11	88	165	249	665	413	NM	1.25	25.9	62.5	RS Hill
			± 10	5	5	10	3	10	2	89	28	NM	0.11			
Site 02-1072	243	2361	32	32	114	154	21	105	29	3060	512	NM	2.52	40.8	27.6	Black Tank FGV
			± 12	5	4	9	3	10	2	95	28	NM	0.11			
Site 02-1123	244	2386	58	30	110	78	20	85	51	676	519	NM	1.17	19.2	57.6	Government Mountain
			± 9	4	4	9	3	10	2	89	28	NM	0.11			
Coconino NF	245	4CNF 4A-48.1	38	29	121	29	22	56	63	NM	NM	95	NM	7.2	18.8	Unknown Obsidian 4 *
			± 11	5	4	9	3	10	2	NM	NM	32	NM			
Coconino NF	246	4CNF 4A-48.2	142	39	133	11	77	702	132	NM	NM	0	NM	31.0	58.7	San Francisco Peaks (Fremont-Agassiz
			± 11	5	4	10	3	11	2	NM	NM	31	NM			
Coconino NF	247	7CNF 7-54.1	41	36	72	230	17	139	22	4320	558	1045	3.42	50.4	26.4	Presley Wash FGV
			± 12	5	4	10	3	10	2	98	28	32	0.11			
Coconino NF	248	7CNF 7-54.2	47	18	58	465	23	125	31	5240	659	1072	4.19	52.0	26.6	Unknown FGV
			± 12	6	4	10	3	10	2	99	28	32	0.11			
Coconino NF	249	8CNF 8A- 61.1	48	15	47	499	17	184	33	3179	512	1300	3.32	53.3	34.8	Unknown FGV A
			± 11	6	4	10	3	10	2	96	28	33	0.11			
Coconino NF	250	8CNF 8A-61.2	45	31	103	74	19	75	47	NM	NM	277	NM	18.3	28.2	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	32	NM			
Coconino NF	251	8CNF 8A-61.5	46	37	92	66	19	77	45	NM	NM	299	NM	16.4	42.8	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	32	NM			
Coconino NF	252	8CNF 8A-61.6	54	29	75	206	16	135	19	2860	451	1099	2.74	50.4	32.1	Presley Wash FGV
			± 11	5	4	10	3	10	2	95	28	32	0.11			
Coconino NF	253	8CNF 8A-61.7	74	19	63	426	18	103	18	3799	546	1145	3.08	46.5	27.1	Unknown FGV
			± 10	5	4	10	3	10	2	96	28	33	0.11			
Coconino NF	254	8CNF 8B-72.1	67	26	102	71	19	80	49	NM	NM	311	NM	13.0	37.4	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	32	NM			
Coconino NF	255	8CNF 8B-72.2	66	32	105	73	19	79	46	NM	NM	284	NM	13.8	40.0	Government Mountain *
			± 9	5	4	9	3	10	2	NM	NM	32	NM			
Coconino NF	256	8CNF 8B-72.3	62	36	100	74	18	80	46	NM	NM	295	NM	11.7	37.6	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	32	NM			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Site	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Coconino NF	257	8CNF 8B-72.4	39	30	72	211	17	128	20	NM	NM	1079	NM	58.1	29.2	Presley Wash FGV
			± 11	5	4	10	3	10	2	NM	NM	33	NM			
Coconino NF	258	8CNF 8B-72.5	55	24	72	214	15	135	20	NM	NM	1017	NM	62.9	27.0	Presley Wash FGV
			± 11	5	4	10	3	10	2	NM	NM	33	NM			
Coconino NF	259	8CNF 8B-72.6	71	44	54	457	18	125	58	NM	NM	941	NM	30.5	30.0	Unknown FGV *
			± 10	5	4	10	3	10	2	NM	NM	32	NM			
Coconino NF	260	9CNF 9A-65.1	28	31	203	23	36	79	28	NM	NM	67	NM	18.0	91.6	Unknown Obsidian 1 *
			± 11	5	5	9	3	10	2	NM	NM	32	NM			
Coconino NF	261	9CNF 9A-65.2	52	37	95	71	20	75	43	NM	NM	253	NM	11.0	30.9	Government Mountain *
			± 10	4	4	9	3	10	2	NM	NM	32	NM			
Coconino NF	262	9CNF 9B-68.2	69	30	94	216	20	107	26	3207	631	704	3.09	40.3	32.2	Unknown FGV
			± 11	5	4	10	3	10	2	95	28	32	0.11			
Coconino NF	263	9CNF 9B-68.3	55	36	110	79	23	80	48	286	584	268	0.89	13.2	99.2	Government Mountain
			± 10	4	4	9	3	10	2	88	28	32	0.11			
Coconino NF	264	10CNF 10A-45.1	53	33	103	73	20	78	48	NM	NM	276	NM	17.3	39.9	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	32	NM			
Coconino NF	265	10CNF 10A-45.2	43	31	98	74	21	78	46	NM	NM	291	NM	16.8	74.2	Government Mountain *
			± 11	5	4	9	3	10	2	NM	NM	32	NM			
Coconino NF	266	10CNF 10A-62.1	39	26	105	76	18	81	50	922	550	276	1.40	21.5	50.7	Government Mountain
			± 11	5	4	9	3	10	2	90	28	32	0.11			
Coconino NF	267	14CNF 14B-69.2	61	24	124	25	18	58	61	NM	NM	87	NM	6.6	15.6	Unknown Obsidian 4 *
			± 9	5	4	9	3	10	2	NM	NM	32	NM			
Coconino NF	268	16CNF 16-59.3	37	27	104	76	20	80	47	257	665	270	0.98	12.8	120.2	Government Mountain
			± 11	5	4	9	3	10	2	88	28	32	0.11			
Coconino NF	269	16CNF 16-59.4	60	24	75	219	17	136	18	3522	357	1082	2.93	68.1	27.9	Presley Wash FGV
			± 11	5	4	10	3	10	2	96	28	32	0.11			
Coconino NF	270	16CNF 16-59.5	55	36	108	76	18	79	47	NM	NM	274	NM	14.6	32.8	Government Mountain *
			± 10	4	4	9	3	10	2	NM	NM	32	NM			
West of Coconino NF	271	20W 20A-47.1	33	38	228	8	33	88	49	NM	NM	0	NM	16.1	85.6	Partridge Creek (Round Mountain) *
			± 11	5	5	11	3	10	2	NM	NM	31	NM			
Partridge Cr. Watershed	272	21PC 21A-56.2	45	41	232	9	38	89	48	NM	NM	38	NM	16.7	39.1	Partridge Creek (Round Mountain) *
			± 10	5	5	10	3	10	2	NM	NM	34	NM			

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NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

	Specimen		Trace Element Concentrations											Ratios		
Site	No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
Partridge Cr. Watershed	273	21PC 21B-35.1	61	27	98	75	19	79	46	NM	NM	298	NM	17.3	64.8	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	32	NM			
Partridge Cr. Watershed	274	22PC 22A-35.2	59	25	79	195	15	140	19	2427	315	1131	2.40	63.4	33.1	Presley Wash FGV
			± 11	6	4	10	3	10	2	94	28	32	0.11			
Little Colorado River	275	28LCR 28A-52.1	45	30	107	77	23	82	51	861	551	310	1.01	15.9	40.1	Government Mountain
			± 11	5	4	9	3	10	2	89	28	32	0.11			
Little Colorado River	276	28LCR 28A-52.2	48	30	137	72	22	82	48	NM	NM	275	NM	10.9	31.9	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	32	NM			
Little Colorado River	277	28LCR 28A-52.3	56	34	47	463	19	179	37	3315	2070	1345	3.42	13.5	34.4	Unknown FGV A
			± 12	5	4	10	3	10	2	97	30	33	0.11			
Little Colorado River	278	28LCR 28A-52.4	45	29	103	72	19	82	49	156	534	298	0.89	14.5	168.2	Government Mountain
			± 11	5	4	9	3	10	2	88	28	32	0.11			
Little Colorado River	279	28LCR 28A-52.5	37	18	49	503	12	189	35	3178	543	1258	3.20	48.5	33.5	Unknown FGV A
			± 12	5	4	10	3	10	2	95	28	33	0.11			
Little Colorado River	280	28LCR 28A-52.6	66	21	78	228	24	105	19	4475	605	329	4.63	62.5	34.4	Unknown FGV
			± 11	5	4	10	3	10	2	97	28	32	0.11			
Little Colorado River	281	28LCR 28A-52.7	63	24	47	501	16	186	32	2963	1194	1296	2.86	19.6	32.2	Unknown FGV A
			± 11	5	4	10	3	10	2	95	29	33	0.11			
Little Colorado River	282	28LCR 28B-69.1	58	32	108	77	22	84	50	183	595	339	0.90	13.2	149.0	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
Little Colorado River	283	28LCR 28B-69.2	75	26	102	77	22	81	50	629	511	290	0.91	15.5	49.0	Government Mountain
			± 9	5	4	9	3	10	2	89	28	32	0.11			
Little Colorado River	284	29LCR 29A-37.7	81	32	209	8	64	178	93	NM	NM	0	NM	15.1	34.4	Unknown Obsidian 6 *
			± 10	5	5	11	3	10	2	NM	NM	31	NM			
Little Colorado River	285	29LCR 29B-63.1	52	24	112	79	21	83	48	NM	NM	316	NM	14.0	35.2	Government Mountain *
			± 10	4	4	9	3	10	2	NM	NM	32	NM			
Little Colorado River	286	29LCR 29B-63.2	37	22	104	73	19	81	50	687	553	288	0.82	12.9	40.7	Government Mountain
			± 11	5	4	9	3	10	2	89	28	32	0.11			
NW of Coconino NF	287	MN-N61 19A-50.1	26	27	133	41	19	124	22	NM	NM	342	NM	18.4	22.8	Unknown Obsidian 5 *
			± 11	5	4	9	3	10	2	NM	NM	32	NM			
NW of Coconino NF	288	MN-N61 19A-50.2	68	19	79	215	15	133	18	3295	368	1065	2.87	64.6	29.1	Presley Wash FGV
			± 10	5	4	10	3	10	2	96	28	32	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Northwest Research Obsidian Studies Laboratory

Table D-1. Results of XRF Studies: Flagstaff Area Obsidian and Fine-Grained Volcanic (FGV) Artifacts, Coconino County, Arizona

			Trace Element Concentrations											Ratios		
Site	Specimen No.	Catalog No.	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Geochemical Source
NW of Coconino NF	289	MN-N61 19A-50.3	56	25	108	86	20	84	51	NM	NM	303	NM	13.6	41.7	Government Mountain *
			± 10	4	4	9	3	10	2	NM	NM	32	NM			
NW of Coconino NF	290	MN-N61 19A-50.4	48	26	103	174	23	99	29	2500	515	692	2.76	44.3	36.8	Black Tank FGV
			± 11	6	5	9	3	10	2	94	28	32	0.11			
NW of Coconino NF	291	MN-N61 19A-50.5	43	38	249	9	40	93	51	NM	NM	NM	NM	16.0	113.1	Partridge Creek (Round Mountain) *
			± 10	5	5	10	3	10	2	NM	NM	NM	NM			
474516/3899622	292	474516/3899622	70	20	67	135	29	206	45	897	590	1340	1.64	23.3	60.5	O'Leary Peak/Robinson Crater
			± 10	5	4	9	3	10	2	91	28	33	0.11			
474831/3899767	293	474831/3899767	46	22	98	76	17	77	51	NM	NM	NM	NM	11.4	64.5	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	NM	NM			
473126/3898195	294	473126/3898195	46	28	108	79	17	81	48	NM	NM	NM	NM	12.7	30.7	Government Mountain *
			± 10	5	4	9	3	10	2	NM	NM	NM	NM			
473126/3898213	295	473126/3898213	48	26	99	79	20	79	47	233	456	274	0.77	14.9	104.7	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			
473379/3897160	296	473379/3897160	46	25	87	176	14	128	17	NM	NM	1074	NM	52.8	25.7	Presley Wash
			± 10	5	4	9	3	10	2	NM	NM	33	NM			
473158/3897477	297	473158/3897477	42	37	103	74	20	77	45	NM	NM	304	NM	16.7	25.4	Government Mountain *
			± 10	4	4	9	3	10	2	NM	NM	32	NM			
474892/3899482	298	474892/3899482	46	29	103	76	22	80	48	531	543	294	0.79	12.9	50.7	Government Mountain
			± 10	5	4	9	3	10	2	89	28	32	0.11			
474755/3898670	299	474755/3898670	51	26	97	71	17	79	46	213	491	291	0.84	14.9	121.8	Government Mountain
			± 10	5	4	9	3	10	2	88	28	32	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Appendix E:
Projectile Point Database

ID#	Point_Type	Period	Source	Notes	AutoNumber	Area
P5-11	0	0	0	NOT OBS	45	
4CNF 4A-48.1	0	0	15		248	2
NW-N 61 19A-50.	0	0	0		249	5
P6-5	0	0	0	NOT OBS	244	
14CNF 14A-62.1	0	0	0		257	2
P8-7	0	0	1		238	
4CNF 4A-48.2	0	0	0		247	2
P5-12	0	0	4		46	
P5-16	0	0	4		50	
P5-10	0	0	0	not sent to	44	
P5-9	0	0	8		43	
P4-12	0	0	4		33	
29LCR 29A-37.7	0	0	0		255	3
14CNF 14B-69.2	0	0	0		256	2
P3-13	0	0	8		20	
P5-15	0	0	0	not sent to	49	
2361	1	1	1		242	1
28LCR 28B-69.1	1	1	4		252	3
P8-3	1	1	8		208	
28LCR 28-52.7	1	1	18		254	3
20030308	1	1	8		59	1
NW-N 61 19A-50.	1	1	1		253	5
P8-4	1	1	1		207	
20060540	1	1	4		149	1
20060234	1	1	1		147	1
20030080	1	1	9		60	1
20060544	1	1	18		148	1
20030592	1	1	8		58	1
20030399	1	1	4		57	1
20030344	1	1	4		56	1
20030544	1	1	8		55	1
20030485	1	1	4		54	1
P5-19	1	1	4		53	
P4-11	1	1	8		32	
P4-10	1	1	17		31	
20060597	1	1	7		145	1
28LCR 28A-52.5	1	1	18		275	3
22PC 22A-35.2	1	1	8		259	4
28LCR 28A-52.3	1	1	18		290	3
NW-N 61 19A-50.	1	1	8		261	5
20060438	1	1	4		146	1
20030205	2	1	7		61	1
10CNF 10A-45.1	2	1	4		278	2
10CNF 10A-45.2	2	1	4		258	2
P6-4	2	1	18		206	
20030740	2	1	8		62	1

ID#	Point_Type	Period	Source	Notes	AutoNumber	Area
20030038	3	2	4		64	1
20030660	3	2	4		73	1
20030400	3	2	1		72	1
20030212	3	2	8		71	1
20030500	3	2	7		70	1
20030620	3	2	4		69	1
20030469	3	2	8		68	1
20030228	3	2	8		67	1
20030518	3	2	13		65	1
7CNF 7-54.2	3	2	17		283	2
20030361	3	2	8		63	1
20030632	3	2	7		74	1
8CNF 8A-61.7	3	2	17		284	2
20030671	3	2	4		77	1
8CNF 8B-72.2	3	2	4		277	2
8CNF 8B-72.4	3	2	8		281	2
P5-18	3	2	8		52	
P5-17	3	2	17		51	
20030670	3	2	7		66	1
20060008	3	2	4		159	1
28LCR 28A-52.1	3	2	4		273	3
NW-N 61 19A-50.	3	2	8		293	5
8CNF 8A-61.2	3	2	4		272	2
20060058	3	2	4		150	1
20060408	3	2	4		151	1
20060609	3	2	8		152	1
20060299	3	2	14		153	1
20060027	3	2	17		154	1
20060530	3	2	1		155	1
20060214	3	2	8		156	1
20030527	3	2	13		75	1
20060561	3	2	4		158	1
8CNF 8B-72.3	3	2	4		288	2
20060193	3	2	7		160	1
20060121	3	2	4		161	1
20060110	3	2	7		162	1
20060581	3	2	8		163	1
20060551	3	2	4		164	1
20060235	3	2	4		165	1
20060591	3	2	7		166	1
20030203	3	2	7		78	1
21PC 21A-56.2	3	2	7		282	4
20030076	3	2	9		76	1
20060206	3	2	4		157	1
8CNF 8A-61.6	3	2	8		267	2
6CNF 6A-1	3	2	4		224	2

ID#	Point_Type	Period	Source	Notes	AutoNumber	Area
6CNF 6A-5	3	2	4		225	2
NW-N 61 19A-50.	3	2	4		291	5
P4-6	3	2	1		27	
P4-4	3	2	4		25	
P4-3	3	2	4		24	
P4-2	3	2	4		23	
P4-1	3	2	4		22	
8CNF 8A-61.5	3	2	4		269	2
P5-7	3	2	4		41	
6CNF 6A-10	3	2	4		221	2
8CNF 8A-61.1	3	2	18		280	2
2386	3	2	4		243	1
8CNF 8B-72.6	3	2	17		268	2
P3-14	3	2	4		21	
29LCR 29B-63.1	3	2	4		292	3
P3-12	3	2	0	not sent to	19	
P3-10	3	2	18		17	
P3-9	3	2	2		16	
P3-5	3	2	4		12	
P3-2	3	2	4		9	
P5-5	3	2	18		39	
P5-3	3	2	4		37	
P5-2	3	2	4		36	
P5-1	3	2	4		35	
28LCR 28B-69.2	3	2	4		260	3
P4-13	3	2	8		34	
28LCR 28A-52.2	3	2	4		262	3
29LCR 29B-63.2	3	2	4		263	3
6CNF 6A-7	3	2	4		223	2
28LCR 28A-52.4	3	2	4		289	3
6CNF 6A--2	3	2	4		222	2
8CNF 8B-72.5	3	2	8		265	2
7CNF 7-54.1	3	2	8		266	2
P8-1	3	2	8		215	
P8-8	3	2	0	not sent to	216	
6CNF 6A-8	3	2	4		217	2
6CNF 6A-6	3	2	16		218	2
6CNF 6A-3	3	2	4		219	2
6CNF 6A-9	3	2	4		220	2
20030266	4	2	8		81	1
9CNF 9A-65.1	4	2	13		251	2
9CNF 9A-65.2	4	2	4		276	2
20060243	4	2	8		135	1
20030323	4	2	9		83	1
P8-9	4	2	8		212	
P6-3	4	2	17		213	

ID#	Point_Type	Period	Source	Notes	AutoNumber	Area
P6-1	4	2	4		214	
20030577	4	2	4		82	1
20030397	4	2	7		80	1
21PC 21B-35.1	5	3	4		279	4
20060427	5	3	9		131	1
20060279	5	3	9		130	1
20060143	5	3	7		129	1
P3-7	5	3	18		14	
20030688	5	3	7		95	1
20030553	5	3	4		94	1
P3-1	5	3	4		8	
20030216	5	3	7		92	1
P3-6	5	3	4		13	
20030079	5	3	4		91	1
P3-8	5	3	4		15	
20030202	5	3	7		90	1
P3-3	5	3	4		10	
20030813	5	3	4		93	1
20060044	5	3	7		128	1
8CNF 8B-72.1	5	3	4		270	2
P6-2	6	3	4		210	
20030360	6	3	4		87	1
P4-5	6	3	0	NOT OBS	26	
20030548	6	3	9		88	1
20030061	6	3	4		89	1
P4-8	6	3	4		29	
20030609	6	3	4		86	1
P3-4	6	3	4		11	
20060554	6	3	9		137	1
20060301	6	3	4		136	1
20060377	7	3	4		171	1
P5-6	7	3	8		40	
20060444	7	3	7		167	1
20060515	7	3	1		168	1
20030550	7	3	8		97	1
20060494	7	3	4		181	1
20030675	7	3	7		99	1
16CNF 16-59.4	7	3	8		274	2
20060777	7	3	8		176	1
P5-13	7	3	4		47	
16CNF 16-59.5	7	3	4		286	2
16CNF 16-59.3	7	3	4		287	2
20060152	7	3	4		180	1
20060548	7	3	8		179	1
20060432	7	3	4		169	1
20060184	7	3	8		177	1

ID#	Point_Type	Period	Source	Notes	AutoNumber	Area
20030541	7	3	8		100	1
20060532	7	3	4		175	1
20060080	7	3	8		174	1
20060325	7	3	9		173	1
20060327	7	3	4		172	1
20030588	7	3	9		98	1
20060116	7	3	4		170	1
20060207	7	3	4		178	1
20030615	7	3	4		102	1
20030225	7	3	7		103	1
20030372	7	3	4		104	1
20030374	7	3	7		105	1
P8-2	7	3	8		209	
20030614	7	3	7		101	1
20030556	7	3	4		96	1
P4-7	7	3	4		28	
6CNF 6A-4	8	3	4		211	2
20030224	8	3	7		84	1
P5-4	8	3	13		38	
20030676	8	3	7		85	1
20060063	8	3	7		132	1
P2-4	9	3	7		4	
P2-3	9	3	4		3	
P2-5	9	3	8		5	
20060034	9	3	9		200	1
P2-6	9	3	17		6	
20060064	9	3	8		203	1
P2-2	9	3	4		2	
P2-7	9	3	18		7	
20060553	9	3	8		201	1
3CNF 3B-6	9	3	7		234	2
20060196	9	3	7		199	1
20060348	9	3	4		198	1
20060318	9	3	4		197	1
20060603	9	3	8		196	1
20060453	9	3	4		202	1
3CNF 3B-3	9	3	4		232	2
20060201	9	3	4		195	1
20060189	9	3	7		204	1
P8-5	9	3	8		226	
2CNF 2A-2	9	3	4		227	2
2CNF 2A-1	9	3	4		228	2
4CNF 4A-2	9	3	4		229	2
3CNF 3B-2	9	3	15		235	2
3CNF 3B-4	9	3	4		231	2
20W 20A-47.1	9	3	7		250	6

ID#	Point_Type	Period	Source	Notes	AutoNumber	Area
3CNF 3B-5	9	3	4		233	2
P5-8	9	3	4		42	
P3-11	9	3	18		18	
3CNF 3B-1	9	3	7		236	2
3CNF 3B-7	9	3	8		237	2
P6-6	9	3	18		245	
4CNF 4A-1	9	3	4		230	2
20030221	9	3	9		122	1
20030664	9	3	1		111	1
20060304	9	3	1		194	1
20030218	9	3	8		113	1
20060194	9	3	4		183	1
20030314	9	3	8		115	1
20030811	9	3	8		116	1
20030363	9	3	4		117	1
20030276	9	3	1		118	1
20030204	9	3	9		119	1
20030325	9	3	4		110	1
20030326	9	3	7		121	1
20030604	9	3	4		112	1
20030052	9	3	4		123	1
20030537	9	3	7		124	1
20030555	9	3	8		125	1
20030247	9	3	8		126	1
20030809	9	3	8		127	1
20060319	9	3	8		142	1
20060525	9	3	4		141	1
20060505	9	3	0	NOT OBS	140	1
20060491	9	3	1		139	1
20060524	9	3	4		138	1
20030293	9	3	7		120	1
20060504	9	3	4		192	1
20060114	9	3	8		187	1
20060198	9	3	7		189	1
20030315	9	3	8		114	1
20060258	9	3	4		190	1
20030289	9	3	4		109	1
20060200	9	3	7		191	1
20060192	9	3	4		185	1
20060059	9	3	8		188	1
20060179	9	3	4		182	1
20060115	9	3	7		186	1
P2-1	9	3	8		1	
20060112	9	3	8		144	1
20030784	9	3	8		143	1
20030817	9	3	8		106	1

ID#	Point_Type	Period	Source	Notes	AutoNumber	Area
20030373	9	3	8		107	1
20060403	9	3	7		193	1
20030435	9	3	7		108	1
20060459	9	3	4		184	1
20060560	10	3	4		133	1
20060555	10	3	4		134	1
P8-6	10	2	17		246	
P5-14	10	3	4		48	
P8-10	10	3	8		205	
9CNF 9B-68.3	11	3	4		264	2
9CNF 9B-68.2	11	3	17		285	2
20030066	11	3	8		79	1
2113	12	1	9		241	1
28LCR 28A-52.6	12	1	17		271	3
P4-9	12	1	4		30	
2321	13	4	1		240	1
20030643	13	4	4		239	1